DESIGN AND IMPLEMENTATION OF INDUCTION MOTOR DRIVE USING FUZZY LOGIC CONTROLLER

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Abstract – This paper proposes the controlling of three phase induction motor drive using Fuzzy Logic Controller (FLC). Basically, the motor drive system comprises a voltage source inverter-fed induction motor (VSIM), namely a three-phase voltage source inverter and the induction motor. The squirrel-cage induction motor voltage equations are based on an orthogonal d-q reference-rotating frame where the coordinates rotate with the controlled source frequency. The paper presents a novel FLC for high performance induction motor drive system. The inputs to the FLC are the linguistic variables of speed error and change of speed error, while the output is change in switching control frequency of the voltage source inverter. The results validate the robustness and effectiveness of the proposed FLC for high performance of induction motor drive. Simulink software that comes along with MATLAB was used to simulate the proposed model.

Keywords—Induction Motor Drive (IMD), Voltage Source Inverter (VSI) & Fuzzy Logic Controller (FLC)

I. INTRODUCTION

The Induction Motor (IM), thanks to its well known advantages of simple construction, reliability, ruggedness, and low cost, and has found wide spread industrial application. In contrast to the commutation dc motor, the IM can be operated in an aggressive or volatile environment since there are no problems with spark and commutation. These advantages however are suppressed due to requirement of complex control circuit and nonlinear characteristics of the IM. IM control methods can be divided into scalar and vector control. In scalar control, which is based on relationships valid in steady state, only magnitude and frequency (angular speed) of voltage, current, and flux linkage space vectors are controlled. Thus, the scalar control does not act on space vector position during transients. Contrarily, in vector control, which is based on relations valid for dynamic states, not only magnitude and frequency (angular speed) but also instantaneous positions of voltage, current, and flux space vectors are controlled. Thus, the vector control acts on the positions of the space vectors and provides their correct orientation both in steady state and during transients. In the vector control the motor equations are transformed in a coordinate system that rotates in synchronism with the rotor flux vector. The torque and flux components are identified and controlled independently to achieve a good dynamic response. However there is a necessity of transforming the variables in the synchronously rotating reference frame to the stator reference frame to control actual currents/ voltages. Simulink induction machine models are available in the literature [1-2], but they appear to be black boxes with no internal details. Some of them in [1-2] recommend using S functions, which are software source codes for Simulink blocks. This technique does not fully utilize the power and ease of Simulink because S-function programming knowledge is required to access the model variables. Another approach is using the Simulink Power System Block set [3] that can be purchased with Simulink. This block set also makes use of S-functions and is not as easy to work with as rest of the Simulink blocks. Reference [4] refers to an implementation approach similar to the' one in this paper but fails to give any details. In this paper, a modular, easy to understand Simulink induction motor model is described. With the modular system, each block solves one of the model equations. Though induction motors have few advantageous characteristics, they also posse's nonlinear and time-varying dynamic interactions [5], Using conventional PI controller, it is very difficult and complex to design a high performance induction motor drive system. The fuzzy logic control (FLC) is attractive approach, which can accommodate motor parametric variations and difficulty in obtaining an accurate mathematical model of induction motor due to rotor parametric and load time constant variations. The FLC is a knowledge-based control that uses fuzzy set theory and fuzzy logic for knowledge representation. This paper presents a novel FLC suitable for speed control of induction motor drives. For designing a fuzzy logic based controller, first thing we have to decide is what will be the inputs. As our main aim is to provide constant speed during load changes so the variable to be controlled will be speed. As shown in the diagram by the feedback ω_m (motor speed) is fed back and compared with ω_{ref} (reference speed). Then the error and the change is given as input to the fuzzy logic controller.

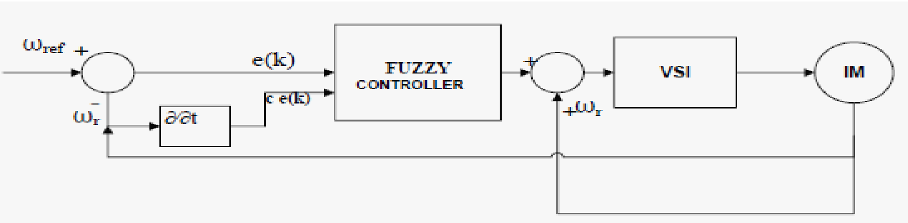

Fig.1: Block Diagram for Speed Control of IM using Fuzzy Logic Controller

The fuzzifier, fuzzifies these two inputs and then the decision making block or the inference system processes the inputs based upon the rule bases and provides output, which is defuzzified by defuzzifier and provided as the output of the controller. This output is called change in control $_{(\omega sl)}$. This ω_{sl} is then added with ω_m (motor speed) and the result is fed to the VSI. As control method is scalar control method, so frequency and magnitude of supply voltage of the induction motor are varied such that it operates at the desired speed and at constant flux.

II. SIMULINK IMPLEMENTATION

One of the most popular induction motor models derived from this equivalent circuit is Krause's model. An induction machine model can be represented with five differential equations. To solve these equations, they have to be rearranged in the state-space. Form, X=Ax+b Where $X=[F_{qs}\ F_{ds}F_{dr}\ F_{dr}\ \omega_r]^T$ is the state vector. The inputs of a squirrel cage induction machine are the three-phase voltages, their fundamental frequency, and the load torque. The outputs, on the other hand, are the three phase currents, the electrical torque, and the rotor speed. The d-q model requires that all the three-phase variables have to be transformed to the two-phase synchronously rotating frame. Consequently, the induction machine model will have blocks transforming the three-phase voltages to the d-q frame and the d-q currents back to three-phase. The induction machine model implemented in this paper. It consists of five major blocks: the o-n conversion, abc-syn conversion, syn-abc conversion, unit vector calculation, and the induction machine d-q model blocks.

A. O-N Conversion Block

This block is required for an isolated neutral system, otherwise it can be bypassed. The transformation done by this block can be represented as follows:

$$\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} = \begin{bmatrix} +\frac{2}{3} & -\frac{1}{3} & -\frac{1}{3} \\ -\frac{1}{3} & +\frac{2}{3} & -\frac{1}{3} \\ -\frac{1}{3} & -\frac{1}{3} & +\frac{2}{3} \end{bmatrix} \begin{bmatrix} V_{ao} \\ V_{bo} \\ V_{co} \end{bmatrix} \qquad (1)$$

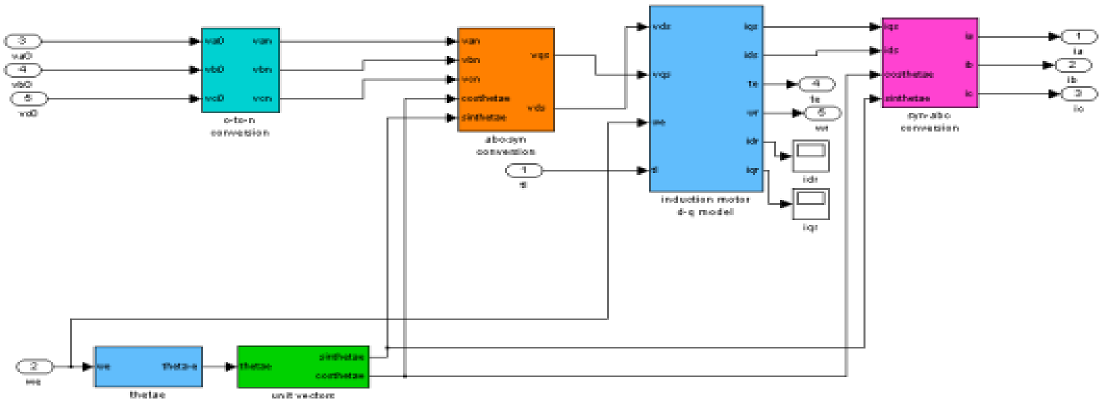

Fig.2: Simulation of Transformation Model

B. Unit Vector Block Calculation

Unit vectors cos θe and sin θe are used in vector rotation blocks, "abc-syn conversion block" and "syn-abc conversion block". The angle θe is calculated directly by integrating the frequency of the input three-phase voltages, ωe.

$$\theta e = \int \omega e\ dt. \qquad (2)$$

The unit vectors are obtained simply by taking the sine and cosine of Be' This block is also where the initial rotor position can be inserted, if needed, by adding an initial condition to the Simulink "Integrator" block. Note that the result of the integration in (2) is reset to zero each time it reaches2n radians so that the angle always varies between 0 and 2n.

C. abc-syn con version block

To convert three-phase voltages to voltages in the two phase synchronously rotating frame, they arc first converted to two-phase stationary frame using (3) and then from the stationary frame to the synchronously rotating frame using

$$\begin{bmatrix} v_{qs}^{s} \\ v_{ds}^{s} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & -\frac{1}{\sqrt{3}} & \frac{1}{\sqrt{3}} \end{bmatrix} \begin{bmatrix} v_{an} \\ v_{bn} \\ v_{cn} \end{bmatrix} \quad (3)$$

$$\begin{Bmatrix} v_{qs} = v_{qs}^{s} \cos\theta_e - v_{ds}^{s} \sin\theta_e \\ v_{ds} = v_{qs}^{s} \sin\theta_e + v_{ds}^{s} \cos\theta_e \end{Bmatrix} \quad (4)$$

Where the superscript "s" refers to stationary frame.

D. syn-abc conversion block

This block does the opposite of the abc-syn conversion block for the current variables using (5) and (6) following the same implementation techniques as before.

$$\begin{Bmatrix} i_{qs} = v_{qs} \cos\theta_e + v_{ds} \sin\theta_e \\ i_{ds} = -v_{qs} \sin\theta_e + v_{ds} \cos\theta_e \end{Bmatrix} \quad (5)$$

$$\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{qs}^{s} \\ i_{ds}^{s} \end{bmatrix} \quad (6)$$

E. Induction machine d-q model block

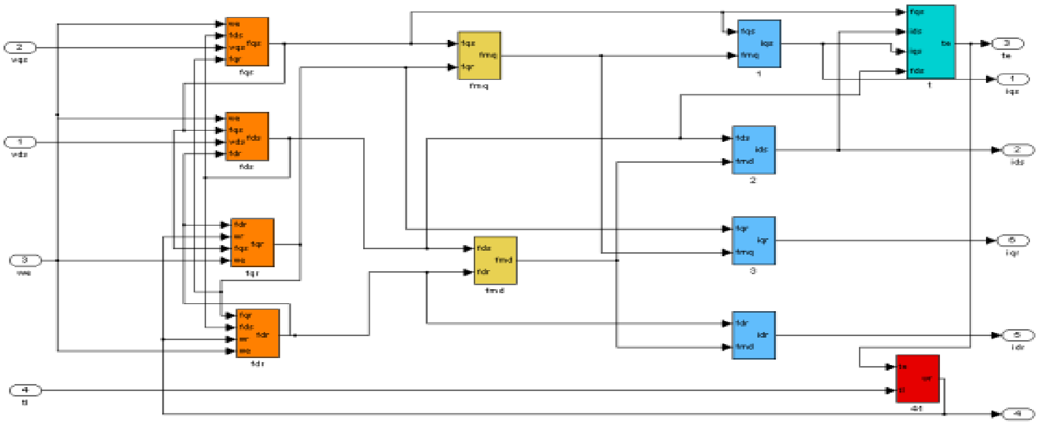

Fig.3: Simulation of IM d-q Model Block

The resulting model is modular and easy to follow. Any variable can be easily traced using the Simulink 'Scope' blocks. The blocks in the first two columns calculate the flux linkages, which can be used in vector control systems in a flux loop. The blocks in Column 3 calculate all the current variables, which can be used in the current loops of any current control system and to calculate the three-phase currents. The two blocks of Column 4, on the other hand, calculate the torque and the speed of the induction machine, which again can be used in torque control or speed control loops, these two variables can also be used to calculate the output power of the machine.

III. OPEN-LOOP CONSTANT V/HZ OPERATION

Fig. 4 shows the implementation of open-loop constant V/Hz control of an induction machine. This figure has two new blocks: command voltage generator and 3-phase PWM inverter blocks. The first one generates the three-phase voltage commands, and it is nothing more than a "syn-abc" block explained earlier. The latter first compares the reference voltage, Vref to the command voltages to generate PWM signals for each phase, then uses these signals to drive three Simulink "Switch" blocks switching between +VJ2 and -Vd/2 (Vd: dc link voltage). The open-loop constant V/Hz operation is simulated for 1.2s ramping up and down the speed command and applying step load torques. The results are plotted in the response of the drive to changes in the speed command and load disturbance scan be observed.

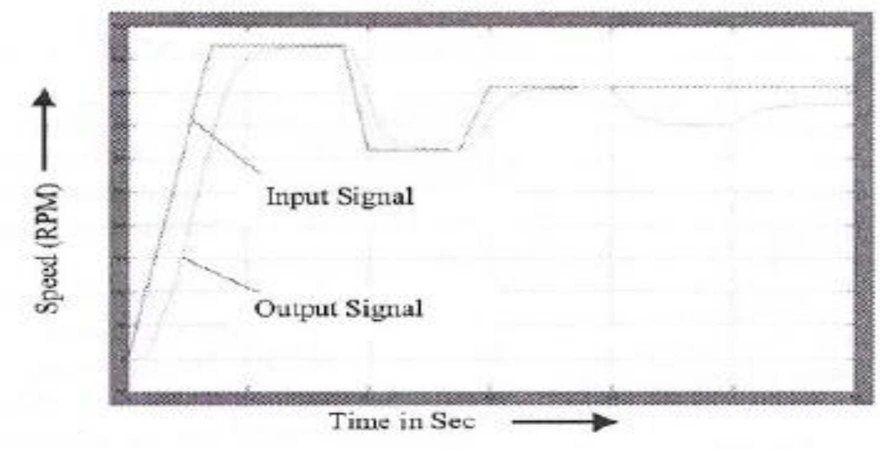

Fig.4: Open loop Constant V/Hz Response

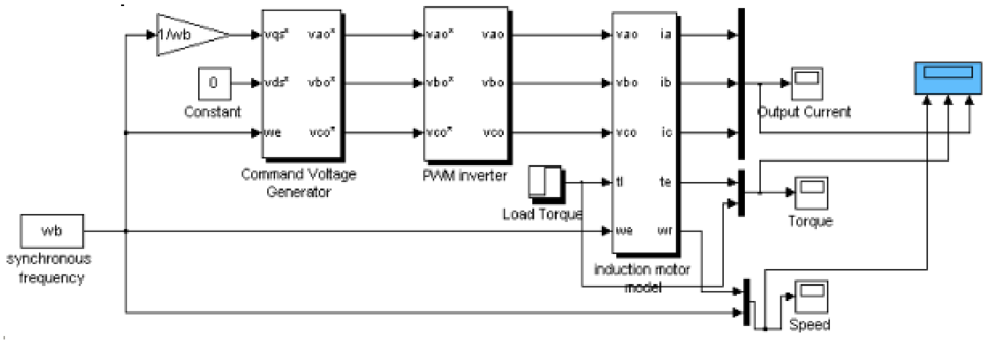

Fig.5: Simulation of IM with VSI Model

IV.STRUCTURE OF FUZZY CONTROLLER

The basic internal structure of a fuzzy logic controller is presented. The FLC allows one to use a control strategy expressed in the form of linguistic rules for the definition of an automatic control strategy. A typical fuzzy logic controller can be decomposed into four basic components as shown in Fig.6.

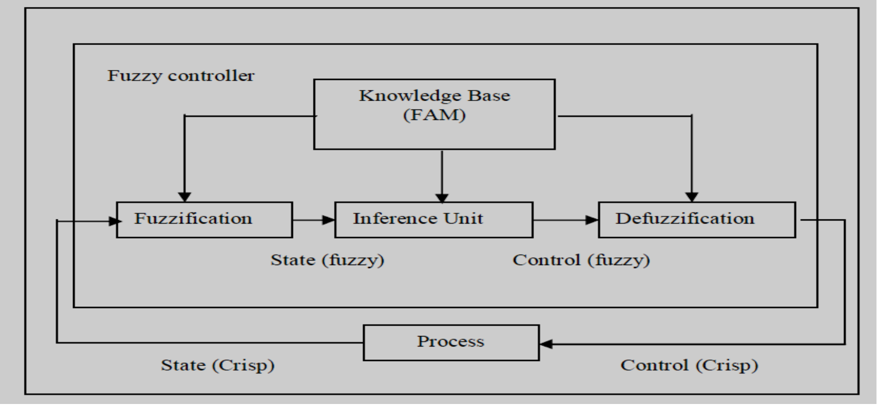

Fig.6: Structure of Fuzzy Logic Controller

Knowledge Base

The Knowledge base consists of two components. A rule base, which describes the behaviour of control surfaces, which involves writing the rules that tie the input values to the output model properties. Rule formation can be framed by discussing with the experts. A database contains the definition of the fuzzy sets representing the linguistic terms used in the rules. The knowledge base is generally represented by a fuzzy associative memory.

Inference Unit

This unit is the core of the fuzzy controller. It generates fuzzy control actions applying the rules in the knowledge base to the current process state. It determines the degree to which each measured valued is a member of a given labeled group. A given measurement can be classified simultaneously as belonging to several linguistic groups. The degree of fulfillment (DOF) of each rule is determined by applying the rules of Boolean algebra to each linguistic group that is part of the rule. This is done for all the rules in the system. Finally the net control action is determined by weighting action associated with each rule by degree of fulfillment.

Defuzzification Unit

It converts the fuzzy control action generated by the inference unit into a crisp value that can be used to drive the actuators. The defuzzification methods such as centroid method, center of maxima method have been predominant on fuzzy control. Perhaps the most frequently used defuzzification method is the centroid method.

Steps to design a Fuzzy Logic Controller at a glance are as follows:

1. Selecting the input to the FLC.
2. Selecting proper MFs both for input and output variables.
3. Fuzzification of the input variable.
4. Preparing a Fuzzy rule base for the controller.
5. Selecting proper defuzzification technique.
6. Defuzzification of output that is to be given to the system for desired operation.

V. FUZZYLOGIC CONTROL ALGORITHM

A fuzzy algorithm consists of situation and action pairs. Conditional rules expressed in IF and THEN statements are generally used. For example, the control rule might be: if the output is lower than the requirement and the output is dropping moderately then the input to the system shall be increased greatly. Such a rule has to be converted into a more generally statement for application to fuzzy algorithms. To achieve this the following terms are defined: error equals the set point minus the process output, error change equals the error from the process output minus the error from last output: and control input applied to the process. In addition, it is necessary to quantize the qualitative statements and the following linguistic sets are assigned such as 1. Large Positive (LP), 2. Medium Positive (MP), 3. Small Positive (SP), 4. Zero (ZZ), 5. Small Negative (SN), 6. Medium Negative (MN) & 7. Large Negative(LN). Thus the statement of the example control will be: if the error is large positive and the error change is small positive then the input to the system is large positive.

VI. FUZZY CONTROL ACTION

1. Specify and store the minimum and the maximum ranges of the error signal E=er(k) , the error change dE= der(k)and the control input change df.
2. If the minimum and maximum ranges of step one are different then quantize then into a common universe of discourse using scaling factors such that the maximum and minimum of the quantized error signal E, the quantized error change dE, and the quantized control input changed f are all the same.
3. Define the symmetrical linguistic fuzzy subsets of E, dE, and df.
4. Calculate the error er and the error change der for the current sampling period and find their quantized values E and dE respectively in the common universe of discourse.
5. From the E and dE the contribution of each rule given in table 1in the fuzzy subsets of control input df and scaling of its membership grades using the rule can be found.
6. The result of application of all rules is membership function grades of control input df through the universe of its discourse. To calculate the crisp or numerical value of df the COA Criteria is used as follows:

   $$dF(k) = \frac{\sum_{j=1}^{n} \mu_{\sigma r}(df_j) * df_j}{\sum_{j=1}^{n} \mu_{\sigma r}(df_j)}$$

   Where n is the number of quantization levels of the output.
7. Add the control input change dF(k) to the previous value F(k-l) to calculate the new control action to be taken for the kth sample: F(k)=F(k-l)+dF(k).

Table 1: Fuzzy Control Rule Decision Table

$\dot{e}$ \ e_r	NL	NM	NS	ZZ	PS	PM	PL
NL	NL	NL	NL	NM	NM	NS	ZZ
NM	NL	NM	NM	NS	NS	ZZ	PS
NS	NM	NM	NS	NS	ZZ	PS	PS
ZZ	NM	NS	NS	ZZ	PS	PS	PM
PS	NS	NS	ZZ	PS	PS	PM	PM
PM	NS	ZZ	PS	PS	PM	PM	PL
PL	ZZ	PS	PM	PM	PL	PL	PL

VII. CLOSED LOOP CONSTANTV/Hz OPERATION

The closed loop circuit has the fuzzy logic controller as the new component. The inputs to the fuzzy logic controller are the speed error and rate of change of speed error. The output is fed to the power converter-pwm inverter, which is used to adjust the inverter switching control frequency. The output of FLC controls the firing angle of the inverter, thereby varying the output voltages. The reference speed of the pwm inverter is modified each time when there is a different output of the fuzzy controller. These outputs are found from the truth table (rule table). The pwm inverter output is then fed to the induction machine where a constant V/Hz operation is carried out.

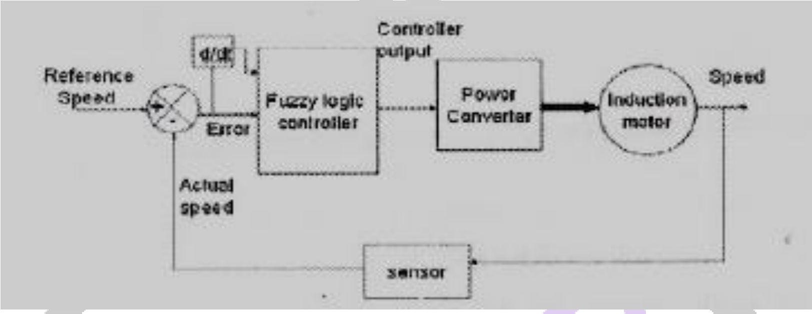

Fig.7: Block Diagram Closed Loop Using Fuzzy Logic Controller

VIII. SIMULATION RESULTS

The output of the fuzzy logic controller (FLC) is used to adjust the inverter switching control frequency and the dc voltage at the inverter using a constant (VF) ratio. The induction motor drive system using FLC results were obtained using a three-phase squirrel cage induction motor with 208 volt phase to phase voltage, 50Hz rated frequency, 1750 rpm rated speed and 1/4 Hp rated power. The parameters of the motor at rated conditions in per unit are given by (all per unit values are based on Base=1/4 Hp, Vbase=208volt and Ibase=1.2amp) Rs=198 p.u. Rr=1353P.u., X1s=117 p.u., & Xlr=.117 p.u., XM=2.2 p.u.

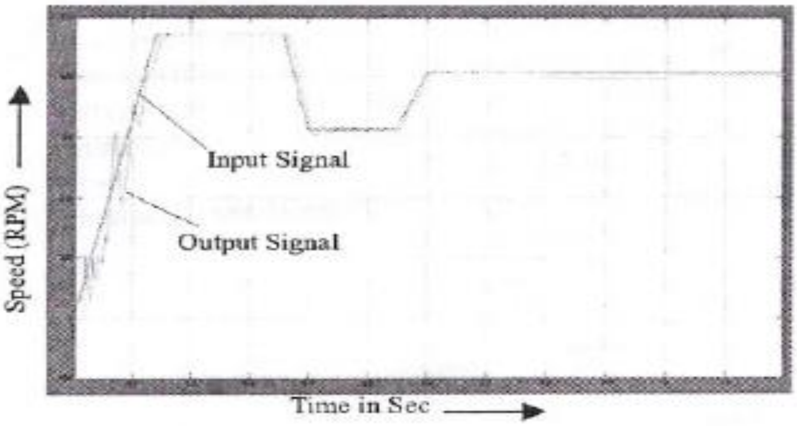

Fig.8: Closed Loop Constant V/Hz with Fuzzy Logic Controller

IX. CONCLUSION

This paper presents a simple, novel and robust fuzzy logic speed controller for high performance induction motor drives. The FLC does not need exact knowledge of induction motor and tolerate range load excursions and parametric variations. The control assignment rules are obtained using heuristic trial and error and human expertise. The simulation test results validate the FLC robustness for different speed trajectories.

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