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Research paper

Electric vehicle air conditioning system performance prediction based on artificial neural network

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HIGHLIGHTS

- EEV opening influences on EVACS performance were experimentally studied.
- ANN used for EVACS performance prediction was trained with two transfer functions.
- Parametric study and hidden neurons test were performed to determine ANN structure.
- ANN was defined as a configuration of 4-13-4.
- ANN showed MRE, RMSE and R^2 in the range of 0.92–2.71%, 0.0044–0.0141 and 0.9975–0.9998, respectively.

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ABSTRACT

In this study, electric vehicle air conditioning system (EVACS) performances with scroll compressor and electronic expansion valve (EEV) were experimentally investigated by varying scroll compressor speed, EEV opening and environment temperature. An artificial neural network (ANN) model for EVACS performances (such as refrigerant mass flow rate, condenser heat rejection, refrigeration capacity and compressor power consumption) prediction was developed based on experimental data. The ANN model was tested with two transfer functions (logsig and tansig) and different hidden neurons (3–13) using Levernberg-Marquardt algorithm. The optimized ANN was determined as a configuration of 4-13-4 with logsig transfer function, which demonstrated the best capability with mean relative errors, root mean square errors and correlation coefficients in the range of 0.92–2.71%, 0.0044–0.0141 and 0.9975–0.9998, respectively.

1. Introduction

Electric vehicle air conditioning system (EVACS) is utilized to provide a comfortable driving environment. Battery energy consumed by EVACS can be up to 30%, which greatly limits electric vehicle's mileage [1]. Performance prediction of EVACS is the first step for its energy efficiency optimization. Meanwhile, EVACS must be capable of maintaining stable cabin temperature under dramatic change of climate condition and driving condition. Therefore, the EVACS performance prediction is more complex than that of domestic air conditioning system [2].

Compared with the traditional automobile air conditioning system (AACS) in internal combustion engine vehicle, EVACS makes a big difference. Compressor in AACS is generally reciprocating type, which is belt driven by engine to adjust cooling capacity. However, scroll compressor controlled by motor is a better choice for EVACS when taking small volume, light weight and high efficiency into consideration [3,4]. The H-type thermostatic expansion valve (TEV) is conventionally utilized in AACS to adjust evaporator superheat. However, due to the moving parts and response lag, TEV fails to meet the demand of energy efficiency in EVACS. Electronic expansion valve (EEV) with a fast response to load variation has proved its energy saving for air conditioning systems [5–7]. Nevertheless, the application of EEV into EVACS is rarely reported in open literature.

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Nomenclature

b	bias
h	specific enthalpy, kJ kg^{-1}
i,j	ANN input and output
m	refrigerant mass flow rate, kg h^{-1}
N_{comp}	compressor speed, rpm
N_{pul}	EEV opening pulse, bpm
p	pressure, kPa
Q	heat capacity, kW
t	temperature, °C
W	power consumption, kW
w	weighted coefficients
Y	independent variables
z	sum of input
δ	uncertainty

Subscript

air	air side
comp	compressor
cond	condenser
env	environmental
evap	evaporator
exp	experimental
in	inlet
max	maximum
min	minimum
out	outlet
pre	predicted
r	refrigerant

Acronym

AACS	Automotive Air Conditioning System
AHU	Air Handling Unit
ANN	Artificial Neural Network
bpm	Beats Per Minute
DAS	Data Acquisition System
EES	Engineering Equation Solver
EEV	Electronic Expansion Valve
EI	Error Index
EVACS	Electric Vehicle Air Conditioning System
MRE	Mean Relative Error
PTC	Positive Temperature Coefficient
RMSE	Root Mean Square Error
R^2	Correlation Coefficient
rpm	Revolutions Per Minute

Performances of AACS have been experimentally studied by variation of refrigerant charge, compressor speed, environmental temperature, and air velocities through condenser and evaporator [8–10]. Experimental results could provide foundation for the establishment of performance prediction models. Prediction models in published works can be divided into two categories namely classical model and intelligent model. The classical model based on thermodynamic and heat transfer theory requires large number of geometrical parameters to define system components and takes efforts to solve redundant mathematical equations [10–12]. However, these issues can be avoided by intelligent methods. The intelligent model developed on the basis of experimental data and system identification with a black-box method, such as artificial neural network (ANN), has been extensively applied to air conditioning systems and components performance prediction [13–15]. Hosoz and Ertunc [16] demonstrated ANN applicability in predicting performances of an AACS using R134a. The results showed that ANN could give an accurate prediction with a variable speed compressor. Ng et al. [17] identified two different ANNs to predict AACS performances, such as evaporating temperature, cooling capacity and compressor power. Atik et al. [18] carried out a three-layer ANN in modeling AACS with different refrigerant charge and different compressor revolution speeds. The least problem-yielding ANN was determined as a configuration of 2-10-3. Kamar et al. [19] optimized the ANN configuration as 4-3-3 for an AACS performance prediction. The proposed ANN model showed good performance with error index in the range of 0.65–1.65%, mean square error between 1.09×10^{-5} and 9.05×10^{-5} and root mean square error in the range of 0.33–0.95%.

The previously mentioned ANN models are applied to AACS performance prediction, however, very limited works refer to EVACS performance prediction with scroll compressor and EEV. The difference caused by main components between AACS and EVACS should not be neglected when it comes to system performance analysis [20]. In this study, EVACS performances were tested in an environmental chamber by varying compressor speeds, EEV openings and environmental temperatures. Based on experimental data, an ANN model was developed to predict EVACS performances, such as refrigerant mass flow rate, condenser heat rejection, refrigeration capacity and compressor power consumption. Through transfer function comparison, hidden neuron variation and parametric study, the final determined ANN model provided an efficient access to EVACS performance prediction with satisfying accuracy, which could form the foundation for system performance optimization and interlocking control algorithm optimization.

EVACS experimental setup and test conditions were described in Section 2. Afterward, thermodynamic analysis of EVACS was processed using engineering equation solver (EES) and experimental results were presented in Section 3. Development process of the ANN model for EVACS performance prediction was detailed in Section 4. Results and discussions were summarized in Section 5. Finally, conclusions were provided in Section 6.

2. Experimental setup and test conditions

2.1. Experimental setup

EVACS experimental setup was depicted in Fig. 1a and its photograph was shown in Fig. 1b. Air handling unit (AHU) and blower were applied to control environmental temperature and air velocity, respectively. Incandescent lights were used to simulate solar radiation. Schematic of the EVACS and its photograph were presented in Fig. 2a and b. EVACS with R134a as refrigerant was composed of a scroll compressor, a micro channel condenser, an electronic expansion valve, a laminated evaporator, a sight glass, a gas–liquid separator, a filter drier and two axial fans. Positive temperature coefficient (PTC) heater was employed to simulate heat load caused by human and electronic components in the electric vehicle cabin. Details about the environmental chamber and EVACS principal components were listed in Table 1.

Refrigerant temperature and air temperature were measured by type-T thermocouples, which were placed at upstream and