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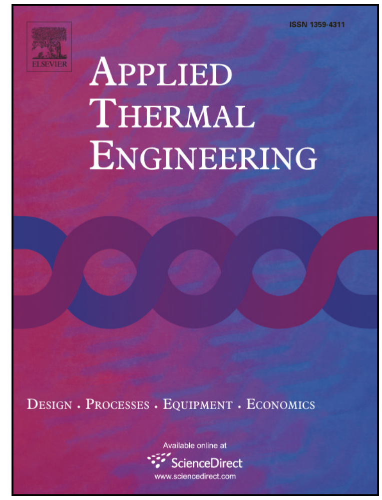

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Non-linear system identification of a latent heat thermal energy storage system

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Abstract

Latent heat storage systems utilising phase change materials have potential to offer several advantages over sensible heat storage, including higher energy storage densities and thermal modulation. Despite these advantages, only a few commercialised products incorporating this technology exist due to several engineering challenges. One problem is how to model this technology in a computationally efficient manner which allows simulating this technology with variable heat sources such as solar thermal and heat pump systems and assess their long-term system performance. In this study, the application of a dynamic neural network for this purpose is investigated, where a Layered Digital Dynamic Neural (LDDN) type network is trained using experimental data to approximate the outlet fluid temperature of a latent heat storage system given inlet fluid temperature and mass flow rate.

To acquire the training data necessary for the neural network, an experimental apparatus was designed, built and operated under laboratory conditions. Twenty experiments were conducted to obtain training data where the latent heat storage system was charged to different operating temperatures ranging from 25 to 70 degrees Celsius. The mass flow rate of the heat exchanger fluid flowing through the heat exchanger was also varied: 0.045 and 0.05 kg/s such that the flow of heat exchanger fluid remained turbulent. These data were then presented to the network for training and optimisation of the network architecture using the Bayesian Regularization training algorithm. It was found, that the LDDN type architecture was suitable to characterise the thermal operational behaviour of a latent heat storage system with good accuracy and with little computational effort once trained. Based on an energy analysis, the neural network response predicted the quantity of energy stored and discharged with approximately 5% and 7% accuracy respectively when presented with data not used during the training process. These results indicate that a dynamic neural network may be a computationally efficient method to model the non-linear operational characteristics of a latent heat storage system. It may therefore be implemented within a simulation environment such as TRNSYS or Simulink.

Keywords: Dynamic neural network; latent heat storage; phase change material; modelling; thermal characterisation

1.0 Introduction

According to the results presented in the latest REN21 report [1], the addition of renewable power capacity has overtaken fossil fuel powered sources. Due to the intermittency typically experienced by renewable energy sources such as solar and wind, energy storage technologies are essential components for these systems to address the mismatch between the supply of energy and user demand. This issue is particularly relevant to solar energy systems, where solar radiation is converted to electricity and heat via photovoltaic and solar thermal technologies respectively. An additional need for storage arises when there is a disparity between the rate of energy supplied from a renewable energy source, and the rate at which it is required at time of use is considered. Frequently, applications require energy transfer rates during operation far higher than the rate at which it is collected; this is the case for air-sourced heat pumps and solar thermal systems for domestic hot water applications. In Europe, it has been estimated that approximately 1.4 million GWh/year could be saved and some 400 million tons of CO_2 emissions avoided in the building and industrial sectors with increased penetration of thermal energy storage [2]. The focus of this work therefore is on thermal storage systems for solar thermal systems to address the above-mentioned issues.

Currently, commercialised thermal energy storage technologies may be largely split into two categories based on the dominant mode of heat transfer: sensible and latent heat types. For sensible