BNXS41: Dynamic demand control of domestic appliances

Version 1.11

This Briefing Note and referenced information is a public consultation document and will be used to inform Government decisions. The information and analysis form part of the Evidence Base created by Defra's Market Transformation Programme.

1 Summary

This Briefing Note aims to:

1. Outline the potential for Dynamic Demand Control (DDC).
2. Summarise testing already carried out.
3. Project possible progress.

Everyday domestic electricity demand can be shown as a load profile [1] which peaks strongly between 4 and 8 pm. Since most power stations cannot be switched on-line in an instant, energy providers have to be mindful of this peak and keep some fossil fuelled power stations 'running' so that generators can be quickly powered up. The carbon impact of this 'spinning reserve' can be lowered if the peak demand is reduced. Appliances such as refrigerators, air conditioners and immersion heaters cycle on and off for much or all of the day, can under DDC operation, be made to adjust their cycling during periods of high grid load. Their cycling can be moderated by a matter of seconds or minutes and, if tuned to the demands of the appliance, does not unduly affect appliance performance.

The imbalance between supply and demand is indicated by mains frequency which dips slightly under high stress and rises slightly at other times [2]. These frequency deviations can be easily sensed by inexpensive electronics on the appliance's control board which can also automatically modify the cycling of the appliance. DDC appliances therefore need no user intervention.

DDC appliances also have the potential to smooth the varying output from alternative power sources such as wind turbines, wave generators which feed into the grid. Many thousands of DDC appliances collectively act like a large capacitor.

The UK domestic refrigerator market is around 3.8 million units per year so if only half of these are DDC appliances (a realistic possibility), market penetration could happen relatively quickly. Since the DDC does not save energy for the domestic

[1] Demand for the last hour, 1 day or 8 days can be seen from the links on www.nationalgrid.com/uk/Electricity/Data/Realtime/
[2] Mains frequency normally keeps within ± 0.20 Hz. Power companies are required by law to keep at least within ± 0.5 Hz.

consumer, it is recognised that there needs to be a market incentive to help make DDC appliances attractive to manufacturers and their customers.

Dynamic demand technology is currently available and has been tested on domestic refrigerators in small laboratory trials showing appliances can respond to grid stress while still maintaining acceptable internal cabinet temperatures. The overall impact of millions of DDC appliances and their carbon saving potential is predicted by mathematical modelling. The modelling needs to be examined under a wider field trial and it is hoped this trial will begin shortly.

If manufacturers have sufficient influence from market incentives, DDC could be incorporated into new appliances early next decade.

2 Introduction

DDC can modify the on-off cycling (duty cycle) of various appliances to continuously participate in peak demand management to help balance demand with electricity supply. DDC can sense overall grid load by monitoring mains frequency which varies second by second through the day – decreasing with more load and increasing with less load. The appliance 'juggles' its own on-off cycling while still maintaining its *primary* function – to heat or cool etc.

The National Grid is legally obliged to keep the frequency within 50 ± 0.5 Hz. Mains frequency normally remains within ± 0.2 Hz – achieved by switching in different levels of response depending on the severity of the change in demand. Coal power stations form the mainstay of supply and gas stations come on as the 4 – 8 pm peak approaches [3]. Even gas power stations cannot adapt quickly to the second-by-second change in demand so a spinning reserve [4] or backup generation has to be in place to cater for anticipated [5] and sometimes unanticipated peak within the 4 – 8 pm daily peak. Any imbalance between demand and supply causes a variation in network frequency.

DDC appliances can respond to these frequency fluctuations and 'shuffle' appliance duty cycles accordingly while still maintaining the function of the appliance – cooling, heating, etc. Appliances under DDC operation can reduce peak demand on the national grid and therefore help balance demand and supply – together many thousands of DDC appliances become a 'smoothing unit' making demand less noisy and reducing the requirement for spinning reserve. CO_2 savings have been estimated at 2 million tonnes per year [6] but the predictive model needs more verification and refinement, hence the proposal for a field trial (see Section 5.2).

[3] See Energy Trends September 2007 www.berr.gov.uk/files/file41460.pdf Chart 5.2 Page 14. Together electricity from coal and gas amounts to 70 – 75% depending on nuclear capability. The coal or gas share depends on price and availability.
[4] Spinning reserve - power stations are full or part-powered and can switch to generation in seconds. This is the primary response, secondary response can include switching off power lines.
[5] Kettles being switched on in the FA Cup Final half-time 'tea break' is a well known example.
[6] BERR *DYNAMIC DEMAND* August 2007, section 3.1. www.berr.gov.uk/files/file41011.pdf

The smoothing demand response of DDC appliances also means that alternative power sources such as wind generation and the like can be more easily catered for on the grid system.

DDC is suitable for appliances which cycle on and off for significant parts of the day eg. all types of domestic and commercial refrigeration, immersion heaters, air conditioners and pumps. Adaptations of DDC may also prove useful for other appliances, eg. dishwashers and washing machines – an intensive heating part of their programme could be delayed slightly until grid load is less. By definition, DDC operation is fully automatic, no consumer intervention is required, unlike some 'smart metering' schemes where the user is prompted to switch off appliances.

DDC would be fitted as integral appliance components as part of the thermostatic control and / or modify the software that governs the control strategy of the appliance – it is not an 'add-on' or a 'plug-in'. Outside development, DDC adds a modest component cost of around 5 Euros to each appliance. In addition, the theoretical market value of balancing demand is predicted to be of the order of £30 during the lifetime of a single appliance [7].

3 Background

The DDC principle is not a new idea, Fred Schweppe, an American power systems engineer, patented this principle in 1979. This patent has now lapsed and is available to all with no infringement of intellectual property rights. Providing the reserve to balance grid demand and supply, causes millions of tonnes of CO_2 emissions per year. Balancing supply and demand saves both CO_2 and money for the power companies.

Depending on the set sensitivity, DDC will moderate the 'switching temperatures' for the on-off cycling of a fridge compressor ie. the on-cycle will begin slightly later or finish slightly earlier until the mains frequency indicates less overall load. DDC sensitivity to mains frequency variation is denoted by a 'k value'. See Appendix II for a fuller discussion of k value.

Constant monitoring of the mains frequency implies a standby consumption but appliance manufacturers are committed to 1 W standby or less and powering of extra electronics on a control board is a tiny fraction of 1 watt.

4 UK market picture

'Combi' fridge-freezer appliances are in approximately 65% of homes [9]. These are mostly 'top-bottom' type with American style 'side-by-sides' taking an increasing 10% share of sales. Chest freezer ownership levels decreased from 16% in 1999 to 13% in 2020. Upright freezer ownership levels remained at 24% in 1999 and are predicted to stay at this level through to 2020. Larder fridges and fridges with internal cold boxes are in about 42% of homes (some homes have more than one type).

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[7] www.dynamicdemand.co.uk/pdf_economic_case.pdf
[8] IPR – Intellectual Property Rights
[9] BNC08: Assumptions underlying the energy projections for cold appliances www.mtprog.com/ApprovedBriefingNotes/BriefingNoteTemplate.aspx?intBriefingNoteID=83

UK domestic refrigerated appliance sales are currently about 3.8 million per year [10] which implies the domestic stock of 40 million appliances could be replaced in 10½ years. In reality, many appliances are kept for 12 years or longer. Older inefficient but still functioning appliances are sometimes kept to store beer or wine or additional cold storage – a DDC 'retrofit programme' is not thought to be financially viable unless part of a normal service call-out, eg. if the control board has to be replaced, it might just as well be a DDC one.

Tests as Intertek RPT have already shown that DDC operation can be applied to both mechanical and electrically controlled refrigerators, ie. there is no technical restriction to DDC operation. Once DDC appliances are available, a significant impact could be made even in the first year. Previously a significant component supplier (with a 50% market share) and the main UK manufacturers have expressed considerable interest in DDC appliances.

4.1 Incentive scheme

To encourage widespread adoption of DDC, an incentive scheme could be established – the precise nature and funding of any scheme to be discussed. The following has been suggested and an agreed proposal could be a combination of measures from the following options:

- DDC appliances could display a strong market promotion 'Green Footprint' or similar label to be designed.
- To prevent misinformation or fear about appliances not performing properly, retailers could be offered a free training programme.
- Retail price could be reduced via a future EEC [11] funding scheme or similar.
- Homes with DDC appliances could have a lower electricity tariff.

To qualify for this scheme, sample appliances could be tested to confirm that model's correct DDC operation.

5 Testing

Concerns about appliance performance and impact on the grid mean that the following should be verified:

1. The affect of DDC on appliance performance by lab testing.
2. The mathematical model which predicts the benefit to the grid by field trial.

5.1 Lab testing

Earlier in 2006 Defra's Market Transformation Programme commissioned Intertek Research and Performance Testing (an independent appliance test house) to check DDC operation on two domestic cold appliances: a top-bottom fridge-freezer and an under-counter upright freezer. Both appliances were loaded with lab test material and real food to check possible food safety issues.

[10] From Gfk figures.
[11] EEC – Energy Efficiency Commitment www.energysavingtrust.org.uk/housingbuildings/localauthorities/theguide/scotland/commitment/

DDC operation affected fridge temperatures by 1-2°C for short periods caused by mains frequency 'noise' widening the gap between switching temperatures or slightly increasing T_{high} – (minus) T_{low}. Freezer temperatures were more stable under different operating conditions, as expected.

Temperature effects cannot be ignored – the ideal DDC refrigerator should be temperature and energy neutral. These initial short trials were designed to mimic the same switching temperatures of the modified thermostatic control.

Later in 2006 a DDC *frost-free* fridge-freezer was examined for effects on the defrost function as well as temperatures and energy consumption. Fridge temperatures and freezer temperatures were affected by approximately 1 and 1.5 degrees respectively with energy consumption about the same. The number of defrost cycles increased slightly in response to less regular compressor on-off cycling.

See Appendix I for a sample of lab test results.

5.2 Field trial

To verify the benefit of DDC appliances to the grid, a consortium headed by Imperial College including power companies and fridge manufacturers and 'Dynamic Demand' [12] has been successfully submitted to the DTI Technology Programme for funds to carry out a wide ranging field trial and is hoping to start shortly.

This field trial will go some way to answer the following questions about the potential of dynamic demand technology:

- How much will the need for expensive balancing services be reduced?
- How much carbon dioxide could be saved both collectively and on a per-appliance basis?
- Would DDC allow greater integration of variable renewable energy generation?
- Could appliances possibly become synchronised and cause undesired effects [13] ?
- To what extent could the provision and use of 'peaking' plant be avoided, with further possible savings in carbon emissions?
- Will there be conflicts with existing control from governor-controlled plant?

[12] Dynamic Demand (www.dynamicdemand.co.uk) is an independent not-for-profit organisation supported by the Esmée Fairbairn Foundation. Other UK companies concerned with demand-side management include Econnect (www.econnect.co.uk) and RL Tec (www.rltec.com).

[13] 'Lost of diversity' is one concern ie. would DDC appliances which were switched off then suddenly switch on together and overload the grid? See Section 6 of this Briefing Note.

- What other ‘emergent’ properties could an aggregation possibly have and how costly could this be in practice?

- What are the design and manufacturing issues?

6 Options

Current modelling suggests that within reasonably small frequency fluctuations (± 0.2 Hz), not all appliances will be hunting for a ‘healthy’ mains and appliances do not behave in an identical manner even when built from the same components (performance differences from sample variability is well known). However, if necessary, a short random delay could be an option with DDC operation and is particularly useful for ‘black start recovery’ [14], ie. not all DDC appliances will have to operate in exactly the same way.

Fridge temperatures could be safeguarded by DDC thermostat operation with an upper temp limit – ‘constant cut-in’ appliances are common and the DDC need only modify the ‘cut-out’ temperature if desired [15].

Fridge compartments could be redesigned with thermal mass lining (ice lining). This technology is not new, ice-lined fridges are already used by the WHO to help vaccines remain colder than +8°C when power supply is unreliable in the third world.

7 Recent history and possible timetable options

June 2006 The Climate Change and Sustainable Energy Act was passed – this requires government to identify and address barriers to the introduction of dynamic demand on the electricity grid.

2006 Tests at Intertek RPT to check the performance of ‘mechanical fridge-freezer an ‘electric’ freezer, then later tests on an ‘electronic’ frost-free fridge-freezer.

August 2007 BERR publishes a report as required by Section 18 of the Climate Change and Sustainable Energy Act [16].

2008 – 2009 A field trial of more than 400 DDC operated cold appliances to be carried out.

2008 – 2010 stakeholders to examine possible policy options. Adoption of any market incentive scheme to encourage manufacturing and selling of DDC appliances (of all types) to be discussed.

Depending on the outcomes of the field trial and other activities, DDC appliances to be promoted to manufacturers in *2009* for initial adoption in *2010* or soon after.

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[14] After a power failure, nearly all appliances would be seeking to come on, DDC controlled or otherwise.
[15] Compressor ‘cuts in’ and ‘cuts out’ at a pre-designated warm and cold temperatures respectively. These temperatures are either sensed on the evaporator or inside the cabinet according to appliance design.
[16] The August 2007 report can be found at www.berr.gov.uk/files/file41011.pdf

DDC applications to include commercial refrigeration, air conditioning and other appliances, both domestic and commercial.

Appendix I: Sample test results

The following charts show sample test results from Intertek RPT testing. The detail in these is condensed; these are for illustrative purposes only. 'k = 0' is compressor on-off cycling with no response to grid stress.

Figure 1: Fridge-Freezer with k = 15

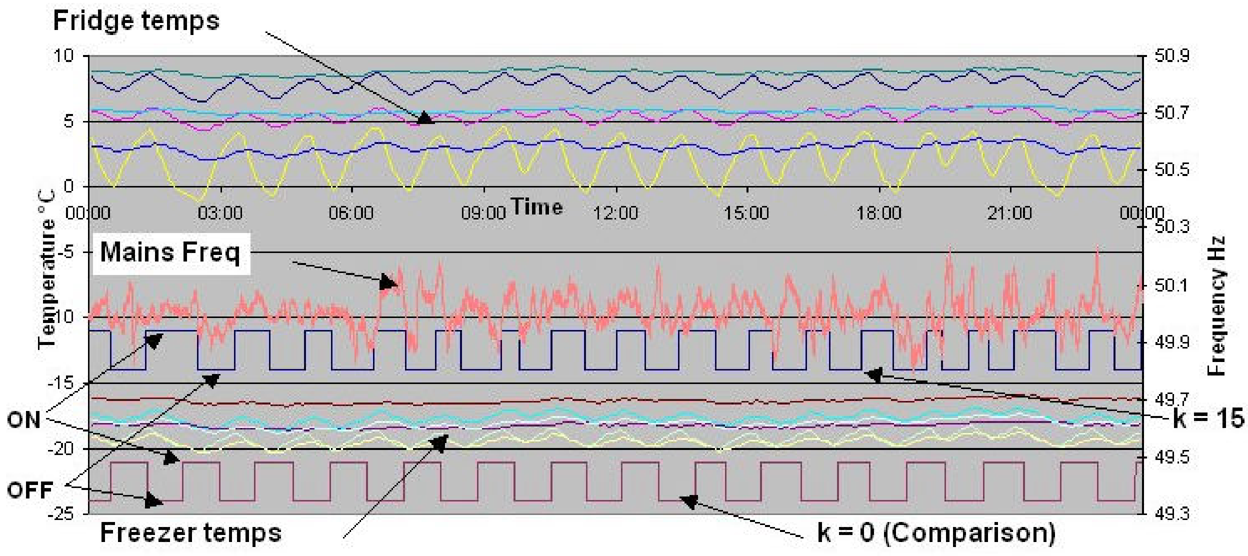
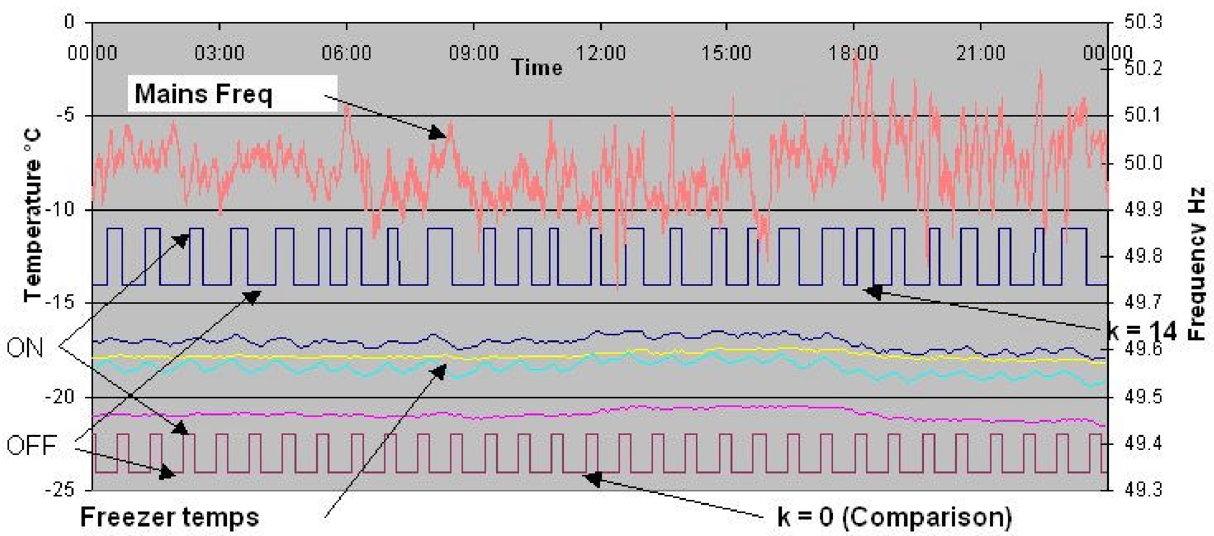


Figure 2: Freezer with k = 14



Both figures show a slight moderation of compressor cycling (in response to the mains frequency) and internal temperatures remaining under control.

Appendix II: Sensitivity of DDC to mains fluctuations

A thermostat will switch the compressor on or off at temperatures 'T-high' and 'T-low'. These temperatures are based on either the evaporator temperature or the internal cabinet temperature depending on the design of the appliance. DDC can modify thermostat operation changing switching temperatures in accordance with a simple algorithm:

$$T'_{high} = T_{high} - k\ \Delta F$$
$$T'_{low} = T_{low} - k\ \Delta F$$

T' = new switching temperature
T = original switching temperature
k = sensitivity
ΔF = change in frequency

ΔF is negative when the frequency drops during additional grid load. With a frequency drop, the new switching temperatures are slightly warmer than the old switching temperatures depending on the 'k value' set.

At T_{high}, the thermostat or DDC switches the compressor on. At T_{low}, the compressor is turned off. With decreased mains frequency, DDC operation will delay compressor switch-on and/or advance compressor switch-off.

Mains frequency variation is so much faster than the variation in internal cabinet temperatures that, for short-term frequency excursions, refrigerator temperatures can be considered static.

A nominal k value is to set k so that the shift in temperatures for a fall in frequency of 1 Hz equal to the difference between T-high and T-low. This value and other values for k will be tested at Intertek RPT.

Related MTP information

Briefing Note BNC08: Assumptions underlying energy projections for cold appliances
http://www.mtprog.com/ApprovedBriefingNotes/pdf.aspx?intBriefingNoteID=83

Changes from version 1.10

Summary reworded for clarity especially with regard to alternative power sources.

Consultation and further information

Stakeholders are encouraged to review this document and provide suggestions that may improve the quality of information provided, email **info@mtprog.com** quoting the document reference, or call the MTP enquiry line on +44 (0) 845 600 8951.

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