Control Algorithm Optimization of Electric Air Conditioning Based on ADVISOR

Jinrui Nan, Zhichao Zhou
The National Engineering Laboratory for Electric Vehicles, Beijing Institute of Technology
Beijing, 100081, China
E-mail: nanjinrui@163.com

***Abstract*—In order to develop more energy-saving control algorithm, an electric vehicle air conditioning system model is established. Electric air conditioning system compressor model, compartment thermal load model, heat transfer model, controller model and temperature calculation model are built based on certain pure electric commercial vehicle air conditioning system. A compound control method applying fuzzy and PID theory is put forward in this paper. A secondary development of EV model is established in ADVISOR. As the result shows, the Fuzzy-PID control method is more accuracy and consuming less energy. Optimized control algorithm for air conditioning is realized.**

Keywords-electric air conditioning; fuzzy-PID; modeling

I. INTRODUCTION

With the increasing importance of resource and environment, the automotive industry is developing toward to a low-carbon and low-emission direction. New energy vehicle has been developed and made great progress in a relatively short period of time. As present relatively mature new energy vehicles, pure electric vehicle, hybrid electric vehicle and fuel cell vehicle have better popularization. Electric vehicles will be gradually launched in the market in the coming years and will to contribute to change the daily life of urban regions[1]. The pure electric vehicle has less energy consumption, zero-emission and low noise, but the existing limitation of battery technology which does not guarantee the endurance mileage becomes the bottleneck of popularization. While concerned about battery technology currently researchers are devoting themselves to improving the energy efficiency of the system and studying methods for diminishing energy consumption.

Whatever is traditional vehicle or electric vehicle, as the second largest power-consumption part, the air conditioning system has been an indispensable part of vehicle and its power consumption cannot be underestimated. Electric air conditioning compressor model, compartment thermal load model, heat transfer model, compartment temperature controller model and calculation model are built based on MATLAB and Simulink in this paper. A composite control method using fuzzy and PID theory is put forward. A secondary development of EV model is established in ADVISOR. Last, the simulation for air conditioning system is finished and this article is focused on the affection for air conditioning system power consumption by studying different control methods of air conditioning motor.

II. MODELING OF THE ELECTRIC AIR CONDITIONING SYSTEM

A. *Compartment Thermal Load Model*

The calculation of compartment thermal load is to predict the dynamic load in the operation progress of the car and select the appropriate refrigerating capacity. The main vehicle parameters involved in the calculation progress is shown in table Ⅰ.

TABLE I. TABLE TYPE STYLES

Item	Parameter	Item	Parameter
Size/mm	11980/2550/3150	Sandwich skin	Foam
Minimum gap/mm	150	Interior	ABS/PVC
Skin	Steel	Roof	Aluminum
Floor	Wood	Glass	Colorless/France green

In the modeling progress, it is required to calculate the sum of all thermal loads coming from roof and side of the car, window glasses, outside atmosphere, passengers' bodies, new fresh wind and electric appliances. Formula (1) is shown in the following. Building different heat transfer models are based on different parts and heat types because of the difference of materials used in different parts of the car room and intensities of solar radiation and equivalent temperature [2].

$$Q_e = Q_{Gi} + Q_G + Q_B + Q_F + Q_P + Q_L \qquad (1)$$

Q_e——AC heat load, W;

Q_B——Heat load into the carriage through roof and surroundings, W;

Q_G——Heat load into the carriage through glass surface, W;

Q_S——Heat load into the carriage permeated through outside air, W;

Q_P——Heat load into the carriage released by driver and passengers, W;

Q_L——Heat load into the carriage through new wind, W;

Q_D——Heat load into the carriage released by electric appliances.

B. *Air Conditioning Controller Model*

Air conditioning of the traditional vehicle is controlled by on/off control system. The control objective is usually focused on the indoor temperature instead of human comfort conditions[3]. The shortcoming of this way is affecting the riding comfort and the compressor is easy to damage while turning it on and off frequently. However, adopting the fuzzy-PID control strategy can effectively improve the performance of air conditioning and enhance riding comfort.

In the air conditioning design of fuzzy control, the difference between compartment temperature and setting temperature is confirmed within the scope of [-3, 11] and quantified for 15 grades.

{-3,-2,-1,0,1,2,3,4,5,6,7,8,9,10,11}

Given that fuzzy and PID control work together in the temperature difference interval of [-1, 1], the relative multiples can be magnified. Therefore fuzzy subset is quantified for 6 grades.

{N, S, PS, PM, PB, B}

The input is the rate of temperature change per second which range is [-0.1, 0.1] and quantified for 11 grades. The larger error is regarded as boundary value. Follow is fuzzy subset of temperature difference.

{NB, NS, Z, PS, PB}

As a control variable, output speed is the important parameter influencing the performance of air conditioning. Because a rule in parameters of compressor is the maximum continuous speed cannot be higher than 4800 rpm in operation, the fuzzy interval of the electric compressor speed is confirmed through 1300 to 4800 and quantified for 12 grades. It is regarded as boundary value for the value beyond the scope. Follow is fuzzy subset of speed.

{Z, PS, PM, PB, BS, BM, BB}

The fuzzy control rules are shown as table Ⅱ. According to engineering experience, Ma Danni maximum-minimum reasoning method and center of gravity are adopted separately for reasoning and ambiguity resolution [2]. Then fuzzy control system model is built based on the fuzzy control rules.

TABLE II. THE RULES OF SPEED FUZZY CONTROL

Rate of change of difference in temperature	Difference in temperature					
	N	Z	PS	PM	PB	B
NB	Z	PS	PM	PB	BS	BS
NS	PS	PM	PB	BS	BS	BM
Z	PM	PB	BS	BS	BM	BB
PS	PB	PB	BS	BS	BM	BB
PB	BS	BS	BM	BM	BB	BB

To compare fuzzy-PID compound control method and traditional control method, traditional control method model should be built. In the modeling of traditional control method temperature difference and its rate of change are still taken as inputs and output is compressor speed [3]. The model is shown as figure 1.

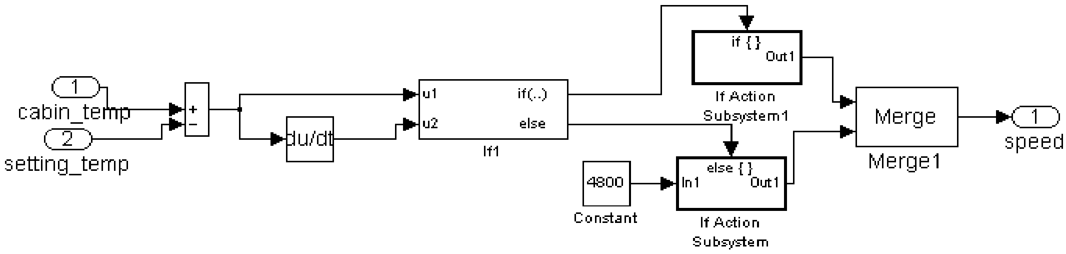

Figure 1. Tradional control method model

C. Building Other Models

Other models include heat exchange model, electric compressor model and temperature calculation model.

Heat exchange model is built by simulating main parts of air conditioning including compressor, condenser and evaporator. Through the simulation of whole process of refrigeration of air conditioning and studying the changes of thermodynamics state of refrigerant and affection of heat exchange around, refrigerating output is obtained by speeding input finally.

The electric compressor model is established by using power loss method in the environment of MATLAB and Similink. The car room temperature is mainly affected by heat load and refrigerating output, then final room temperature will be obtained after transferring changes of compartment heat to temperature changes. So temperature calculation is set up and data files are designed lastly.

III. MODELING OF WHOEL VEHICLE AND ANALYSIS SIMULATION

A. Modeling of Whole Vehicle

The vehicle model of certain pure electric bus is built by using advanced vehicle simulation (ADVISOR), which inner procedures are programmed by language of Matlab/Simulink. Its model library can be modified based on what you need.

It is needed to amend electrical auxiliary device library when modifying electric vehicle model. At the same time new auxiliary system model should be packaged by add the air conditioning system model built previously to electrical auxiliary system model.

B. Experimental Comparison and Analysis of Simulation Result

The simulation result is checked in real vehicle tests after building electric air conditioning model. The method is to adopt compartment temperature change values with the compressor speed values in certain working condition. Then entering compressor speed values into the simulation system, simulated compartment temperature change values will be obtained. It is need to compare measured values with simulated values for checking simulation effect finally.

Experiment 1: At 12 o'clock, certain day of April, Beijing, compartment temperature is tested with change of compressor speed for 17 minutes when the bus is stopped. Don't disturb original air conditioning on trial and set temperature as 15℃ while outside temperature is 23℃. The adopted compressor speed values are shown as figure 2.

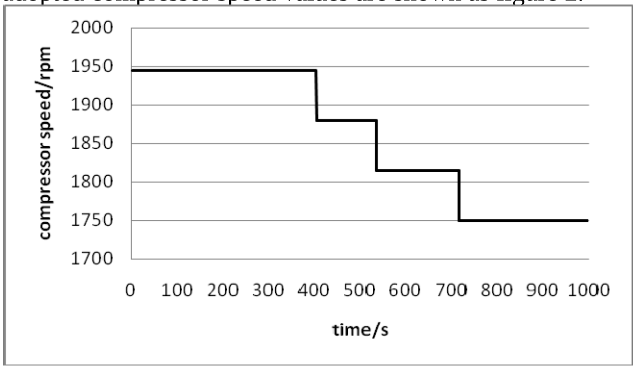

Figure 2. The Compressor speed of Experiment 1

The comparison between simulated values and measured values is shown as figure 3. The average simulated equilibrium temperature is 15℃ lower than measured equilibrium temperature, 16℃. They do have margins of error, but the changing trends are the same.

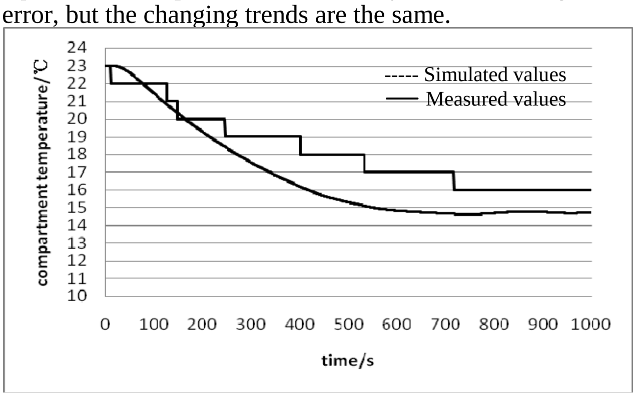

Figure 3. Comparison Between Simulation and Experiment Values in Experiment 1

Experiment 2: At 11 o'clock, certain day of May, Guangzhou, compartment temperature is tested with change of compressor speed for 30 minutes when the bus is processing. Don't disturb original air conditioning on trial and set temperature as 15℃ while outside temperature is 31℃. The adopted compressor and bus speed values are shown as figure 4.

The comparison between simulated values and measured values is shown as figure 5. The average simulated equilibrium temperature is 19.5℃ lower than measured equilibrium temperature. They do have margins of error, but the changing trends are the same.

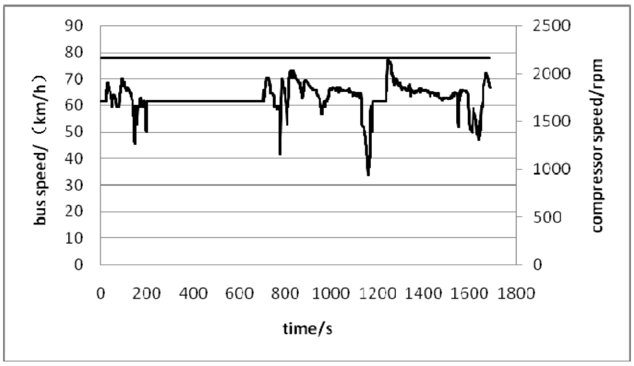

Figure 4. The Compressor and Vehicle Speeds of Experiment 2

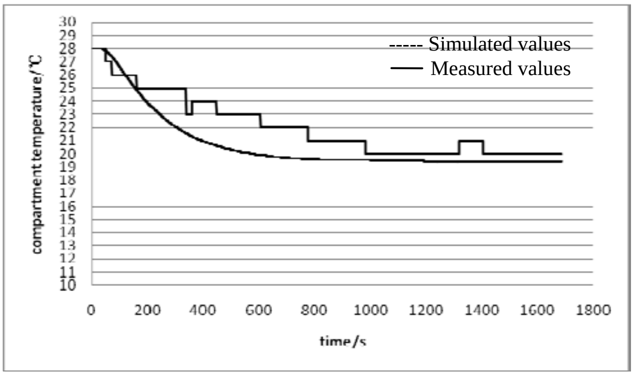

Figure 5. Comparison Between Simulation and Experiment Values in Experiment 2

From the above, simulated compartment temperature is lower than measured value in same condition. There are margins of error. But the error is less than 10% and changing trends of temperature are the same. So it is considered that the built model can be used to finish bus air conditioning system simulation.

C. Contrastive Analysis of Control Optimization

The comparison between traditional control method and fuzzy-PID control method is made by built whole vehicle model. It chooses two test conditions including constant condition in Beijing and urban bus condition in Beijing.

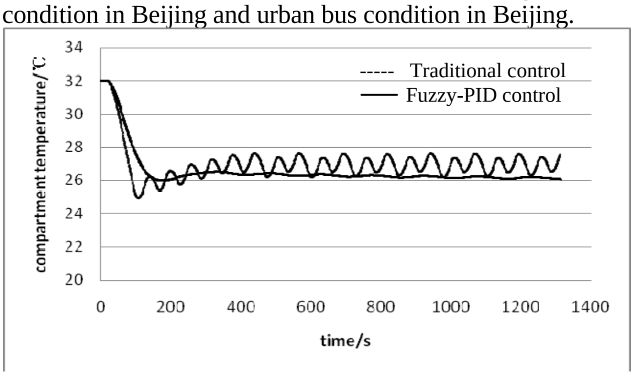

Figure 6. Compartment Temperature Comparison of Beijing and Constant Condition

Firstly, simulation of constant condition in Beijing is made. The needed temperature is set as 26℃, and the results are shown as figure 6 and 7. The compartment average temperature of traditional control method is 26.2℃ between 800 and 1400 second. The range of temperature is [26.2, 26.3] ℃. The energy consumption of air conditioning system is 619kJ under traditional control method, while that is 583kJ under fuzzy-PID control method saving energy of 5.8%.

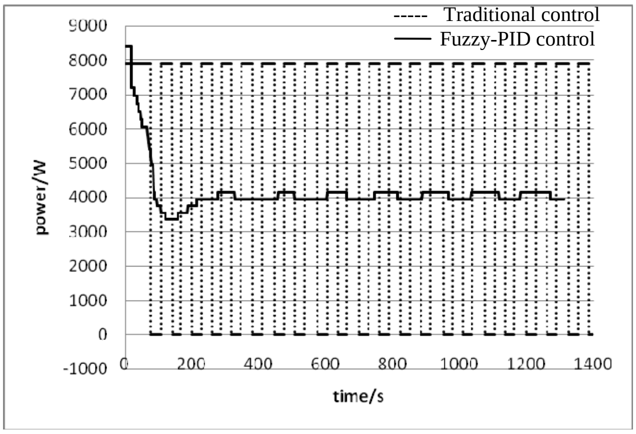

Figure 7. Air Conditioning Power Comparison of Beijing and Constant Condition

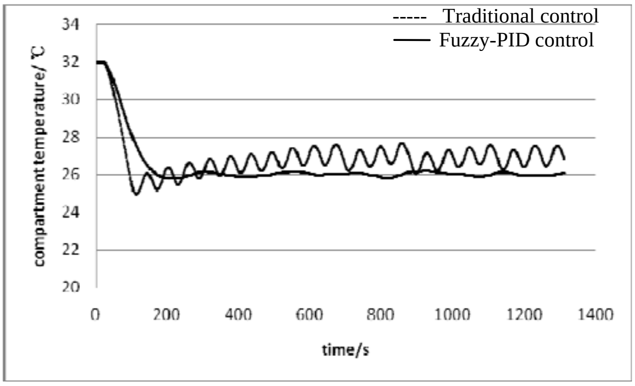

Figure 8. Compartment Temperature Comparison of Beijing and Urban Bus Condition of China

Secondly, simulation of urban bus condition in Beijing is made. The temperature is set as 26℃, and the results are shown as figure 8 and 9. The average temperature of traditional control method is 26.0℃ between 800 and 1400 second. The range of temperature is [25.8, 26.2] ℃. The energy consumption of air conditioning system is 559kJ under traditional control method, while that is 525kJ under fuzzy-PID control method saving energy of 6.2%.

As is known from foregoing simulation, the fuzzy-PID control method is more accuracy and smaller overshoots than traditional control method, which can reduce energy consumption of air conditioning system of 5%~7% and the higher heat load, the more obvious energy saving effect. It is a kind of good control optimization strategy of air conditioning.

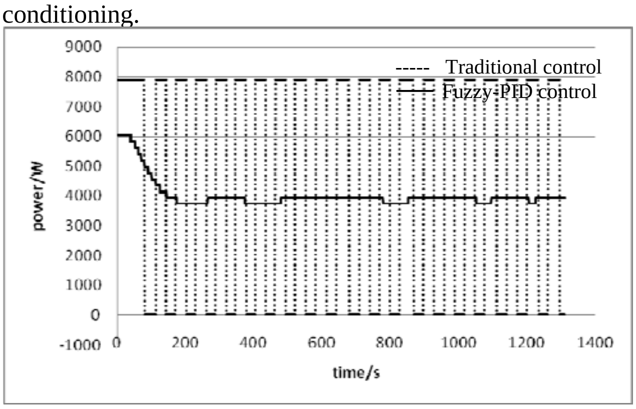

Figure 9. Air Conditioning Power Comparison of Beijing and Urban Bus Condition of China

IV. CONLUSIONS

Electric vehicle air conditioning system model is built and the research is mainly focused on control method of electric compressor and building compartment model. The simulation precision is improved by utilizing MATLAB and Simulink to build electric bus system model.

The change of temperature and air conditioning power are analyzed and compared between traditional control method and fuzzy-PID control method. It turns out that designed fuzzy-PID control method has obtained good control effect and saved energy, which provides the reference for designing procedures of electric variable frequency air conditioning in the future.

ACKNOWLEDGMENT

This work was supported by National High-tech Research and Development Projects called 863 projects (No.2011AA11A245) and supported by the Research Foundation of National Engineering Laboratory for Electric Vehicles 2012-NELEV-03. Thanks for the support. For the authors whose papers were cited, sincere gratitude was expressed.

REFERENCES

[1] J. M. Terras, D. M. Sousa, A. Roque, A. Neves. “Simulation of a Commercial Electric Vehicle: Dynamic Aspects and Performance”, Power Electronics and Applications (EPE 2011), Proceedings of the 2011-14th European Conference on.

[2] Q.Y Ning. Matching Design for Air Conditioning System of Electric Vehicle. Ms D Thesis, Jilin: Jilin University, 2011 (in Chinese).

[3] Y.H Huang, N.P LI. “Fuzzy Model Predictive Control for a Comfort Air-Conditioning System”, Automation Science and Engineering, 2006. CASE’06. IEEE International Conference on.

[4] Y.B Cao. Development and Performance Simulation of Electric Air Conditioner Module Based on ADVISOR. Ms D Thesis. Jilin: Jilin University, 2009 (in Chinese).

[5] R. Johnston. Fuzzy Logic control. Micorelectronics Journal, 1995, 126:481-495