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A Gray-Box Model of a Two-Stage Heat Pump for Electrical Load Forecasting in a Single-Family Residence

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Abstract

Buildings as a set of electric loads and generation resources can play an essential role in managing the stability of the power system in a smart grid. Traditionally, buildings assumed a passive role in the day-to-day operation of the electric grid, with utilities controlling the supply of energy to match the demand for buildings. However, the dynamics of the power distribution grid are rapidly changing. A critical aspect of managing the balance between supply and demand in the distribution grid is estimating future demand through load forecasting. Load forecasting requires accurate, adaptive, and simple models to account for the dynamic behavior of the electrical demand. In residential buildings, heat pumps are a significant source of energy consumption. This document describes a novel gray-box model (RL Model) to forecast the steady-state and transient current consumption for a two-stage, air-source heat pump in heating and cooling seasons. The RL Model is derived from a solution of a first-order differential equation describing the voltage and outdoor temperature dependent characteristics of a resistor-inductor equivalent circuit. Key parameters of the RL Model were estimated using a learning algorithm. The performance of the RL Model is validated using measurement data from the Net-Zero Energy Residential Test Facility located on the National Institute of Standards and Technology (NIST) campus in Gaithersburg, MD. The predicted output of the RL Model, current consumption, is used to estimate the heat pump's real and reactive power consumption for different operating stages and seasons. A list of key parameters, e.g., the time constant and temperature-dependent coefficients of the RL Model, are tabulated. Knowledge of the time constant provides critical information for analyzing the aggregated effect of controlling many heat pumps as flexible loads on grid stability and provision of ancillary services. The average root mean squared error between the RL Model's predicted current output and the measured current consumption is 0.06.

Keywords

Data-driven model; energy use forecasting; gray-box model, heat pump modeling; heat pump real and reactive power; heat pump time constant; load forecasting; load modeling; parameter fitting; parameter optimization; RL model; temperature dependent heat pump model.

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