ON A FLEXIBLE MODEL FOR NEW ZEALAND'S HYDRO-THERMAL ELECTRICITY GENERATION SYSTEM

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Abstract

This thesis investigates the modelling of the New Zealand hydro-thermal electricity generation system in order to determine an optimal strategy for generation, in terms of minimizing fuel costs. The model currently used by ECNZ (Electricity Corporation of New Zealand) uses an SDP (Stochastic Dynamic Programming) method for solution; this allows little detail of the physical system, and models *two* explicit hydro reservoirs. The model developed in this thesis is flexible, in order to allow the balance between ensuring stochastically stable solutions and the detail of the physical system, to be altered, whilst ensuring computational tractibility. The areas of the system which are important to be modelled accurately are isolated, as are those which may lead to computational intractibility if they are modelled in too much detail. The flexibility in the model also allows the effects of the approximations used on solutions to be explored in a wider framework.

The time horizon of the model is one to two years, with time steps of the order of a week. The time horizon describes the level to which many aspects of the system are to be modelled. Transmission is modelled explicitly so as to include information on the geographical locations of power stations and power users; this takes the form of a network structure underlying the model. The load at each geographic location is represented by a Load Duration Curve (which is more robust, in terms of forecasting, than a direct representation of load with respect to time). Hydro river chains are modelled as single power stations with a single reservoir and connect the model temporally; we model six explicit hydro river chains. Thermal stations are modelled individually, and the generation from run-of-river and geothermal stations is removed from load before solution begins.

The initial approach considers a model which, upon further investigation, is unacceptable. However, examination of the issues highlighted by this approach provide insight into the system. The resultant re-modelling of the problem leads to a linear model which does not explicitly model the uncertainty in the generating

capacity of stations due to forced outages. This accentuates the reason why the usual approach to explicitly modelling the uncertainty of supply (within a week) cannot be used in the case where the geographic distribution of generation has been explicitly modelled. The deterministic model may then be formulated as a Generalized Network with side constraints.

The deterministic model developed can be extended stochastically in many ways. The stochastic extension investigated uses Rockafellar and Wets' *Progressive Hedging Algorithm.* This takes a scenario approach, in which the stochastic variables are approximated by a number of scenarios of observed values. A policy is required which minimizes the expected cost of generation over these scenarios, ensuring that information on the observed values of the stochastic variables is not used before it would be available in practice.

Results and implementation issues are discussed for both the deterministic and stochastic models. Consideration is given to the implementation of a finished product, as well as implementation for the purposes of investigating the feasibility and examining the computational effectiveness of approximations made in the model.

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I would like to thank ECNZ for their funding of this project and for sending me to the 15th Symposium on Mathematical Programming which gelled many of the ideas in this thesis. My chief supervisor Dr. John Giffin deserves a lot of praise for his help, support, extensive knowledge of the English Language, and, "in some ways," for telling me when to stop. I would also like to thank my second supervisor Dr. Jonathan Lermit for his help, ideas (it's a shame about the cumulants), valiantly trying to print the colour figures within this thesis, for coming up every month or so to ensure I was actually doing some work, and for his nice comments about markets (which I have studiously tried to avoid). I would also like to thank Philippa, my wife, for her love and support, for her proof reading (even though she complained about not understanding most of it), and especially for her interest and enthusiasm in my thesis.

There are many other people I would like to thank but don't have the room for, although a special note of thanks goes to Richard "Vancouver Coast Guard" Rayner for getting Saruman and Matlab back up again (well, for calling the repairman) when I had only two weeks to finish this think, and for being away the six days before I sent it in to be bound, while I was trying to get the colour pages printed.

Special thanks goes to Philippa (my wife) and Mark Johnston for helping me to "colour in" the coloured pictures, *by-hand*, the night before binding. Thankyou.

Addendum

Page 25, line 11; "*optimallity*" should read "*optimality*".

Page 109, §6.2, sentences two and three should become:

"The general stochastic program can be written as a multi-stage stochastic program with recourse. The two-stage stochastic program with recourse can be written as follows:

$$\text{Min} \quad f_1(x) + \underset{\tilde{\xi}}{E}\left[f_2(x, \tilde{\xi})\right]$$

subject to: (6.0a)

$$Ax = b$$

where x is the decision variable representing a decision that must be implemented prior to the realization of the random variable $\tilde{\xi}$, $f_1(x)$ represents the cost of decision x, and $f_2(x, \xi)$ (where ξ is a single observation of $\tilde{\xi}$) is defined as:

$$f_2(x, \xi) = \text{Min} \quad g(y)$$

subject to: (6.0b)

$$Wy = \xi - Tx,$$

$$y \geq 0$$

where this involves the determination of the optimal recourse variable y given the initail decision x. Extension to the multi-stage case invloves defining (6.0b) in a similar manner to (6.0a). In our case the recourse variables are the releases of the subsequent weeks."

Page 113, paragraph 3; should be appended with the sentence:

"While there are many other stochastic techniques which could be considered, since the focus here is to show that it is *feasible* to extend the deterministic model developed to a full stochastic model and we cannot cover every method here, the following are a *selection* of approaches which have been used in the past to model such a system."

Page 115, §6.5, line 2; "...as it offers the greatest flexibility in the extent ..." should read "...as it appears to offer the greatest flexibility, of any of the many possible stochastic approaches which could be used, in the extent ..."

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