Expert Systems with Applications 40 (2013) 4362–4369

Contents lists available at SciVerse ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

Analysis of a variable speed vapor compression system using artificial neural networks

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A R T I C L E I N F O

Keywords:
Artificial neural network
Vapor compression system
Energetic performance
Mapping configuration
Simulated annealing
Hidden neurons

A B S T R A C T

An artificial neural network (ANN) is a mathematical model that is inspired by the operation of biological neural networks. However, this is typically considered a computational model. An ANN can easily adapt to multiple situations and extract information that is apparently hidden in a system.

An ANN can be used in three basic configurations: mapping, auto-association and classification. An ANN in a mapping configuration can be used to model a two port system with inputs and outputs. Therefore, a vapor compression system can be modeled using an ANN in a mapping configuration. That is, some parameters from the compression system can be used for input while other parameters can be used as output. The simulation experiments include the design, training and validation of a set of ANNs to find the best architecture while minimizing over-fitting.

This paper presents a new method to model a variable speed vapor compression system. This method accurately estimates the number of neurons in the hidden layer of an ANN. The analysis and the experimental results provide new insights to understand the dependency between the input and output parameters in a vapor compression system, concluding that the model can predict the energetic performance of a variable speed vapor compression system. Additionally, the simulation results indicate that an ANN can extract, from the data sets, information that is implicit in the configuration of the vapor compression system.

1. Introduction

The vapor compression cycle is the most extended system for cold generation. It is largely used in domestic, commercial, and industrial refrigeration (including air conditioning systems). These systems typically present a high energy consumption, see Buzelin, Amico, Vargas, and Parise (2005), and this consumption may increase in case of system failure. In order to reduce their consumption, it is necessary to have efficient systems and operate them properly. Therefore, it is convenient to design computational models to analyze and simulate a cooling facility in order to improve its energetic performance.

Different models of vapor compression systems have been developed (Guo-liang, 2007). Some of them are based on a physical model to predict the system performance, (Belman, Navarro-Esbr, Ginestar, & Milian, 2009; Saiz, Gonzales, & Ianella, 2002). These physical models frequently require some geometrical parameters that are difficult to obtain or some operating parameters that are not available. Because it is difficult to accurately characterize a refrigeration system, empirical models have been proposed and used. Examples of empirical models may be based on a polynomial curve, a regression analysis or an artificial neural network. Several studies of neural networks related to HVAC& R research can be found in Mohanraj, Jayaraj, and Muraleedharan (2012).

An ANN has been used by several researches for evaluation and analysis of a vapor compression system, see Esen, Inalli, Sengur, and Esen (2008) and Secan (2011); for thermodynamic analysis see Kizilkan (2011); for determination of thermodynamic properties see Sözen, Arcaklioglu, Menlik, and Özalp (2009), and for the performance of individual components such as the compressor see Yang, Zhao, Zhang, and Gu (2009).

This paper presents the development and validation of a variable speed vapor compression system using artificial neural networks. The input parameters of the model are: compressor rotation speed, volumetric flow rates, and temperatures of the secondary fluids (at the evaporator inlet and at the condenser inlet). Note that these input parameters can be easily obtained in this kind of installation when measurement devices are set up.

2. System test bench

The test bench of the vapor compression system, used to develop and validate the neural network model, is shown in Fig. 1. The

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http://dx.doi.org/10.1016/j.eswa.2013.01.015

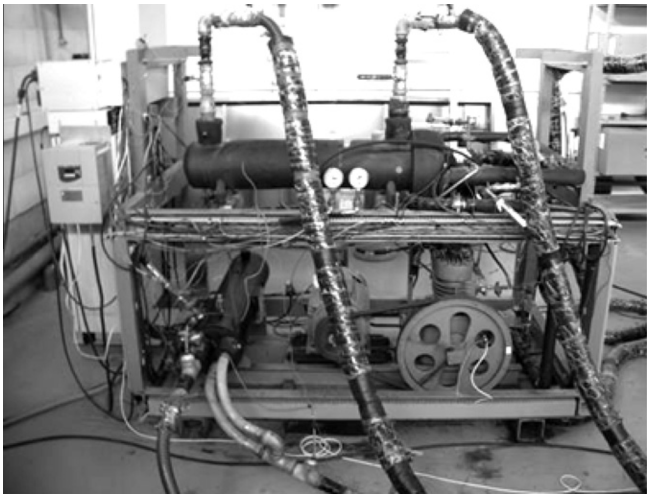

Fig. 1. The test bench of the vapor compression system.

experimental test bench basically consists of: one vapor compression circuit and two secondary fluids circuits. The vapor compression circuit is a single-stage compression system using the working fluid *R*134*a*. This circuit has: an open type variable speed compressor, a shell-and-tube evaporator, a shell-and-tube condenser, and a thermostatic expansion valve. Inside the evaporator, the refrigerant flows within the tubes, and a brine of water-propilenglycol (50/50 % by volume) is used as secondary fluid. In the interior of the condenser, the refrigerant flows along the shell while the secondary fluid (water) flows inside the tubes.

The secondary fluid circuits are: the load simulation system and the condensing system. The load simulation system consists of a tank (with several electrical resistances to control the thermal load of the evaporator), a variable speed pump, and a temperature control. The condensing system sets the water conditions at the condenser using a commercial chiller with variable speed pump. With these two systems, it is possible to control the conditions of the secondary fluids at the evaporator and at the condenser. Fig. 2 shows the schematic diagram of the test facility representing the principal components of the vapor compression circuit.

Table 1
Measured parameters and uncertainty.

Parameter	Instrument	Uncertainty
Volumetric flow	Electromagnetic flow-meter	±0.33%
Temperature	K-type thermocouples	±0.3 K
Power	Digital wattmeter	±0.5%
Mass flow	Coriolis flow-meter	±0.22%
Rotation speed	Inductive sensor	±1%

Table 2
Range of operating conditions in the experimental tests.

Parameter	Notation	Unit	Range
Compressor rotation speed	V_N	rpm	400–560
Evaporator volumetric flow	V_{evap}	m^3/h	1.5–3.0
Condenser volumetric flow	V_{cond}	m^3/h	0.6–1.2
Condenser input temperature	$T_{cond-in}$	°C	15–30
Evaporator input temperature	$T_{evap-in}$	°C	7–17

The experimental facility has several sensors to measure key variables such as: pressure, temperature, volumetric flow rate, mass flow rate, compressor speed, and energy consumption. Table 1 presents a summary of the variables measured. The table also includes the type of sensor used, and the uncertainty associated with each measurement. The signals generated by all sensors, as well as those provided by the measuring devices, were gathered using a PC-based data acquisition system *SCXI* 1000 from National Instruments.

Several experimental test were carried out to collect 38,071 samples of the system including transient and stationary states. Table 2 shows the operating ranges covered by the different tests used to train and validate the neural network model.

The tests used to develop and validate the model are carried out in a wide range of operating conditions (see Table 2).

3. Artificial neural networks

An artificial neural network (ANN) is a computational method inspired in biological processes, see Russel and Norvig (2009). An ANN can adapt to solve a broad kind of problems where a mathe-

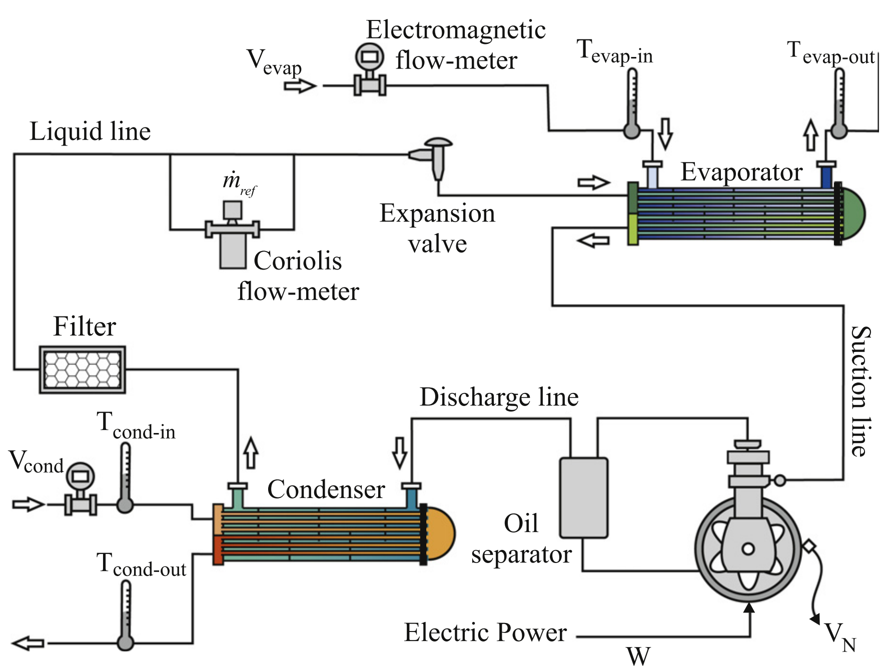

Fig. 2. Schematic diagram of the vapor compression system.