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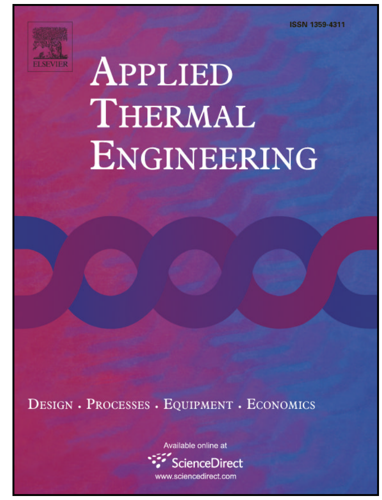

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On the use of thermal inertia in building stock to leverage decentralised demand side frequency regulation services

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Abstract

Most governments are applying financial instruments and other polices to encourage distributed renewable electricity generation (DREG). DREG is less predictable and more volatile than traditional forms of energy generation. Closure of larger fossil-fuelled power plants and rising share of DREG is reducing system inertia on energy networks such that new methods of demand response are required. Usually participation in non-dynamic frequency response is reactive, affecting the duty cycle of thermostatically controlled loads. However, this can adversely affect building thermal efficiency. The research presented takes a proactive approach to demand response employing heat transfer dynamics. Here, thermal dynamics exhibit a significantly larger inertia than electrical power consumption. Thus, short-term fluctuations in energy use should have less effect on temperature regulation and user comfort in buildings than existing balancing services. A prototype frequency sensor and control unit for proactive demand response in building stock is developed. The paper reports on hardware-in-the-loop simulations, testing real thermal loads within a simulated power network. The instrumented approach adopted enables accurate real-time electrical frequency measurement, while the control method offers effective demand response, which suggest the feasibility of using decentralised frequency control regulation as a novel approach to existing demand response mechanisms.

Keywords Frequency regulation; decentralised control; demand response.

Nomenclature

d	transport delay, s
D	load damping constant, s
Δf	frequency deviation, Hz
H	inertia time constant, s
I	TCL controller integral gain
K_i	ALFC secondary loop gain, p.u. MW/Hz s
K_h	thermal load gain
P	TCL controller proportional gain
ΔP_d	step change in power demand, p.u.
ΔP_g	change in hydraulic amplifier output
ΔP_{hp}	electrical power deviation, p.u.
ΔP_t	change in turbine power output
R	regulator, Hz/p.u. MW
ΔT	temperature deviation, p.u.
T_g	governor time constant, s
T_h	thermal load time constant, s
T_t	turbine time constant, s
$\bar{x}$	sample mean
n	number of entries
s	sample standard deviation
σ	standard error
z	standardized test statistic

1 Introduction

Historically national electrification followed a trajectory of increasing integration and centralisation [1]. In centralised electricity networks the transmission system operators (TSOs) are primarily responsible for balancing the network [2]. Recently however an expanding share of power generation on the distribution network is challenging existing approaches to balancing supply and demand [3,4]. In light of this, it is widely argued that distributed system operators (DSOs) need to take on some of the responsibility for balancing electricity networks [1]. Improving coordination between TSO-DSO to unlock new flexible services that seek to optimise the distribution grid operations will encourage more active participation of the consumer in demand side response DSR [5]. However, as outdated perceptions of technology cost and performance continue, the centralised approach to energy production, delivery and consumption fails to cope with an evolving energy landscape [6–8].

Most conventional generation plants use large synchronous machines to meet time-invariant imbalances between supply and demand. This stored kinetic energy provides rotational inertia that helps absorb extemporal transient