INTERNATIONAL JOURNAL OF REFRIGERATION 50 (2015) 69–79

Available online at www.sciencedirect.com

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

Fault and sensor error diagnostic strategies for a vapor compression refrigeration system by using fuzzy inference systems and artificial neural network

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ARTICLE INFO

Article history:
Received 24 June 2014
Received in revised form
12 October 2014
Accepted 18 October 2014
Available online 27 October 2014

Keywords:
Vapor refrigeration
Faults and errors diagnosis
Fuzzy inference system
Artificial neural network

ABSTRACT

A fuzzy inference system (FIS) and an artificial neural network (ANN) were used for diagnosis of the faults of a vapor compression refrigeration experimental setup. A separate FIS was developed for detection of sensor errors. The fault estimation error of the FIS and ANN were evaluated by using the experimentally obtained sensor data. Separate FIS estimated the system faults and detected defective sensors in all test cases without any error. Levenberg Marquart (LM) type ANN algorithm was implemented to diagnose the system faults. Scaled conjugate gradient (SCG) and resilient backpropagation (RB) network type were also used to compare performances with the estimation of the LM algorithm. The LM type ANN estimated all fault conditions accurately in the test cases never observed before. The study demonstrated that the FIS and ANN could be used effectively to estimate the faulty conditions of the vapor compression refrigeration system.

Stratégies de diagnostic des défaillances et des erreurs de captation dans un système frigorifique à compression de vapeur utilisant des stratégies d'inférence floues et un réseau neuronal artificiel

Mots clés : Froid par vapeur ; Diagnostic des fautes et erreurs ; Système d'inférence floue ; Réseau neuronal artificiel

1. Introduction

Heating, ventilation, air conditioning, and refrigeration (HVAC&R) systems operated under faulty conditions often result in extra energy consumptions of up to 30% for commercial buildings, when multiple faults happening simultaneously (Han et al., 2011). Faults in vapor compression system have led to increase chiller energy consumption and decrease

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http://dx.doi.org/10.1016/j.ijrefrig.2014.10.017
0140-7007/

Nomenclature

$\dot{m}$	mass flow rate (kg s^{-1})
P	pressure (kPa)
p-h	pressure-enthalpy
R	error
T	temperature (°C)
μ	membership degree

Abbreviation

ANN	artificial neural network
AXV	automatic expansion valve
ARX	exogenous variables
EEV	electrical expansion valve
FDD	fault detection and diagnosis
FDFIS	fault diagnostic fuzzy inference system
FIS	fuzzy inference system
HVAC&R	heating, ventilating, air conditioning & refrigeration
SDFIS	sensor diagnostic fuzzy inference system
TXV	thermostatic expansion valve
H	high
HP	high pressure
HP-M	high pressure sensor error
L	low
LP	low pressure
LP-M	low pressure sensor error
Mref	mass flow rate of refrigerant
Mref-M	mass flow rate sensor error
N	normal
No	no differences
VL	very low
PH	partially high
PL	partially low
SV	solenoid valve
SC	subcooling
SC-M	subcooling sensor error
SH	superheat
SH-M	superheat sensor error
Tsur	surface temperature of compressor
Tsur-M	surface temperature sensor
VH	very high

Subscripts

a	air
ave	average
c	condenser
comp	compressor
dis	discharge
e	evaporator
LP	low pressure
max	maximum values
min	minimum values
ref	refrigerant
sat	saturated
suc	suction
sur	surface of compressor
sc	subcooling
sh	superheat

chiller efficiency (Zhao et al., 2012). Because cooling and refrigeration cause over a third of the electrical energy consumption in residential and commercial buildings, detecting incipient faults leads to reduce the energy cost and save the energy consumption. Reducing the energy consumption is significant for the environment as well.

In the late 1980s, the earlier development of diagnostics systems for HVAC&R systems was mainly implemented by rule-based expert systems. During the late 1990s, the development of automating fault detection and diagnosis was given emphasis. Inputs and outputs of the HVAC&R operating process are to be mathematically related to each other by using autoregressive models with exogenous variables (ARX), artificial neural network (ANN) models, and numerous other developing models (Wang, 2001). Both ARX and ANN are named as black-box because they have need of less physical knowledge of the operating process.

In general, present fault detection and diagnosis (FDD) algorithms for vapor compression cycles have two categories: steady-state model-based algorithms and neural network/fuzzy model approaches (Halm-Owoo and Suen, 2002). In the recent years, many researchers have carried out numerous studies on the vapor compression system faults. A data mining method and an ANN were combined to detect and diagnosis sensor faults in HVAC systems (Hou et al., 2006). All FDD features in the steady-state detector were imposed by using seven measurements in a vapor compression system (Kim et al., 2008). A reference model to predict the value of system parameters during fault-free operation for fault detection and diagnosis in a heat pump system was developed by using an ANN (Kim et al., 2010). A split residential heat pump with a thermostatic expansion valve (TXV) was tested during steady-state no-fault and imposed-fault operation. Faults such as compressor valve leakage, outdoor improper air flow, indoor improper air flow, liquid line restriction, refrigerant undercharge, and refrigerant overcharge were imposed. Evaporator fouling, condenser fouling, and refrigerant overcharge have led to cause the greatest performance degradation (Yoon et al., 2011). A hybrid method incorporating auto-regressive model with ARX and support vector machines (SVM) were imposed for FDD in chillers (Yan et al., 2014). A decoupling-based FDD method with multiple simultaneous faults was fully implemented online and evaluated in the field test environment. (Zhao et al., 2014). Other related publications of research on FDD have also been presented (Bulgurcu, 2009; Piacentino and Talamo, 2013). The author recently detected eight faulty conditions in a vapor compression refrigeration system with hermetic reciprocating compressor by using the refrigeration cycle on the p-h diagram (Kocyigit et al., 2014).

Furthermore, sensor error methods were applied to several systems in the recent years. A method (virtual fouling monitor sensor) using chiller measurement for monitoring the fouling status of the condenser was imposed to detect the condenser fouling faults in chillers. The proposed virtual fouling monitor sensor was also implemented and evaluated on a field chiller (Zhao et al., 2012). A new fault diagnosis method for sensors in an air-handling unit based on neural network pre-processed by wavelet and fractal was imposed. By comparing the