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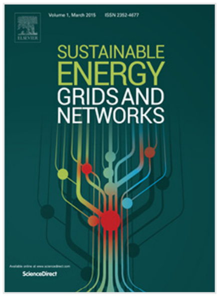

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Stochastic Control of Cooling Appliances under Disturbances for Primary Frequency Reserves

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Abstract

To stabilize power system frequency both in normal operation and after a contingency, a hierarchy of distributed-proportional and centralized-integral controllers is employed in most power systems. Providing proportional control—commonly referred to as primary frequency control or droop—with conventional generators constitutes significant cost. This led to strong interest in utilizing demand response as a cost-effective primary control reserve. This paper investigates an approach that allows a population of domestic refrigerators to reliably and continuously adjust its demand proportional to system frequency. The control relies exclusively on stochastic switching of refrigerators, and thus avoids synchronization and implementation issues associated with control strategies based on temperature-band adjustments. The scheme is tested on a realistic two-area power system model to investigate interaction with system frequency. The modeling of refrigerators is refined by analyzing the effect of door openings on cooling demand, and response of the refrigerator population under these conditions is described both analytically and with simulations.

Keywords: Primary frequency reserves, demand response, cooling appliances, stochastic control.

1. Introduction

If electric power generation and demand are not in exact balance, the system frequency of a power system will increase or decrease. To stabilize frequency excursions and restore power balance, frequency control reserves are used [1]. Primary frequency control or droop is activated proportionally to deviations from nominal system frequency. In some control areas, provision of primary control is a compulsory condition to enter the electric market [2]. Other Transmission System Operators (TSOs) acquire primary reserves by means of an auction. As of today, sufficient primary reserves are available but procurement creates significant cost, and maintenance costs of hydro power plants that participate in load frequency control are increasing [3]. Wind and photo-voltaic generation can in theory provide frequency reserves, but at the cost of reduced energy production. In addition, such inverter-connected generation sources add little or no rotational inertia to the system, so frequency deviations might become more severe in future power systems, an effect already observed in the Irish system [4]. ERCOT recognizes this by proposing synchronous inertial response and fast frequency response services [5]. Considering these challenges, new sources for frequency reserves are investigated and Demand Response (DR) is one much-discussed option.

The idea of using domestic cooling appliances to stabilize grid frequency stems from the 1980's [6]. Intuitively, one would adjust temperature limits proportional to frequency changes, as proposed in [7, 8]. With increasing system frequency the temperature limit is reduced, leading to an increase in demand—and vice versa for frequency drops. Such a control scheme has also been tested in experiments [9]. However, a detailed discussion of this approach finds two shortcomings. First, lasting frequency deviations would require continuously decreasing temperature limits, and second, temperature limit adjustments can lead to synchronization of refrigerators that introduce unstable oscillations in power demand [10]. Recently stochastic switching was proposed to avoid these issues [10], introducing the notion of duty-cycle adjustments as opposed to temperature limit adjustments. A drawback of the control scheme in [10] is a rather slow response to sudden frequency changes. To improve the response, additional temperature adjustments are needed.

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