Institution: BRUNEL UNIVERSITY (H0113)

Unit of Assessment: 15 – General Engineering

Title of case study: Development of Generator Dispatch Algorithms for National Grid

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

Prof Irving and Prof Sterling of the Institute of Power Systems at Brunel University collaborated with National Grid (NG) to develop and deploy a Sparse Dual Revised Simplex (SDRS), optimisation engine for real-time power allocation of all generators that were controlled by the NG. Since 2005-6 NG has been using the algorithms to aid in operation of their Balancing Mechanism, which provides a means of adjusting the level of production or consumption of individual generators or demands in the British Electricity Trading and Transmission Arrangements (BETTA). The algorithms enable the Balancing Mechanism (BM) to efficiently adjust outputs of generators in real time in order to balance the demand for electricity at minimum cost. Therefore, providing economic balancing of the transmission system at a scale of 2-3% of the £5bn annual electricity market (approximately £100M-200M per annum), hence about £800 million has been optimally traded in total in the BM since 2008. It is also important to acknowledge the reliability of the algorithms and SDRS optimisation engine from 2006 to present day, as periods of software outage carry high operational costs. The algorithms developed at Brunel continue to have very significant real world impact in terms of financial volume and its reach, such that every transmission scale power generator in the UK participates in the balancing mechanism and by implication every electricity-user benefits.

2. Underpinning research (indicative maximum 500 words)

The underpinning research pertaining to the highly efficient and cost-effective algorithms for dispatching and scheduling power output of electricity generators was conducted at Brunel University's Institute of Power Systems. The algorithms determine an optimal generation pattern or schedule resulting in substantial economic benefits, especially for large scale systems. The algorithm comprises of various functions:

- The unit commitment phase determines the optimum pattern for starting-up and shutting-down the generating units over the designated scheduling period, taking into account economic objectives and operational constraints.
- The economic dispatch is concerned with the allocation of target output powers to the online generators to satisfy the predicted load demand at minimum operational cost.

Both the unit commitment and economic dispatch functions assume the appropriate load forecasts are available. The load frequency control phase regulates the system frequency and scheduled tie line interchange, and is an online control process that uses the economic dispatch unit loadings to match the system load demand with the power generation.

Since 1993, SDRS software has been researched and developed at Brunel University under a series of research contracts awarded to Prof Irving and Prof Taylor. NG applied the software to their on-line, real-time generator dispatching. Later, a second version of the software, SDRS2, was introduced and NG undertook some benchmark tests to compare the performance of SDRS2 with well-known commercially available linear programming optimisation packages. They found that SDRS2 was approximately an order of magnitude more efficient than the commercial packages. This was thought to be due to the specialised nature of SDRS2, which was tailored to the characteristics of power dispatch problems. NG also used SDRS2 as an optimisation engine within a number of their other in-house software developments (ESCORT, ORION, etc.) which were applied in power system operation and planning. Brunel University has continued to support the SDRS2 software to the present day, with the software remaining relatively stable in recent years. The algorithms, embedded in software, have been in continuous use by the NG control centre since the mid-1990s. The algorithms provide the SDRS optimisation engine which is presently responsible for the real-time power allocation of all the generators controllable by National Grid in the current balancing mechanism, with real-time generator target outputs being determined every 5 minutes.

Key research activities include:

1. An algorithm for constraint relaxation when using sparse linear programming techniques to solve optimal power flow problems was developed at BIPS [Zhang & Irving 1993]. Prof Irving was the principal investigator for this project.
2. A combined active and reactive power dispatch algorithm was developed by BIPS [Chebbo & Irving 1995] to optimise power flows on the transmission system as owned and operated by National Grid. The algorithm was tested using large-scale security constrained power flow models of the National Grid transmission system [Chebbo & Irving 1995]. Dr Ahmed Chebbo was the funded BIPS research fellow for this project. He is now employed by National Grid.
3. It was demonstrated by BIPS under the sponsorship of National Grid that a sparse linear programming approach could be extended to the problem of transition optimised reactive power control [Taylor et al. 2003]. Prof Taylor of BIPS was funded BIPS research fellow for this project. He is now the current BIPS director.
4. It was demonstrated that practical large-scale security constrained optimal reactive power flow problem of determining the optimal switching of large numbers of discrete devices such as shunt capacitors or reactors is best addressed using a compact as opposed to a sparse linear programming formulation [Macfie et al. 2010]. Dr Peter Macfie was the BIPS research engineer for this project. He is now employed by National Grid. Prof Gary Taylor and Prof Malcolm Irving were the principal investigator and co-investigator, respectively.

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

Relevant Completed Projects at Brunel Institute of Power Systems (BIPS)			
Topic	*Project Duration*	*Funded Amount*	*Funded by*
The potential for environmentally significant loss reduction on the NG transmission system using operational measures	2007-11	£145,000	EPSRC & NG
Integrated Algorithmic and Heuristic Techniques for Transition-Optimised Voltage and Reactive Power Control	2001-04	£128,000	EPSRC

Authors	**Title**	**Year of Publication**	**Type of output**	**Details**
S. Zhang and M.R. Irving	Analytical Algorithm for Constraint Relaxation in LP-based Optimal Power Flow	1993	Journal	IEE Proceedings C: Generation, Transmission and Distribution 140 (4) 326- 330
A.M. Chebbo and M.R. Irving	Combined Active and Reactive Dispatch, Part I: Problem Formulation and Solution	1995	Journal	IEE Proceedings - Generation, Transmission and Distribution 142 (4) 393- 400
A.M. Chebbo and M.R. Irving	Combined Active and Reactive Dispatch, Part II: Test Results	1995	Journal	IEE Proceedings - Generation, Transmission and Distribution 142 (4) 401- 405

G.A. Taylor, S. Phichaisawat, M.R. Irving and Y.H. Song	Voltage security and reactive power management	2003	Journal	IMA Journal of Management Mathematics 15 (4): 369- 386
P.J. MacFie, G.A. Taylor, M.R. Irving, P. Hurlock and H-B. Wan,	Proposed shunt rounding technique for large-scale security constrained loss minimization	2010	Journal	IEEE Transactions on Power Systems 25 (3)1478- 1485

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

In the UK, the National Grid decides which power stations are to be scheduled within the balancing mechanism, taking into account factors such as:

- Load pattern
- Price at which the various capacities of generation can be supplied
- Constraints in supplying the said capacities
- Amount of power generation capacity offered by the different generators at each time interval over the scheduling period
- Transmission network constraints etc.

These factors are also taken into account in determining the wholesale price at which electricity is traded in the balancing mechanism. This price is dependent on the generation schedules of the various power generators, compiled by the National Grid, using the Brunel Institute of Power Systems' scheduling algorithms since 1993. In 2005-6, as a consequence of the introduction of BETTA, the scheduling algorithms developed at Brunel University affects everyone (residential & commercial establishments in the UK) using electricity, since the cost-effective dispatching of generation is determined by the scheduling algorithms. The algorithms in continuous day-to-day use at the National Grid control centre has very significant real world impact in terms of financial volume and in terms of its reach (every transmission scale power generator in the UK is controlled and by implication every electricity-user benefits).

The algorithms provide the optimisation engine (*SDRS - Sparse Dual Revised Simplex*) for real-time power allocation of all the generators controlled by National Grid, with targets being sent to each generator every 5 minutes. In this process the real outputs of generators are adjusted to balance the demand for electricity at minimum cost. Balancing power generation is currently achieved by power generators that modify their output in response to varying load demand. However, generators must be responsive to control signals, making it difficult for utilities to accommodate variable power demands while maintaining a continuous and instantaneous balance. Balancing power can reduce inefficiencies in electricity production and cut carbon emissions (electricity generation is currently a major source of CO_2 emissions in the UK, responsible for about a third of total CO_2 emissions).

Benefits of the algorithm -

- Provides a continuous and instantaneous balance of power generation
- Reduces CO_2 emissions
- Saves significant energy generation costs each year

Exploitation by the National Grid

Initially the research results in the form of the SDRS software were exploited and implemented by the National Grid in their national Dispatch project. Due to the efficiencies created by its application, the algorithm has been adopted to operate the "Balancing Mechanism" in the British

Electricity Trading and Transmission Arrangements (BETTA). The arrangements under BETTA are based on bilateral trading between generators, suppliers, traders and customers across a series of markets operating on a rolling half-hourly basis. Under these arrangements generators self-despatch their plant rather than being centrally despatched by the National Grid (as the System Operator). The Balancing Mechanism operates from Gate Closure (the point in time when market participants notify the System Operator of their intended final physical position and is set at one hour ahead of real time and no further contract notification can be made to the central settlement systems) through to real time and is managed by National Grid in its role as Great Britain System Operator (GBSO). It exists to ensure that supply and demand can be continuously matched or balanced in real time. The mechanism is operated with the National Grid acting as the sole counter party to all transactions. Participation involves submitting 'offers' (proposed trades to increase generation or decrease demand) and/or 'bids' (proposed trades to decrease generation or increase demand). The mechanism operates on a 'pay as bid' basis. The National Grid purchases offers, bids and other Balancing Services to match supply and demand, resolve transmission constraints and thereby balance the system. By allowing the National Grid to send control signals that direct responsive loads to move incrementally up or down or to a total set amount, the method provides a cost-effective system of power regulation or spinning reserve to the power grid.

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

[1]. The National Grid (http://www.nationalgrid.com) – algorithms used for the balancing mechanism of the BETTA.

[2]. IEEE Institute of Electrical and Electronics Engineers – transactions on power systems publications of the IEEE.

[3]. Future Control Systems Manager, National Grid Control Centre, St Catherine's Lodge, Bearwood Road, Sindlesham, Wokingham, Reading RG41 5BN.