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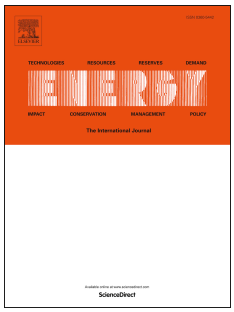

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Hydro-thermal Power Market Equilibrium with Price-Making Hydropower Producers

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Abstract

This paper formulates an electricity market dominated by price-making hydro-thermal generation. Generation companies optimize their unit commitment, scheduling and bidding decisions simultaneously as a Mixed Integer Programming problem and participate in a market under quantity competition, giving rise to a discontinuous Nash-Cournot game. Both hydropower and thermal units are considered as price-makers. The market equilibrium under uncertainty is computed via time stage decomposition and nesting of a Continuous Nash game into the original Discontinuous Nash game that can be solved via a search algorithm. To highlight applicability of the proposed framework, a case study on the Scandinavian power market is designed and suggests positive welfare effects of large scale storage, whereas the implications on scheduling of conventional units are subsequently discussed. Reformulation allows computationally efficient scaling of the problem and possible extensions to allow large scale applications are discussed.

Keywords: Hydropower, Hydro-Thermal, Cournot game, Nash equilibrium, discrete game, electricity market

1. Introduction

1.1. Background

Larger integration of renewable resources increases the challenges on liberal electricity markets. Such means of generation are, compared to conventional forms of generation, characterized by their low cost curves and uncertain capacity profiles. Higher shares of renewable generation could thus lead to increased supply side volatility as well as increased gaps between peak and base prices. Those effects will be eventually carried financially by the end consumer and, in interconnected systems, might spread to otherwise unaffected nodes or areas[1]. Applying flexible means of production mitigates this issue by applying the principle of 'peak skimming'[2], where a producer strategically schedules generation for the periods showing the highest market prices. Such flexible generation can come in form of conventional plants or energy storage, whereas hydropower plants provide the most prevalent large-scale application for latter. Despite their negligibly small cost curves, hydropower units with large enough storage capacities [1] compete with conventional generation for peak loads rather than for base loads with other means of renewable generation[3]. This paper addressed the issue of an electricity market dominated by hydro-thermal generation as price makers. Differing from the existing works on this topic, in this paper the hydropower producers simultaneously decide their unit commitment and scheduling strategies under uncertainty.

Table 1: Model Feature Comparison

Ref	**Hydropower**	**Thermal power**	**Uncertainty**	**Multiple periods**	**Multiple players**	**Price-makers**	**Non-convex players**
[1]	✓	✓			✓		
[3]	✓	✓	✓	✓	✓	✓	

[1]In relation to their generation capacities, as a reservoir with large storage capacity and smaller output capacity has higher flexibility regarding the time stages it chooses to feed into the system.