Institution: Durham University

Unit of Assessment: 15 General Engineering

Title of case study: Supporting the GB Electricity Market: Capacity Assessment and Capacity Market Design

1. Summary of the impact (indicative maximum 100 words)

The risk of having insufficient generating capacity to support demand is a critical issue in electric power system planning and market design. The 2011 Energy Act placed a duty on the Regulator (Ofgem) to produce an annual Electricity Capacity Assessment Report to the Department of Energy and Climate Change (DECC) to assess this risk looking five years ahead. This Case Study demonstrates how Dr. Chris Dent was contracted by National Grid to design technical modelling for the report based on his research, and the impact this has made in government policy and the wider public debate. Additionally it is shown how Professor Janusz Bialek provided input to the Capacity Market which forms a part of the Electricity Market Reform (EMR) due to be implemented in 2014. EMR is envisaged to stimulate estimated £110 billion of investment until 2020 while the Capacity Market itself is estimated to be worth about £1.5 billion per year.

2. Underpinning research (indicative maximum 500 words)

Electricity Capacity Assessment

Research on model structures for generation adequacy assessment, on the capacity value of additional generation, and on the uncertainty in adequacy and capacity metrics due to finite size demand and wind time series underpins this case stud and was carried out between mid-2010 and end April 2013 (the date of submission of National Grid's report to Ofgem on capacity assessment). The relevant researcher at Durham is Dr. Chris Dent, who was at Durham for the whole duration of this work. The underpinning research was carried out in collaboration with Dr. Stan Zachary (a statistician at Heriot-Watt University), partly within their academic duties, and partly within the Capacity Assessment Project itself. Zachary and Dent regard each other as equal authors of this work, Zachary having slightly more emphasis on theoretical matters, and Dent having slightly more emphasis on the application side.

The underpinning research consists of the following:

2.1 ***Formulation of whole-season adequacy assessments in time-collapsed picture [1], [2].*** Generation adequacy assessments have in the past been carried out as either annual peak calculations, or as whole-season risk assessments in a model with an explicit time index. This research reformulates the whole-season adequacy assessment problem in terms of the available conventional (X) and wind (Y) capacity and demand (D) at a randomly chosen point in time within that season.

2.2 ***Probability theory of capacity value of additional generation [1], [2].*** The contribution of wind generation within adequacy assessments is visualised using capacity value metrics such as Equivalent Firm Capacity (υ_Y^{EFC}, defined as $P(M+Y<0)=P(M+\upsilon_Y^{EFC}<0)$ where $M=X-D$). This research derives a new closed-form expression for the EFC of small wind capacities. This, along with other probability results such as that for the capacity value of Y when the left-tail of the distribution of M may be approximated by an exponential function, shows transparently how calculated capacity value results depend on the distributions of M and Y.

2.3 ***Bootstrap uncertainty analysis [1].*** The research demonstrates for the first time how bootstrap uncertainty analysis may be used to quantify the consequences, in terms of uncertainty in adequacy risk and capacity value results, of using a finite size historic wind and demand dataset in adequacy assessment.

2.4 ***Winter severity analysis [3].*** Detailed demand data in GB are only available from 2005 onwards; this is insufficient to give a long-run view of the distribution of demand. The research shows how demand reconstructed from a longer temperature time series (1990-2012) may be used to weight adequacy results conditional on the severity of the 7 winters 2005-12 in order to give that longer-run view of the distribution of demand.

Capacity Market and Electricity Market Reform (EMR)

Research on the capacity market was undertaken by Bialek in Durham from September 2009 in collaboration with Dan Eager from the University of Edinburgh (former PhD student of Bialek) and Ben Hobbs of Johns Hopkins University (USA). That research was utilised by Bialek during his secondment to DECC July-December 2012 when he advised DECC on the EMR.

The underpinning research was based on an original idea of Bialek [4] of modelling the generation investment as closed-loop feedback process. This model was applied to modelling GB capacity investments and informed Bialek's contributions to the design of the Capacity Market.

3. References to the research (indicative maximum of six references)

[1] "Capacity Value of Additional Generation: Probability Theory and Sampling Uncertainty" by C.J. Dent and S. Zachary, International Conference on Probabilistic Methods Applied to Power Systems, Istanbul, 2012.
[2] S. Zachary and C.J. Dent, "Probability theory of capacity value of additional generation", Proc. IMechE, Part O: Journal of Risk and Reliability 226(1): 33-43 (2012).
[3] C.J. Dent and S. Zachary, "Winter Severity Analysis", Appendix N in "Capacity Assessment Project: Report to Ofgem", National Grid, 1 May 2013.
[4] D. Eager, B.F. Hobbs and J.W. Bialek, "Dynamic Modeling of Thermal Generation Capacity Investment: Application to Markets With High Wind Penetration", IEEE Trans. Power Systems, Vol. 27, No. 4, 2127-2137, November 2012.

4. Details of the impact (indicative maximum 750 words)

Electricity Capacity Assessment

Dr. Dent was contracted by National Grid from November 2011 to May 2012, and from November 2012 to April 2013, to design technical modelling for the 2012 and 2013 Electricity Capacity Assessment studies. He was chosen for this work on the basis of previous research on capacity value of wind carried out in collaboration with National Grid (including a 3 month full time secondment to the Control Centre in 2010), one output of which was the paper [2] above.

The structure of the Capacity Assessment Model code (the computational engine for which was written by Dr. Dent as VBA code within MS Excel) is based on the time-collapsed formulation of described above in Point 2.1 of Section 2. This code includes a number of features developed by Dr. Dent to increase computational efficiency, most notably using generating capacities and demands rounded to the nearest MW to facilitate use of fast integer arithmetic in convolution of distributions. The bootstrap uncertainty analysis approach described in Point 2.3 was used in the study to assess the consequences of a finite length (2005-11) demand history in terms of uncertainty in model outputs (and is used directly in the Capacity Assessment Reports published by Ofgem in 2012 [A] and 2013 [J], e.g. on page 40 and in Fig. 4.5 of the 2013 report); assessment of such uncertainties is critical to good decision making on the basis of modelling results. Matt Roberts, Senior Future Services Analyst at the National Grid Control Centre and the technical modelling lead from NG's side for the project, corroborates this statement of Dr. Dent's contribution [Q].

One of the key issues in the Electricity Capacity Assessment study is understanding wind's contribution to generation adequacy, which is done through the metric of Equivalent Firm Capacity (EFC). The EFC values calculated were higher as a percentage of the installed wind capacity than expected by many industry figures in the 2012 report, and further work has been done to explain this based on the work by Zachary and Dent. Most notably, the expression for the capacity value of small installed wind capacities published in [2] is used in National Grid's 2013 report to Ofgem to explain how the EFC depends on the distributions of demand and of available conventional capacity, in addition to the distribution of available wind (see [M]).

A further issue in the 2012 study was uncertainty in the calculated values of reliability indices arising from the short history of historic demand data which was available. As described in Point 2.4 above, for the 2013 study Dent and Zachary developed a new approach to reweighting the contributions to model outputs from demand data from winters of different severities, in order to

provide a result based on a longer run weather profile which helps validate the results derived using a short history of metered demand data and which forms the basis of the section 'Winter Severity Analysis' on pages 96-98 of Ofgem's 2013 report [J].

The Electricity Capacity Assessment Study has provided a key input to government policy on security of electricity supply. It has also been a major source of information to the public on security of supply risks over the coming years, and a key source of evidence to the electricity industry and NGOs in the wider public debate on energy security.

The model development and calculations for the 2012 Capacity Assessment Study were carried out between November 2011, and 1 June 2012 when National Grid's report on the technical modelling was submitted to Ofgem. The statutory report from Ofgem to DECC [A] was published on 5 October 2012. The BBC News story published that same day [B] illustrates how the report immediately entered the public debate, as does the article [C] from Page 4 of the following day's Guardian.

The impact on government policy is seen through its citation in DECC's 2012 Statutory Security of Supply Report to Parliament [D], in the DECC documentation providing updates on Electricity Market Reform process in November 2012 [E], and through numerous other mentions in Parliamentary and Government documents and submissions e.g. [F]. Its wider impact in the public debate on energy policy is further illustrated by its citation by non-governmental organisations such as Friends of the Earth [G] and the WWF [H]. Its key position in the thinking of Ofgem is demonstrated by its citation by its Chief Executive in a major public speech [I].

The continuing impact of the underpinning research on the 2013 Capacity Assessment Report [J], following its fundamental study in 2012, is demonstrated by the citation of the paper [2] in an Appendix of National Grid's 2013 report to Ofgem [N], and by the inclusion of new underpinning research as Appendices in the same report [3]. The 2013 report's impact on the wider public debate was greater still than in 2012, making front page headlines in both the broadsheet (e.g. [K]) and tabloid (e.g. [L]) press, [L] and further reports how Michael Fallon, Minister of State for Energy and Climate Change, responded to the report on the previous day's BBC Newsnight.

The Capacity Assessment Report's continuing critical influence on public policy is demonstrated by its citation in DECC's Consultation on the draft Electricity Market Reform Delivery Plan [M], in which the 2013 report is cited on page 48 as a guide to the meaning of the Loss of Load Expectation reliability index in practice. This report further states that "The System Operator (National Grid) will set out how much capacity to issue capacity agreements for, in order to meet the reliability standard, and will provide advice to the Secretary of State who will in turn take the decision over how much capacity to procure", indicating a key role for National Grid's and Durham's technical work on capacity assessment in the running of a future capacity mechanism designed to ensure an appropriate level of security of electricity supply in GB. In a letter [P] to Dr. Dent, the Economic Advisor at DECC confirms that "This analysis has been a crucial piece of evidence in the policy making process."

Capacity Market (CM) and Electricity Market Reform (EMR)

The need for a Capacity Market in GB has been highlighted over the last few years by a number of reports by Ofgem and DECC [B, C, I] which clearly indicated the increasing risk of lights going out in GB before the end of this decade due to insufficient investment in power generation capacity. Lack of adequate generation capacity can have disastrous economic and political consequences as the cost of any blackouts could be many billions of pounds. To address that concern the CM has been proposed as an important part of the EMR package due to be implemented in 2014.

Bialek's particular contribution has been in relation to the penalty regime for plants receiving payment through CM but which failed to deliver during power shortages. The initial proposal put forward by an eminent US economist, Stephen Stoft, advising DECC, was that any plant failing to deliver should be penalised whatever the reason for failure, i.e. whether it was due to a scarcity of generation or an unpredicted contingency due for instance to a sudden tripping of large power

stations. That view was strongly opposed by Bialek who pointed out that the proposed mechanism would result in economic inefficiencies. Consider a peaking generator, i.e. a generator that does not expect to operate 24/7 but only when the price is high or when called on to operate by the System Operator (SO) with a sufficient warning. If a contingency counted as scarcity, then in order to avoid penalties for non-delivery, the peaking generator would have to be prepared to generate at a moment's notice, as contingencies can happen at any time. Thus the additional cost of its preparedness (manning the plant, synchronising it, standing-by etc.) would go up and the consumers would have to pay more. On the other hand, if a contingency did not count as a scarcity event, then the peaking generator need only be prepared to operate when warned by the SO.

The consequent heated debate between Bialek and Stoft was resolved in Bialek's favour as the current view of DECC (subject to consultation) is that penalties for non-delivering generators would be levied only if a Capacity Market Warning has been issued at least 4 hours ahead of an event. The Head of Engineering at DECC, confirmed Bialek's contribution [O]. Bialek's contribution gives a potential of saving millions of pounds of unnecessary costs if peaking plants were required to operate at moment's notice as in the original CM proposal.

5. Sources to corroborate the impact (indicative maximum of 10 references)

[A] '2012 Electricity Capacity Assessment Report', Ofgem, 5 October 2012.
[B] 'Power shortage risks by 2015, Ofgem warns', BBC News, 5 October 2012.
[C] 'Power blackouts possible within three years, energy regulator warns', The Guardian, 6 October 2012, Page 4.
[D] 'Statutory security of supply report 2012', DECC, 29 November 2012.
[E] 'Annex C: Capacity Market: Design and Implementation Update', Department of Energy and Climate Change, November 2012, Accessed 6 May 2013.
[F] 'Energy Bill: Memorandum Submitted by SSE' [submission to the relevant Public Bill Committee of Parliament], January 2013, Accessed 6 May 2013.
[G] 'The Draft Energy Bill: Britain's Energy Future lost', Friends of the Earth, October 2012.
[H] 'Response to comments by Ofgem's Chief Executive ', WWF, 19 February 2013.
[I] 'Will GB's lights stay on and will the gas keep flowing: a look at the next decade?', public lecture by the Chief Executive of Ofgem, 19 February 2013.
[J] '2013 Electricity Capacity Assessment Report', Ofgem, 27 June 2013.
[K] '£10bn boost for nuclear as risk of power blackout rises', The Guardian, 28 June 2013.
[L] 'Electricity to be rationed', The Daily Mail, 28 June 2013.
[M] 'Consultation on the draft Electricity Market Reform Delivery Plan', DECC, July 2013.
[N] C.J. Dent and S. Zachary, "Measures of Capacity Adequacy in the GB Electricity System", App. Q in "Capacity Assessment Project: Report to Ofgem", National Grid, 1 May 2013.
[O] Head of Engineering, DECC, letter to Prof. Bialek.
[P] Department of Energy and Climate Change, letter to Dr. Dent.
[Q] National Grid e-mail communication.