**Academic Journal of Science and Technology**
ISSN: 2771-3032 | Vol. 3, No. 3, 2022

# Research on Fuzzy Control Strategy of Heating Condition Based on Electric Vehicle Heat Pump Air Conditioner

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**Abstract:** The performance of heat pump air-conditioning system under heating conditions is studied, and a fuzzy control strategy is proposed. The heating condition model of the heat pump air conditioning system is built in AMESim, and the control strategy model is established by Simulink for joint simulation, with the cab temperature as the target temperature of the system performance. Compared with the traditional control strategy, the control strategy designed in this paper can rapidly increase the temperature of the passenger compartment to the target temperature, and the temperature control accuracy is more accurate, the callback time is shorter, and the comfort is better.

**Keywords:** Heat pump air conditioning system, Fuzzy control, Heating conditions, Joint simulation.

## 1. Introduction

At present, the biggest obstacle to the wide application of electric vehicles is the short range. The major automobile enterprises, scientific research institutions and universities focus on power related components such as power batteries and drive motors, and there is less research on the largest auxiliary accessory air conditioning system of automobiles [1]. The performance of the air conditioning system of electric vehicles is not only related to the comfort of the driving environment, but also directly affects the range of electric vehicles.Research data shows that if a pure electric vehicle is equipped with an air conditioning system with refrigeration, heating and defrosting functions, its energy consumption during heating will account for about 33% of the vehicle's energy consumption [2].

Based on the development of household heat pump air conditioning technology, some researchers have turned their attention to vehicle heat pump air conditioning. Relevant theories and tests show that when the ambient temperature is - 10 ℃, the heating efficiency (COP) of the electric vehicle heat pump air conditioner is about 2.1, its energy efficiency ratio is far higher than that of the PTC heating, and it can achieve the integration of cooling and heating, with dehumidification, defrosting and other functions. At the same time, only minor modification of the overall structure of the vehicle is required, which can save energy and protect the environment, greatly reduce the energy consumption of the air conditioning system of electric vehicles, and thus extend the vehicle's endurance mileage. Therefore, the air conditioning with heat pump system is the best way to develop the air conditioning of electric vehicles, and has a good role in promoting the popularity of electric vehicles.

## 2. Establishment of Simulation Model for Heat Pump Air Conditioning System of Pure Electric Vehicle

### 2.1. Theoretical Calculation of Heat Pump Air Conditioning

Because the actual working process of heat pump is very complex, when the working fluid flows in the pipeline, it will inevitably lose some energy and the influence of temperature difference heat transfer. Therefore, when analyzing the heat pump cycle, it is usually abstracted and simplified to ensure that the working medium is condensed to the supercooled state and evaporated to the overheated state, so some preconditions are made as follows [3]:

1) The process of compressor compressing working medium is isentropic compression;

2) The condensation process of condenser is isobaric condensation;

3) When the refrigerant flows through the throttling mechanism, it is adiabatic expansion, and the enthalpy of the refrigerant before and after throttling is the same;

4) The evaporation process of evaporator is equal pressure evaporation;

### 2.2. Establishment of simulation model for heat pump air-conditioning

#### 2.2.1. AMESim Assumptions before modeling

AMESim is an advanced modeling and simulation platform software for engineering system applications. Its models are presented through intuitive graphics, which is more understandable. In order to study the heating performance of heat pump air conditioning applied to electric vehicles, without considering the performance change of the heat pump air conditioning system at the start stop moment, the following assumptions are proposed before modeling in AMESim based on this [4]:

1) The refrigerant flow process in the pipeline is stable;

2) The heat transfer of refrigerant in the flow process is not considered, and one-dimensional flow is carried out;

3) The heat exchange between the refrigerant and the outside world and the flow resistance loss are not considered;

4) When refrigerant flows through throttling mechanism, it is adiabatic expansion;

5) When the compressor compresses the refrigerant, the compression process is adiabatic compression;

6) The refrigerant is uniformly mixed in the two-phase state, with the same temperature and no relative slip;

7) The flow resistance and heat loss when the refrigerant flows through the four-way directional valve are not considered;

According to the principle of heat pump air conditioning described above, the simulation model of heat pump automobile air conditioning system should include compressor, indoor and outdoor heat exchanger, four-way reversing valve, throttling device (capillary pipe) and other models. At the beginning of the model establishment, according to the performance characteristics of each component, based on the thermodynamic principle, the characteristic equation of each component is derived, and then the simulation model of each component is established, and the relevant models are connected by pipes to form the general simulation model of the heat pump type automobile air conditioning system.

### 2.2.2. Model building of electric compressor

The theoretical calculation of compressor model mainly involves the calculation of volumetric efficiency, mechanical efficiency, isentropic efficiency and compressor energy consumption.

The theoretical calculation formula of compressor volumetric efficiency is as follows.

$$\eta_v = \frac{60m}{\rho_s \cdot N \cdot disp} \times 10^6 \tag{1}$$

The theoretical calculation formula of compressor mechanical efficiency is as follows.

$$\eta_m = \frac{(h_d - h_s) \cdot m}{\tau \cdot N} \tag{2}$$

The theoretical calculation formula of isentropic efficiency of compressor is as follows.

$$\eta_{is} = \frac{h_{dis} - h_s}{h_d - h_s} \tag{3}$$

Power consumption of compressor, W, in kw, is calculated as follows.

$$W = m \cdot (h_d - h_s) \tag{4}$$

The compressor selected in this paper is an electric scroll compressor with a certain displacement, which is a constant displacement compressor model included in AMESim software (based on a large number of experimental data, the compressor volumetric efficiency in this paper is 0.6, the isentropic efficiency is 0.75, and the mechanical efficiency is 0.9). According to the existing fixed displacement compressor sub model of AMESim air conditioning warehouse, the following simulation sub model is built in combination with the mechanical library and signal library.

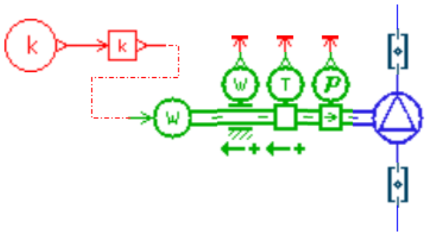


**Figure 1.** Electric scroll constant displacement compressor model

### 2.2.3. Model building of indoor and outdoor heat exchanger for heat pump air-conditioning

The indoor and outdoor heat exchangers of heat pump air conditioners are two heat exchangers. The theoretical calculation of the heat exchanger model involves the calculation of mass flow, heat transfer inside and outside the heat exchanger, heat transfer coefficient and other parameters.

Use Bernoulli formula to calculate the mass flow of refrigerant in the heat exchanger. The formula is as follows.

$$m' = \rho C_q A \sqrt{\frac{2\Delta P}{\rho}} \tag{5}$$

The heat exchange in the heat exchanger is calculated as follows.

$$Q_{\text{int}} = h_c S (T_{ref} - T_{wall}) \tag{6}$$

$$h_c = \frac{\lambda \cdot N_u}{d_h} \tag{7}$$

The calculation formula of heat exchange outside the heat exchanger is as follows.

$$Q_{ext} = h_c' S' (T_{ma} - T_{wall}) \tag{8}$$

$$h_c' = \frac{\lambda' \cdot N_u}{d_h'} \tag{9}$$

Based on the limitation of the model in AMESim software library, the outdoor heat exchanger uses a type 1 (tube fin heat exchanger) heat exchanger, and builds the sub model of the outdoor heat exchanger assembly as shown in Figure 2. A type 2 (U-channel plate fin heat exchanger) heat exchanger is used indoors, and the sub model of indoor heat exchanger assembly is built as shown in Figure 3.

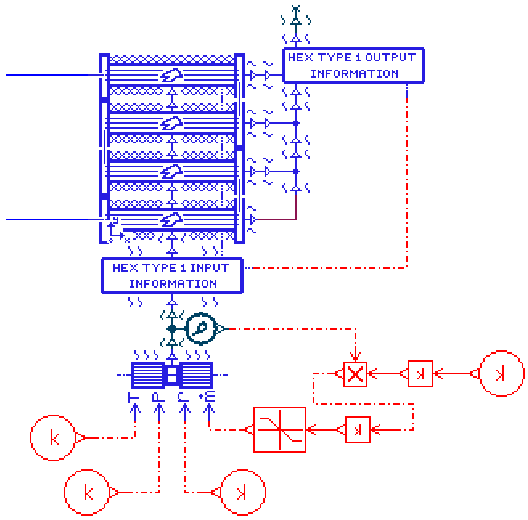


**Figure 2.** Outdoor tube-fin heat exchanger assembly model

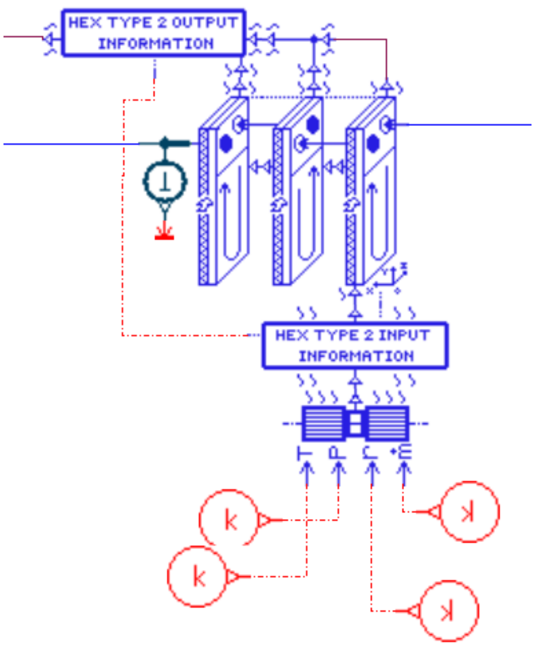


**Figure 3**. Indoor heat exchanger and fan assembly

### 2.2.4. Model building of four-way directional valve and throttling device

The four-way reversing valve is used to change the flow and circulation direction of refrigerant. Limited by the AMESim model, there is no four-way directional valve required in the AMESim library, so the relevant models in the signal library and two-phase flow library in the software are selected. See Fig. 4 for the four-way directional valve model. In consideration of the flow direction and flow resistance of the working fluid in the four-way directional valve, the capillary pipeline is set, and the relevant parameters are set at the same time. To simplify the model, create equivalent super components, as shown in Figure 5.

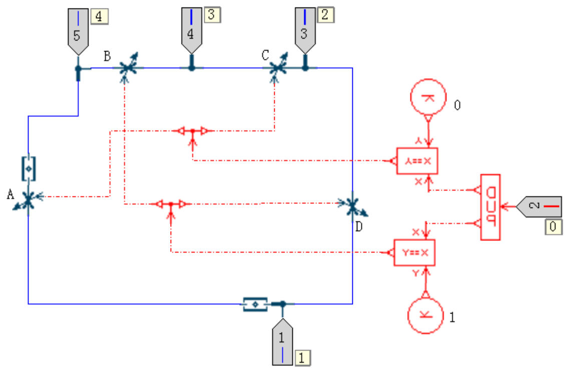

**Figure 4.** Four-way reversing valve model

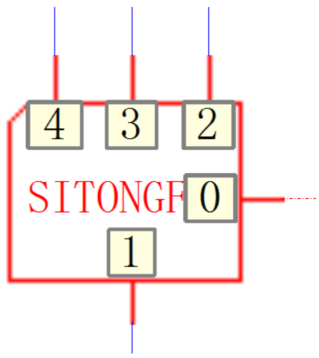


**Figure 5.** Four-way Valve Super Component

The throttling device in the model mainly controls the mass flow of the refrigerant into the heat exchanger in the system, so as to avoid the impact of the liquid refrigerant when it enters the compressor cycle. At the same time, it depressurizes the high-pressure liquid refrigerant to improve the working efficiency of the air conditioning system. Common throttling devices are mainly [5]: capillary pipe, thermal expansion valve and electronic expansion valve. As the temperature sensor of the thermal expansion valve has hysteresis, it will cause system vibration. The electronic expansion valve can avoid this phenomenon, but it is more complex without control. In order to simplify the model, the capillary type throttling device is used in this paper. Based on the assumption made previously, when the refrigerant flows through the throttling device, there is no heat exchange with the outside world, so it can be regarded as an adiabatic process. The enthalpy of the working medium at the inlet and outlet is kept unchanged, and the steady state calculation is adopted. The calculation is as follows: the capillary throttling device is established.

$$m' = C_{tp} A \sqrt{2\rho(p_{up} - p_f)} \tag{10}$$

### 2.2.5. General simulation model of electric vehicle heat pump air conditioning

Combined with the working principle of heat pump air conditioning, according to the established relevant sub models, all parts are connected in turn through pipelines to form the general simulation model of heat pump automobile air conditioning system as shown in the figure below. In Figure 4, the input signal at the 0 interface of the four-way valve is "0" or "1" to control the internal interface continuity of the four-way valve. When "0" is entered, the heat pump air conditioner enters the refrigeration mode; when "1" is entered, the heat pump air conditioner enters the heating mode.

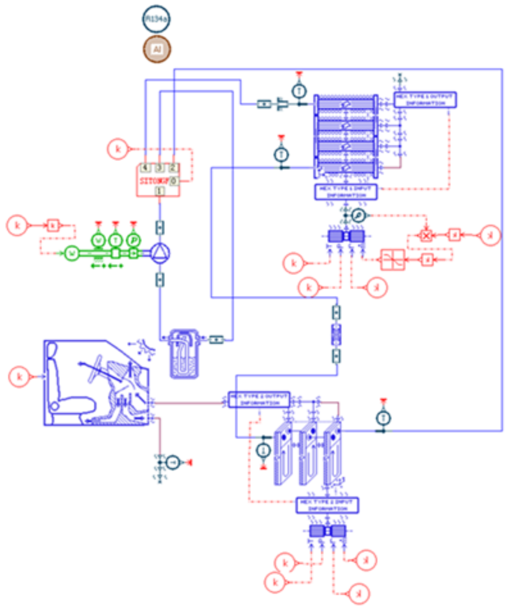

**Figure 6.** General simulation model of heat pump air conditioning system for electric vehicle

### 2.2.6. Combined Simulation of Heat Pump Air Conditioning System AMESim and Simulink

In order to better simulate and analyze the performance of the electric vehicle heat pump air-conditioning control strategy, AMESim and Simulink have matching simulation ports. Therefore, combined with the advantages of the two software, joint simulation can better simulate and analyze the performance of the electric vehicle heat pump air-conditioning system.

Based on the model of the heat pump air-conditioning system established above, build the AMESim simulation model of the heat pump air-conditioning system as shown in the figure below.

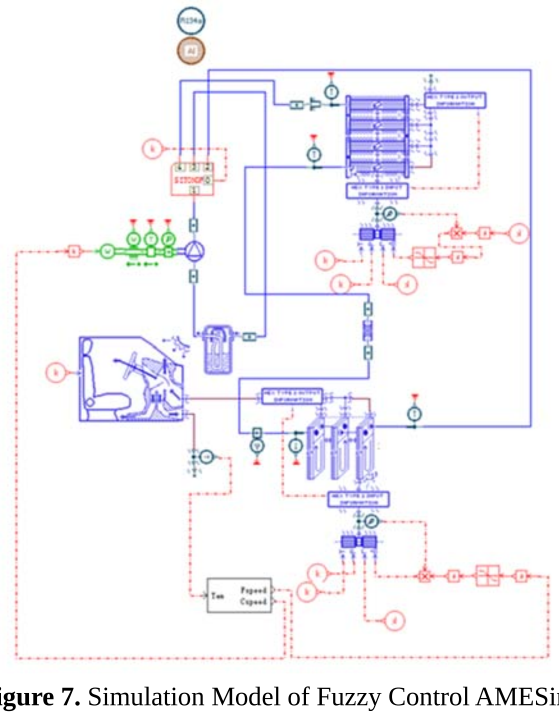

**Figure 7.** Simulation Model of Fuzzy Control AMESim for Heat Pump Air-conditioning

According to the principle of fuzzy control, the simulation model of fuzzy control system is established, as shown in the figure below. The input of the system is the indoor temperature Tem output from port 3 of AMESim passenger compartment and the set temperature Tset, and the output is the speed of electric compressor and indoor fan. The temperature difference and temperature difference change rate are derived from Tset and Tem. The established fuzzy controller module outputs the speed of the compressor and indoor fan, which is transferred to the speed inlet of the compressor and indoor fan of AMESim software through the S-Function module to change the heating capacity of the system, so as to achieve the purpose of adjusting the temperature in the passenger compartment. Input "fuzzy" in the MATLAB command editing window, open the fuzzy rule file (mohu. fis) established in the MATLAB software above, and import it into the MATLAB workspace. Then load the "mohu. fis" file into the fuzzy controller module in Figure 4.5. In the menu bar of the Simulink software window, select the Solver page of the simulation parameter setting option, set the simulation duration to 300s, use the variable step size method, and the accuracy of the state calculation value is 0.1%. At the same time, use the ode45 solver, and select the default value for other parameters to start the joint simulation.

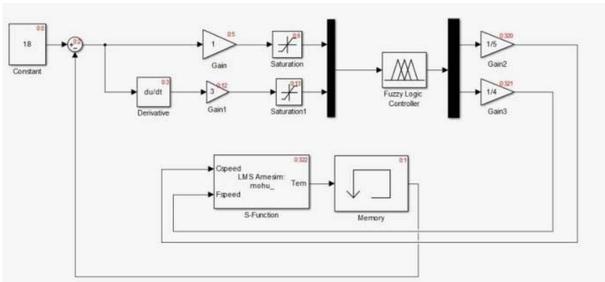


**Figure 8.** Simulation Model of Fuzzy Control System

## 3. Analysis of Joint Simulation Results

This paper mainly studies the heating performance of the heat pump air-conditioning system in winter. The fuzzy control strategy is used to adjust the compressor speed and the indoor fan speed, so as to adjust the heating capacity of the heat pump air-conditioning system and achieve the purpose of adjusting the temperature in the passenger compartment. The heating of automobile winter air conditioner is mainly used to balance the heat consumption in the car, including the heat consumption of the car roof, skirt, car floor, cold air penetration, solar radiation, passenger body, etc. In winter, the solar radiation intensity in Chengdu is small and can be ignored; The heat dissipation of passengers has a positive effect on the indoor temperature, so it can also be ignored in the design simulation. Based on this, the passenger compartment model is selected from the models provided by AMESim. The volume of the passenger compartment is 2.25m3, and the indoor and outdoor heat exchange area is 10m2.

According to the statistics of the Meteorological Bureau, the average temperature in winter in Chengdu is above 0 ℃. According to the living habits of Chinese people, when the temperature is 15-18 ℃ in winter and the humidity is 30% - 70%, the human body will feel very comfortable. Therefore, this paper mainly focuses on the temperature changes in the passenger compartment under different vehicle speeds when the outdoor ambient temperature is 0 ℃, the humidity is 40%, and the target temperature is set to 18 ℃; And the two-dimensional multi output fuzzy control strategy designed in this paper is compared with the traditional switch control strategy.

## 3.1. Vehicle idling condition in winter

It can be seen from the working principle of the heat pump air conditioner that the compressor of the air conditioning system studied in this paper is driven by a proprietary motor and is not affected by the vehicle speed. Therefore, the amount of heat produced by the heat pump air conditioner is not directly related to the vehicle speed. However, due to different vehicle operating conditions, the air side flow rate of outdoor heat exchanger is different, and the heat consumption of outdoor cold air entering the room is also different. When the electric vehicle runs at idle speed in winter, the speed is 0. Assuming that the indoor and outdoor temperatures of the passenger compartment are the same before the heat pump air conditioner is turned on, both are set at 0 ℃, and the indoor temperature is stable around 18 ℃ after the air conditioner is turned on.

Figure 9 shows the temperature change curve of the passenger compartment of the electric vehicle heat pump air conditioning system under idling conditions in winter. In order to better observe the details, the local enlarged diagram of the vehicle hour temperature rise curve is shown in Figure 10. It can be seen from the figure that due to the large difference between the set temperature difference and the actual temperature difference in the initial stage of the simulation, the compressor speed and the indoor fan speed both operate at the maximum load under the fuzzy control rules, and the temperature in the vehicle rapidly rises to the set temperature. When the simulation reaches 47.79s, the set temperature reaches 18 ℃. After the temperature reaches the set temperature, after an 8s adjustment period, the system reaches a stable state. The temperature is stabilized at 18 ℃ with almost no deviation, and the temperature control effect is good.

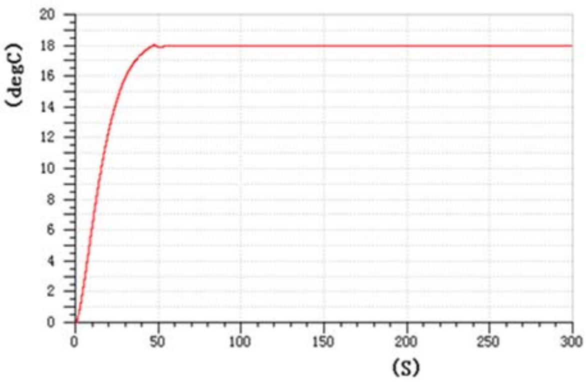


**Figure 9.** Temperature Rise Curve of Vehicle Indoor at Idle Speed

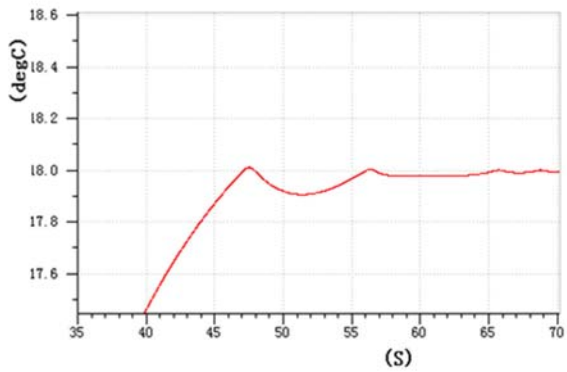


**Figure 10**. Local enlargement of indoor temperature rise curve at idle speed

## 3.2. Common working conditions of electric vehicles in winter in cities

When the electric vehicle runs normally in the city in winter, the urban speed is 54km/h, i.e. 15m/s. It is assumed that the temperature inside and outside the passenger compartment is the same before the heat pump air conditioner is turned on, and both are taken as 0 ℃. Set the temperature in the passenger compartment to reach 18 ℃ after the air conditioner is turned on. As the vehicle speed changes at this time, the air exchange volume of outdoor fresh air increases, so the load in the car room increases. Figure 11 and Figure 12 show the temperature rise curve in the car at this time.

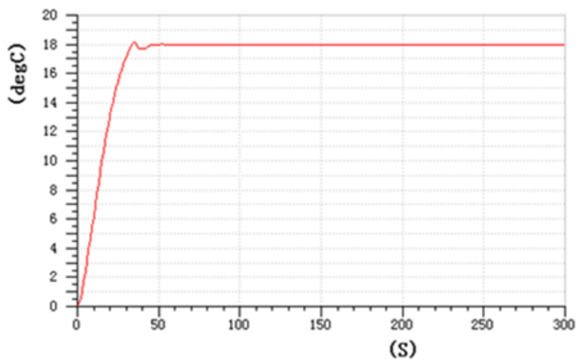


**Figure 11.** Simulated Temperature of Vehicle Room under Common Speed Conditions

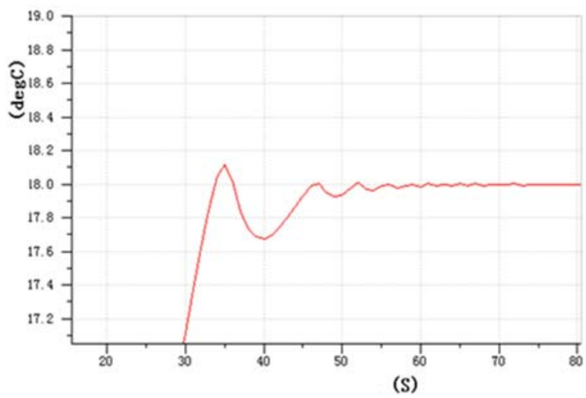


**Figure 12.** Local enlargement of simulated temperature in compartment under common speed conditions

It can be seen from Figures 11 and 12 that the internal temperature rise curve at this time is slightly different from that at idle speed. The time to reach the set temperature is faster. When the simulation reaches 33.79s, the set temperature is 18 ℃. This is due to the increase of the vehicle speed, the air flow rate of the outdoor heat exchanger is accelerated, and the heating capacity is increased. When the temperature reaches the set temperature, it will continue to rise, with the highest reaching value of 18.11 ℃, and then the temperature will rapidly fall back, reaching the lowest stable temperature of 17.76 ℃. The error is about 1.3% (less than 5%), which can be ignored. After a 12s callback process, the system is stable at 18 ℃ with almost no deviation, and the temperature control effect is good.

### 3.3. High speed working condition of automobile in winter

In winter, when the electric vehicle runs at high speed, the vehicle speed is 100km/h, that is, 28m/s. It is assumed that the temperature inside and outside the passenger compartment is the same before the heat pump air conditioner is turned on, both of which are 0 ℃. Set the indoor temperature to be stable around 18 ℃ after the air conditioner is turned on. Other parameters remain unchanged. At this time, due to the high vehicle speed, the air side flow rate of the outdoor heat exchanger is high, and the heat transfer speed is fast, so the temperature rise curve in the passenger compartment is different from that before. At this time, the temperature rise curve in the car is shown in Figure 13, and Figure 14 is a partial enlarged view.

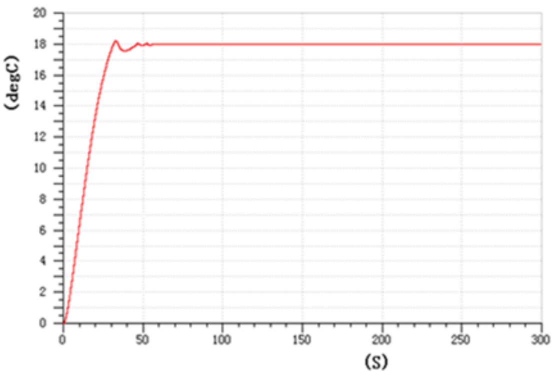


**Figure 13.** Simulation Temperature of Car Room under High Speed Conditions

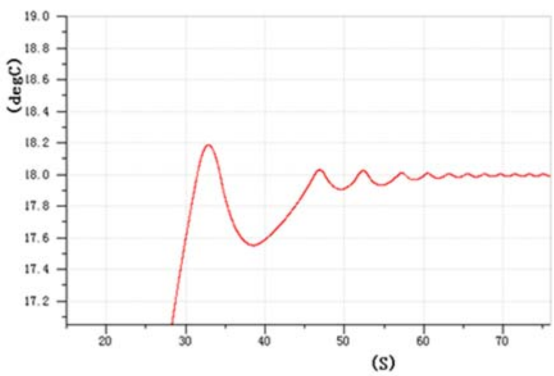


**Figure 14.** Local Amplification of Simulation Temperature in Car Room under High Speed Conditions

It can be seen from the figure that the simulated temperature rise curve in the car at this time is similar to the simulation curve under common working conditions. The time to reach the set temperature was reduced, reaching the set temperature of 18 ℃ at 31.48s, and the curve fluctuated during the temperature callback, with a negative deviation of 0.5 ℃. The error is about 2.4% (less than 5%), which can be ignored. After about 13s of adjustment, the system reached a stable temperature and maintained at 18 ℃ with almost no deviation. The temperature control effect was good.

### 3.4. Comparison between fuzzy control and traditional control

When the vehicle speed is set to 15m/s and the ambient temperature is 0 ℃, other parameters remain unchanged. The temperature rise curve in the cab is obtained by comparing the fuzzy strategy designed in this paper with the traditional control strategy, as shown in Figure 15 and Figure 16.

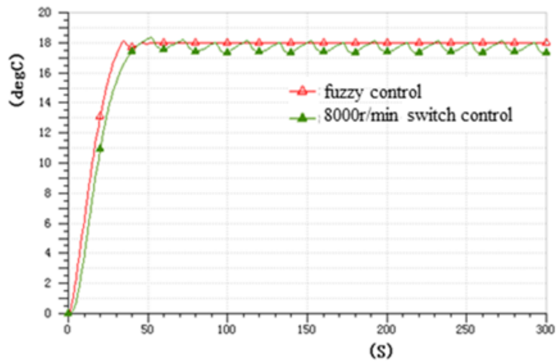


**Figure 15.** Comparison Curve of Simulation Effect

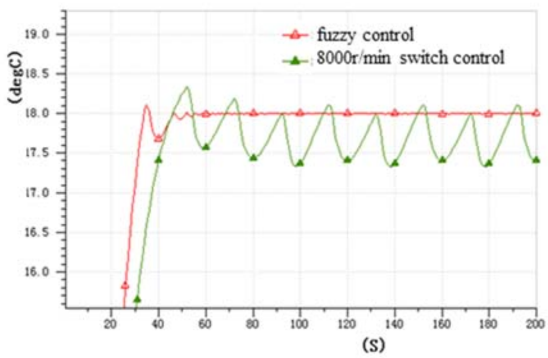


**Figure 16.** Comparisons of simulation results with local magnification curves

## 4. Analysis of Simulation Results

According to the fuzzy control strategy and the heat pump air-conditioning system model established in this paper, the joint simulation is carried out, and the indoor temperature adjustment of the electric vehicle is analyzed when the ambient temperature is 0 ℃ and the humidity is 40% in winter, and the heat pump air-conditioning heating mode is used under three vehicle speed conditions. The conclusions are as follows.

1) With the fuzzy control strategy set in this paper, the heating performance of the air conditioning system of the electric vehicle is good under idling and common working conditions, and the set target temperature can be reached quickly after a short time;

2) Under common working conditions and high-speed working conditions, the system has 1.3% and 2.4% errors in the car interior temperature before stabilization, but the

temperature is rapidly adjusted back, after stabilization, there is basically no deviation, and the temperature control effect is good;

3) The fuzzy control strategy is superior to the traditional control strategy in terms of setting temperature time, temperature callback interval, deviation size and temperature control accuracy.


# Acknowledgment

This work is supported by the teaching and scientific research training project of Geely University, the brand curriculum construction project of Geely University, and the entrepreneurship training project of college students in Sichuan Province.


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