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A low data requirement model of a variable-speed vapour compression refrigeration system based on neural networks

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Abstract

In this work a model of a vapour compression refrigeration system with a variable-speed compressor, based on a black-box modelling technique, is presented. The kernel of the model consists of a full customized radial basis function network, which has been developed to accurately predict the performance of the system with low cost data requirement in terms of input variables and training data. The work also presents a steady state validation of the model inside and outside the training data set, finding, in both cases, a good agreement between experimental values and those predicted by the model. These results constitute a first step to go through future research on fault detection and energy optimisation in variable-speed refrigeration systems.

Keywords: Refrigeration; Air conditioning; Compression system; Variable speed; Compressor; Modelling; Neuronal network; Energy consumption; Detection; Anomaly

Modèle nécessitant peu de données d'un système frigorifique à compression de vapeur, fondé sur des réseaux neuronaux

Mots clés : Réfrigération ; Conditionnement d'air ; Système à compression ; Vitesse variable ; Compresseur ; Modélisation ; Réseau neuronal ; Consommation d'énergie ; Détection ; Anomalie

1. Introduction

Energy optimisation is an important subject in any engineering area. Several reports locate the energy consumption of refrigeration and air conditioning systems to be around 30% of the total energy consumption [1], most of these facilities being based on vapour compression systems. Installing efficient refrigeration facilities is a first step to reduce energy consumption. However, these facilities that run efficiently at their design load can be inefficient, even poor effective, at part load conditions. So, it is necessary to adequately regulate the refrigeration capacity in order to match thermal load, the use of variable-speed compressors being an efficient way to operate the vapour compression facilities in part load conditions [1–4]. In this way, the possibilities of improving the

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Nomenclature

c	Centre of the activation function
COP	Coefficient of Performance
g	Activation function
N	Compressor rotation speed [r.p.m.]
P_C	Compressor power consumption [kW]
Q_o	Cooling capacity [kW]
T	Temperature [K]
x	Input vector
y	Measured output vector
$\hat{y}$	Predicted output vector

Greek symbols

σ	Bias of the activation function
ω	Output layer weights

Subscripts

k	Condenser
in	Inlet
out	Outlet
o	Evaporator
r	Refrigerant
w	Secondary fluid

energy efficiency of these refrigeration facilities need a proper regulation of the compressor speed in any operation condition avoiding the presence of faults [5]. In both cases, it is necessary to count with an appropriate model, which accurately predicts the fault free performance of the system.

There is a large amount of literature that deals with modelling both the steady state and dynamic behaviour of vapour compression chillers [6,7]. Mainly, these models can be classified into two broad groups: empirical (black-box) and physical models. The physical models are based on a detailed information of the elements of the system and their modelling using equations derived from physics laws [8,9]. Given the difficulty to characterise accurately all the components of a refrigeration system and the noticed general good behaviour in time response and accuracy of black-box models [10], the empirical approach has been selected in this work.

In black-box models one tries to estimate both the functional form of relations between variables and the numerical parameters in those functions with no need of detailed information about the components of the system. Examples of empirical models include regression analysis, polynomial curve fits and artificial neural networks [10,11]. Several references about neural networks can be found in HVAC&R research [12–14], most of them using the perceptron structure. Only some authors decided to work with radial basis function networks (RBF networks), despite the good results obtained [15,16].

In this paper a new approach to model variable-speed vapour compression systems with RBF neural networks is presented. The application has been focused on achieving an accurate model, which has low cost input data requirement and which is able to perform a good generalization without an extensive training. This model is expected to be useful in energy optimisation and fault detection and diagnosis (FDD).

2. Model basis

The model proposed in this work is based on an RBF network. Since late 1980s, radial basis function networks have been a subject of study and have been employed with success in numerous fields [17], their main applications being time series forecasting and function approximation.

In general, it can be said that an RBF network is a feedforward network that consists of three layers: the input layer, the hidden layer and the output layer, as it is shown in Fig. 1. The hidden layer is composed of a determined number of nodes or basis functions. These basis functions, also called kernel, can be selected among several types of functions, but for most applications they are chosen to be Gaussian functions. These types of functions have the property of being local functions, which means that only the functions with their centres close to the input patterns will give a response.

So, the hidden layer is composed of a variable quantity of nodes distributed over all the input space. Each node is a Gaussian function, characterised by a centre c and a width σ, that produces a nonlinear output, being its maximum value when the input corresponds to c and decreasing as the input moves away. The width or bias of the Gaussian function controls how the Euclidean distance between the centre and the network input vector affects the response of the node. The number of hidden nodes as well as the overlapping degree among the different functions has a capital importance in the network design.

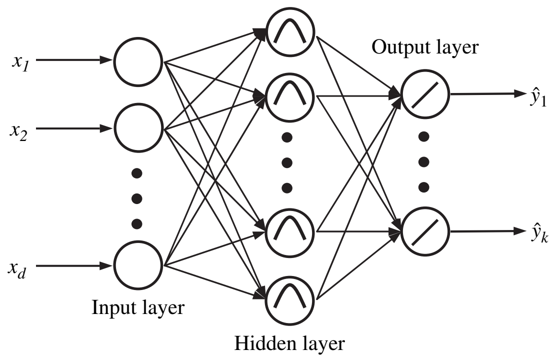

Fig. 1. RBF network structure.