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Niko Karhula*, Seppo Sierla, Heikki Ihasalo, Jaakko Ketomäki, Matti Huotari, and Valeriy Vyatkin

Primary frequency control with an air handling unit

Abstract: The green energy transition threatens stability of the power grid due to associated reduction in grid synchronous inertia. Primary frequency control (PFC) can compensate for the challenge; however, sufficient procurement of primary frequency capacity could depend on more extensive employment of demand-side loads for PFC. Ventilation fans in particular present a promising class of such loads because of ubiquity of variable-frequency drives and relatively large time constants of space heating, cooling and ventilation dynamics. Thus, this research proposes a method for PFC by an air handling unit: the open-loop control is shown to have favourable dynamic characteristics, and its impact on ventilation efficiency is shown to be tolerable. This study suggests that the largely unused primary frequency capacity of ventilation fans could be exploited to provide fast-reacting and dynamically performant and stable primary frequency response.

Keywords: primary frequency control, frequency containment reserve, air handling unit, variable-frequency drive

***Corresponding Author: Niko Karhula:** Aalto University, E-mail: niko.karhula@aalto.fi

1 Introduction

Increasing penetration of inverter-connected variable renewable energy sources and decrease in fossil-fuel powered turbine-generated electricity production threaten the performance and stability of the power grid as a result of reduction in grid synchronous inertia and increase in stochasticity of energy production. Generators and loads—asynchronous included—can compensate for the reduced inertia by providing primary frequency response (PFR). Resources providing PFR adjust their energy production or consumption in proportion to grid frequency deviation from nominal frequency. Traditionally the response has been provided by generators; however, aforementioned trends in power systems challenge the response capacity of generators, and hence demand-side PFR is becoming increasingly attractive. Heating, ventilation and air conditioning (HVAC) loads constitute a significant proportion of global energy demand [1] which make them potentially valuable resources for provision of PFR.

Variable-frequency drive (VFD) controlled induction motors constitute a promising class of primary frequency control (PFC) capable HVAC loads: VFDs enable precise and fast control of motor speed and consequently of instantaneous active power. Ventilation fans in particular present a promising case study because they account for significant part of the energy consumption of an air handling unit (AHU), which in turn is a major energy consumer in a commercial HVAC installation. Robustness of modern induction motors suggest that continuous fan speed adjustment is unlikely to markedly impact lifetime of the equipment; however, the impact on ventilation efficiency and indoor air quality ought to be considered. Implementing PFC should also be economically viable—something challenging in retrofit scenarios.

Rules and regulations concerning PFC vary considerably between different synchronous areas, and thus any investigation pertaining to PFC must be either generic or focused on a particular synchronous area. The Nordic synchronous area presents an interesting case study because new technical requirements [2], to be provisionally enforced in 2023, are considerably more stringent and involved than the currently enforced requirements. Specifically, new frequency domain dynamic requirements are introduced as an addition to the current stationary and time domain dynamic requirements, among other modifications and additions.

This research proposes a method for PFC with an air handling unit. In particular, open-loop fan speed control is implemented and validated in accordance with the new technical requirements. Exemplary intervals of historical grid frequency data, made available by Fingrid, are utilized in assessing the impact of the proposed PFC implementation on ventilation efficiency. The focus of this research is on dynamic characteristics and economic viability of the PFC.

2 Related Work

Several studies have investigated PFC with an AHU; however, to the best of the authors' knowledge, no research validates the control against the aforementioned new requirements.

Rominger et al. pre-qualify an aggregate of AHUs for PFR provision in Germany [3]. Each VFD is controlled in closed loop by a PID controller for instantaneous active power, and the response is validated against time domain dynamic requirements, which are assessed by a step test sequence (synthetic frequency steps are injected to the controller reference). Dynamic performance or stability of the control is not investigated.

Beil et al. investigate secondary frequency control (SFC) using the ventilation fans in the AHUs of a variable air volume (VAV) system [4]. They identify three strategies for frequency regulation: direct fan speed, static pressure setpoint and thermostat setpoint control. Control of thermostat setpoint suffers from substantial delay and inaccuracy, and hence, not applicable for PFC. Static pressure setpoint control is considerably faster due to small time constants of the involved gas dynamics; however, it still introduces additional latency and inaccuracy compared to direct fan speed control. Thus, direct fan speed control appears most promising for fast and accurate control necessitated by the new Nordic requirements.

Lin et al. study SFC using ventilation fans of a single commercial air handling unit [5], [6]. The closed-loop control is shown to pass the technical requirements of the independent system operator of Pennsylvania-New Jersey-Maryland Interconnection (PJM). They also consider dynamic response in frequency domain but the control is not directly applicable to PFC—where stricter dynamic requirements are enforced—since relatively restrictive band-pass filtering is adapted.

3 Methods

The research is conducted on a laboratory installed AHU located at Myllypuro Metropolia campus in Helsinki, Finland. The unit consists of supply, return and recirculation air ducts with associated dampers. The supply and return ducts contain air filters and VFD controlled three-phase squirrel cage induction motors (rated at 1.5 kW) which are attached to centrifugal fans. The supply duct also has heating (district heating) and cooling coils. Figure 1 depicts the air handling unit. The AHU is interfaced with a commercial building automation system (BAS) which provides a Modbus TCP interface for remote control of the VFDs. In addition, an energy meter is installed on-premises for measuring the energy supplied to the drives. PFC is implemented on an Internet of Things (IoT) gateway based on a Raspberry Pi compute module.

The VFDs (VLT HVAC Drive FC 102 by Danfoss) implement an open loop motor control mode with a configurable ramp rate limiter. PFC is implemented by altering motor speed setpoint via the BAS based on real-time grid frequency measurement. Motor speed setpoint control avoids direct interfacing with the VFDs—a factor favourable for economic viability.

Relation between fan speed and fan power is approximated by the affinity (fan) laws. Specifically, fan power is approximately proportional to the third power of fan speed; however, variable frequency drives introduce losses, and thus a more accurate relation between fan speed and incoming power is obtained by a general cubic function. The method of least-squares is applied for parametrizing the cubic function which is then inverted so that the controller can compute desired fan speed based on grid frequency measurement. A recursive implementation is additionally proposed for scenarios where parameters of the cubic function are considerably time-varying (for example VAV systems).

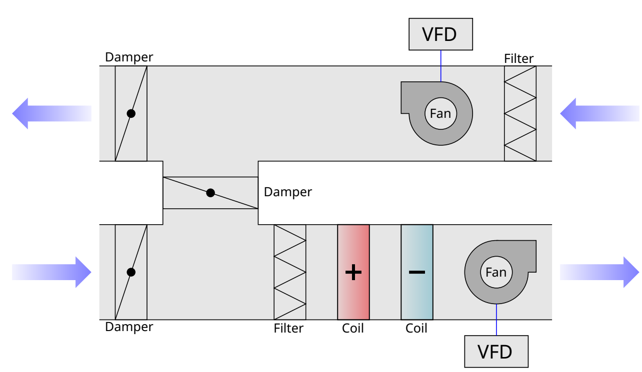

Fig. 1. Depiction of the air handling unit located at Myllypuro Metropolia campus. Blue arrows indicate direction of air flow.

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