Research Article

Nonlinear Control of Induction Motor Based on Network Control System

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With the rapid development of network communication technology and computer technology, network control system has been applied in many different fields. Networked AC induction motor is controlled by a communication network to realize data transmission. This paper mainly studies the nonlinear control of induction motor based on network control system. In order to solve the nonlinear problem of AC induction motor, this paper adopts the method of the linear resolve coupling, and combined with the characteristics of the Internet, establishes the mathematical model of the AC induction motor, and considers the use of the system parameter perturbation to construct the mathematical model of the AC induction motor. Aiming at the problems of system parameter perturbation and network-induced delay in networked AC induction motor control system, the robust control of networked AC induction motor control system is studied. The experimental results show that the proposed control strategy can achieve asymptotic stability of the system with parameter perturbation under the action of the controller and can achieve asymptotic stability even with external disturbance. Compared with control strategies 1 and 2, the adjustment time of the speed waveform oversetting phenomenon is about 0.18 s and 0.26 s, and the adjustment time of the control strategy proposed in this paper is only 0.06 s. It is shown that the nonlinear control method of induction motor based on network control system can significantly improve the validity and stability of the system model.

1. Introduction

An AC induction motor is a nonlinear multiple-input-output object, that is, widely used in industrial enterprises. In recent decades, the rapid development of control science, computer technology, and network communication technology has gradually made industrial production intelligent. At the same time, in order to further improve the compatibility and expansibility of the system, researchers put forward a networked control system based on Ethernet, Internet, and other networks. In general, networked control systems refer to distributed closed-loop feedback control systems [1] that utilize communication networks to exchange information among various links (such as controlled objects, actuators, sensors, and controllers) distributed at different spatial locations. For such a distributed control system, that is, functionally, logically, and geographically dispersed, it simplifies the system structure, while opening the spatial location of the system, making the complex system simple and has the advantages of high reliability and high openness [2].

In the process of information transmission, the inevitable delay phenomenon can be divided into deterministic delay and stochastic delay according to the certainty; according to the length of delay time, it can be divided into long delay and short delay. To solve all kinds of delay problems mentioned above, the methods that can be adopted include stochastic system method, time-delay system method, model predictive control method, robust control method, etc. Morawski et al. converted the network delay into fixed delay by caching method and compensated it by state observer. The proposed delay compensation

algorithm is suitable for the integrated communication control system (ICCS), but the cache will artificially increase the network delay [3]. Ogidan et al. designed the LQG random optimal controller to compensate for the network delay, but the compensation accuracy is low, and it is difficult to realize in practice [4]. Khanesar et al. propose a new fuzzy sliding mode controller, which USES the fuzzy system to estimate the nonlinear dynamic system online, and USES Pade to approximate the network-induced delay [5].

This paper mainly studies the nonlinear control of induction motor based on the network control system, introduces the control network into the operating system of induction motor, solves the problem of tedious network wiring, gives a clear definition of the structure and function of each part of the network control, and establishes a mathematical model of the system network control based on reasonable assumptions. The simulation results show that the designed network controller ensures the stability of the networked servo system. At the same time, this method has a better inhibition effect on network transmission delay and data packet loss, especially in the case of system disturbance and uncertain factors, it has better dynamic performance and meets the control requirements of the high-performance control system. The nonlinear control of induction motor based on network control system can achieve certain performance index and ensure the stability of closed-loop system.

2. Nonlinear Control of Induction Motor under Network Control System

2.1. Network Control System

2.1.1. Development History of Network Control System. With the development of computer technology and network communication technology, industrial control system has also produced many significant changes. Networked control system is a product conforming to The Times. Its characteristic is that a computer network is introduced into the control network, so as to connect the sensors, controllers, actuators and other main components of a closed-loop control system as a whole through the network [6, 7]. State signal acquisition and data exchange are realized through this network resource sharing. The wiring of traditional point-to-point connections is avoided. It provides the convenience of remote operation and control, increases the flexibility of the system, and also improves the working stability of the system. The main advantages of the network control system lie in less system connection, high reliability, flexible structure, easy system expansion and maintenance, and the ability to realize information resource sharing.

Due to its prominent competitive advantages and high-cost performance, Ethernet has a trend of large-scale penetration into the field of industrial control. History has proved for countless times that whoever has the right to set standards can lead the development direction of network communication in the future. Our country started late in this aspect, but the development progress is rapid. We independently developed the industrial automation standard based on Ethernet, which was recognized by the International Electrotechnical Commission. In view of the outstanding performance of Ethernet, it can be predicted that it will become the next generation of Fieldbus basic protocol, leading the development trend of Fieldbus. The modern network control system has the characteristics of structure network, node intelligence, system openness, and product integration.

It is the requirement of information age that information networks and control networks should be connected. Enterprise resource planning needs such an organic whole that combines management decisions and market information together as the structural condition. From this point of view, the Ethernet solution greatly simplifies the design process of enterprise computer network systems and improves the robustness of the network. The emergence and promotion of the Internet have recently received extensive attention in networked control systems. People generally seek for a mode that can realize monitoring, management, and maintenance functions remotely, which undoubtedly means more economic benefits and ultimately contributes to the emergence of NCS. In NCS, any control engineer, once given access, can monitor the circuits of a control network from any computer connected to the Internet. Getting rid of the on-site dependency means more productivity.

2.1.2. Basic Structure of Network Control System. General network control system structure has the following two kinds: direct structure and hierarchical structure.

In a directly structured NCS, the system consists of a local controller and a remote end, which contains the actuators, physical devices, and sensors. Local controller and remote terminal in different spatial locations, through the network control circuit, the control signal in the form of packet transmission through the network to the actuator, its role in the controlled object, then the sensor to interval sampling, such as the system output of sensor signal after sampling is encapsulated in the packet, again through the network to transmit it to the controller, the controller computing control signal, in circulation, in order to realize remote network closed-loop control of [8].

In a layered NCS, the system consists of a local controller and a remote closed-loop control system. Local controller is responsible for regularly receiving sensor signal to calculate the control quantity, the packaging in the packet transmission through the network to the remote closed-loop control system, the auxiliary controller at the remote docking processed by the control signal, its role in the controlled object, and then the output of the system through the sensor sampling is returned to the main controller network closed-loop control of [9]. Obviously, compared with NCS with direct structure, there is an auxiliary controller in the remote control system in layered structure NCS, which makes the system have higher stability. However, because there are two or more closed-loop controls in the whole control loop, the sampling period of the system is longer.

Replication in actual applications, the need to adopt what kind of structure according to the requirements of the control system performance and the location of nodes to determine, in fact, if the remote end of the hierarchical structure is a purely physical device, see it as a state space model, the structure of the direct analysis method and the control strategy can be applied to layered structure.

2.1.3. Network Control System Theory.

Many theories are based on certain idealized assumptions at the beginning. The same is true of traditional control theories, such as information transmission in the network without considering the error, and data calculation time and transmission process are far less than the sampling period.. However, with the introduction of control networks, this assumption is no longer valid, and time delay has become a theoretical problem that has to be considered. Delays can be roughly divided into three categories: object internal delays, network delays, and computational delays.

At present, the main research ideas and objects of NCS system are network topology and network scheduling methods, and solutions are provided through the comprehensive application of operations research and control theory to meet the real-time requirements of the control system [10, 11]. At the same time, the delay problem and parameter uncertainty of the network are suppressed. The main task of the latter is to improve the system stability, tracking accuracy, and speed. On the basis of the inherent communication network, namely, the communication protocol of the control network and the delay characteristic, the delay problem of the control object is considered in the model, the stability of the closed-loop system is studied, and the method of the stabilizer is given synthetically.

2.2. Mathematical Model of Induction Motor.

The original model of induction motor is very complex, with nonlinear, time-varying, high-order, strong coupling characteristics, and the mathematical model can be simplified by coordinate transformation, which is easy to calculate. From simple to complex, the mathematical model under the static two-phase coordinate system is firstly derived and then extended to the rotating coordinate system [12].

2.2.1. Three-Phase Mathematical Model of Induction Motor.

In order to simplify the calculation, the following assumption is made in the derivation process: space harmonics are ignored. The three-phase stator windings are symmetrical and the space difference is 120, and the generated magnetomotive force is distributed along the air gap sine. Magnetic saturation is ignored and the self-inductance and mutual inductance of winding are not changed. Ignore core loss: The influence of frequency and temperature change on winding resistance is ignored.

The mathematical model of induction motor includes flux equation, voltage equation, torque equation, and motion equation, in which the flux equation and torque equation are algebraic equations, and the voltage equation and motion equation are differential equations [13].

(1) Flux Equation. For ψ of $\psi = \mathrm{Li}$ flux linkage equations, the six winding magnetic chain expression is:

$$
\begin{bmatrix} \psi_A \\ \psi_B \\ \psi_C \\ \psi_a \\ \psi_b \\ \psi_c \end{bmatrix} = \begin{bmatrix} L_{AA} & L_{AB} & L_{AC} & L_{Aa} & L_{Ab} & L_{Ac} \\ L_{BA} & L_{BB} & L_{BC} & L_{Ba} & L_{Bb} & L_{Bc} \\ L_{CA} & L_{CB} & L_{CC} & L_{Ca} & L_{Cb} & L_{Cc} \\ L_{aA} & L_{aB} & L_{aC} & L_{aa} & L_{ab} & L_{ac} \\ L_{bA} & L_{bB} & L_{bC} & L_{ba} & L_{bb} & L_{bc} \\ L_{cA} & L_{cB} & L_{cC} & L_{ca} & L_{cb} & L_{cc} \end{bmatrix} \cdot
$$

$$
= \begin{bmatrix} i_A \\ i_B \\ i_C \\ i_a \\ i_b \\ i_c \end{bmatrix}. \tag{1}
$$

Type of i_A, i_B, ..., I_c is the instantaneous value of the constant rotor phase current; bits A, bits of B, ..., all bits of c for each phase winding magnetic chain. L_{AA}, L_{BB}, ... L_{cc} is the self-inductance of each winding, while other terms are the mutual inductance between corresponding windings. The inductance corresponding to each phase flux leakage of the stator is defined as stator leakage inductance L_{is}, the inductance corresponding to each phase flux leakage of the rotor is defined as rotor leakage L_{lr}, the maximum mutual inductance alternating chain of the stator one-phase winding is stator mutual inductance L_{ms}, and the maximum mutual inductance alternating chain of the rotor one-phase winding is rotor mutual inductance L_{mr}. According to the symmetry of windings, leakage inductance values are all equal, because the number of turns of fixed rotor windings is equal after conversion, then $L_{ms} = L_{mr}$ [14]. Therefore, self-inductance of the stator and rotor is as follows:

$$
\begin{aligned} L_{AA} &= L_{BB} = L_{CC} = L_{ms} + L_{is}, \\ L_{aa} &= L_{bb} = L_{cc} = L_{ms} + L_{ls}. \end{aligned} \tag{2}
$$

If difference between three-phase windings is 120°, then the mutual inductance value is as follows:

$$
\begin{aligned} L_{ms} \cos \frac{2\pi}{3} &= L_{ms} \cos\left(-\frac{2\pi}{3}\right), \\ &= -\frac{1}{2} L_{ms}. \end{aligned} \tag{3}
$$

Given that the included angle between fixed rotor shafting is θ, the mutual inductance between stator windings and rotor windings is as follows:

$$\begin{cases} L_{Aa} = L_{aA} = L_{Bb} = L_{bB} = L_{Cc} = L_{cC} = L_m \cos\theta, \\[2mm] L_{Ab} = L_{bA} = L_{Bv} = L_{cB} = L_{Ca} = L_{aC} = L_m \cos\left(\theta + \dfrac{2\pi}{3}\right), \\[2mm] L_{Ac} = L_{cA} = L_{Ba} = L_{aB} = L_{Cb} = L_{bC} = L_m \cos\left(\theta - \dfrac{2\pi}{3}\right). \end{cases} \quad (4)$$

According to the abovementioned equation, a complete flux linkage equation can be obtained, which is represented by a matrix as follows:

$$\begin{bmatrix} \psi_s \\ \psi_r \end{bmatrix} = \begin{bmatrix} L_{ss} & L_{sr} \\ L_{rs} & L_{rr} \end{bmatrix} \begin{bmatrix} i_s \\ i_r \end{bmatrix}. \quad (5)$$

(2) Voltage Equation. Three-phase voltage, rotor equation for $u = R_i + d\psi/dt$, expressed as a matrix form is as follows:

$$\begin{bmatrix} u_A \\ u_B \\ u_C \\ u_a \\ u_b \\ u_c \end{bmatrix} = \begin{bmatrix} R_A & 0 & 0 & 0 & 0 & 0 \\ 0 & R_B & 0 & 0 & 0 & 0 \\ 0 & 0 & R_C & 0 & 0 & 0 \\ 0 & 0 & 0 & R_a & 0 & 0 \\ 0 & 0 & 0 & 0 & R_b & 0 \\ 0 & 0 & 0 & 0 & 0 & R_c \end{bmatrix} \begin{bmatrix} i_A \\ i_B \\ i_C \\ i_a \\ i_b \\ i_c \end{bmatrix} + P \begin{bmatrix} \psi_A \\ \psi_B \\ \psi_C \\ \psi_a \\ \psi_b \\ \psi_c \end{bmatrix}. \quad (6)$$

Type of $u_A, u_B, \ldots, u_c$ represents the instantaneous value of phase voltage of stator winding and rotor winding, respectively; $R_A, R_B, \ldots, R_c$ represents the resistance of stator winding and rotor winding respectively; $i_A, i_b, \ldots, I_C$ represents the instantaneous value of phase current of stator winding and rotor winding; $\psi_A, \psi_B, \ldots, \psi_c$, respectively, of the stator winding and rotor winding phase flux instantaneous value; $p = d/dt$ is the differential operator.

(3) Torque Equation. According to the principle of electromechanical energy conversion, the torque equation of induction motor can be expressed as follows:

$$T_e = -nL_{ms} \begin{bmatrix} (i_A i_a + i_B i_b + i_C i_c)\sin\theta + (i_A i_b + i_B i_c + i_C i_a) \\[2mm] \sin\left(\theta + \dfrac{2\pi}{3}\right) + (i_A i_c + i_B i_a + i_C i_b)\sin\left(\theta - \dfrac{2\pi}{3}\right) \end{bmatrix}. \quad (7)$$

(4) Equations of Motion. The motion equation of induction motor can be expressed as follows:

$$\frac{J}{n_p} \cdot \frac{d\omega_r}{dt} = T_e - T_L. \quad (8)$$

where J represents the moment of inertia of the unit; TL represents load torque.

2.2.2. Dynamic Mathematical Model of Induction Motor in Two-Phase Static Coordinate System. The three-phase rotor winding of induction motor is rotating, and the equation in

the two-phase rotating coordinate system can be obtained only after CLARK and PARK coordinate transformation (usually used for field-oriented control of three-phase AC motors). The rotation transformation can change the coupling relationship between fixed and rotor windings, and the fixed and rotor windings in relative motion are replaced by the equivalent windings in relative rest, thus eliminating the influence of the angle between fixed and rotor windings on flux linkage and torque [15, 16]. The dynamic mathematical model of induction motor in the two-phase static coordinate system after transformation is as follows:

(1) Voltage equation:

$$\begin{bmatrix} u_{s\alpha} \\ u_{s\beta} \\ u_{r\alpha} \\ u_{r\beta} \end{bmatrix} = \begin{bmatrix} R_s + L_s P & 0 & L_m P & 0 \\ 0 & R_s + L_s P & 0 & L_m p \\ L_m P & \omega_r L_m & R_r + L_r P & \omega_r L_r \\ -\omega_r L_m & L_m p & -\omega_r L_r & R_r + L_r p \end{bmatrix} \begin{bmatrix} i_{s\alpha} \\ i_{s\beta} \\ i_{r\alpha} \\ i_{r\beta} \end{bmatrix}. \quad (9)$$

(2) Flux equation:

$$\begin{bmatrix} \psi_{s\alpha} \\ \psi_{s\beta} \\ \psi_{r\alpha} \\ \psi_{r\beta} \end{bmatrix} = \begin{bmatrix} L_s & 0 & L_m & 0 \\ 0 & L_s & 0 & L_m \\ L_m & 0 & L_r & 0 \\ 0 & L_m & 0 & L_r \end{bmatrix} \begin{bmatrix} i_{s\alpha} \\ i_{s\beta} \\ i_{r\alpha} \\ i_{r\beta} \end{bmatrix}. \quad (10)$$

(3) Torque equation:

$$T_e = n_p L_m \left(i_{s\beta} i_{r\alpha} - i_{s\alpha} i_{r\beta} \right). \quad (11)$$

2.2.3. Dynamic Mathematical Model of Induction Motor in Two-Phase Rotating Coordinate System. Rotating coordinate transformation is to transform the stator coordinate system and rotor coordinate system to the same rotating orthogonal coordinate system, it takes synchronous angular velocity s relative to stator winding motion [17]. The dynamic mathematical model of induction motor under the two-phase rotating coordinate system after transformation is as follows:

(1) Voltage equation:

$$\begin{bmatrix} u_{sd} \\ u_{sq} \\ u_{rd} \\ u_{rq} \end{bmatrix} = \begin{bmatrix} R_s + L_s P & -\omega_s L_s & L_m P & -\omega_s L_m \\ \omega_s L_s & R_s + L_s P & \omega_s L_m & L_m P \\ L_m P & -\Delta\omega L_m & R_r + L_r P & \Delta\omega L_r \\ \Delta\omega L_m & L_m P & \Delta\omega L_r & R_r + L_r P \end{bmatrix} \begin{bmatrix} i_{sd} \\ i_{sq} \\ i_{rd} \\ i_{rq} \end{bmatrix}. \quad (12)$$

(2) Flux equation:

$$\begin{bmatrix} \psi_{sd} \\ \psi_{sq} \\ \psi_{rd} \\ \psi_{rq} \end{bmatrix} \begin{bmatrix} L_s & 0 & L_m & 0 \\ 0 & L_s & 0 & L_m \\ L_m & 0 & L_r & 0 \\ 0 & L_m & 0 & L_r \end{bmatrix} \begin{bmatrix} i_{s\alpha} \\ i_{s\beta} \\ i_{r\alpha} \\ i_{r\beta} \end{bmatrix}. \quad (13)$$

(3) Torque equation:

$$T_e = n_p L_m \left(i_{sq} i_{r\,d} - i_{s\,d} i_{rq} \right). \tag{14}$$

2.3. Induction Motor Networked Control

2.3.1. Networked Control Structure. The classical control system structure consists of four parts, namely, controller, actuator, sensor, and controlled object. The controller is a kind of device that produces output signals according to input signals. It usually takes the difference between the feedback signal obtained by the sensor and the reference input signal of the system as input signals. The actuator is a device directly connected with the controlled object. It receives the control signal of the controller and converts it into the required analog quantity to control the controlled object. A sensor is a kind of state measurement device. On some special occasions, the installation of sensor can also be avoided, and the amount to be measured can be calculated by introducing an observer [18, 19]. The determination of the controlled object is generally related to the purpose of the design control. The networked control system is the information channel connecting these four parts, which forms a closed-loop control system. From the perspective of the relationship between structure and function, the sensor has the functions of analog/digital (A/D) conversion, data encapsulation, and transmission, etc. The executor has the functions of digital/analog (D/A) conversion, receiving data packets, etc. The controller is mainly based on industrial computers or intelligent chips. The information flow between the controller and the actuator and the sensor is transmitted in the form of encapsulated data packets under some common communication protocol by means of network channels. Figure 1 shows the basic structure of networked control systems.

This mechanism of transmitting information in the form of data packets ensures the efficiency of communication. And the network bearing this information traffic, according to the system size, performance, and the actual needs of the application environment, can choose flexibly, such as worldwide, industrial Ethernet, and so on. The driving modes of networked control systems can be divided into two types according to the different action conditions, namely, clock-driven and event-driven. Clock-driven means that the network nodes perform tasks at the agreed time. The condition of the action is only time-dependent. The so-called event-driven refers to whether the network node ACTS depends on whether the agreed event occurs, and if it does, it will immediately execute the agreed task. However, event-driven is not easy to implement, and some practical control networks do not support event-driven methods.

2.3.2. Modeling of Networked Control Structure System of Induction Motor. The networked control structure of induction motor can usually be realized in two ways: the beamline structure and the layered structure. The main feature of the beamline structure is that the signal
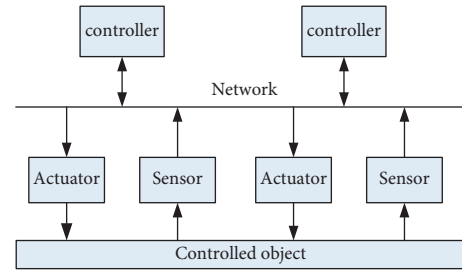

Figure 1: The basic structure of networked control system.

transmission between the motor, controller, and sensor is directly transmitted through the communication network [20]. The network undertakes the closed-loop connection of the whole servo system, and its structural feature is that each motor is equipped with a network interface unit, which undertakes the function of information modulation and demodulation. Specifically, the feedback information collected by the sensor is converted into a data structure acceptable to the controller and transmitted to the controller to form a feedback loop. The other control structure as opposed to the direct structure is the hierarchical structure, in which a separate controller, called the remote controller, is installed for each motor in the network in addition to the main controller. The physical distance between these controllers and the motor body is very close, and the main controller of the system undertakes most of the operations in the control network and transmits the results of the operations to the remote controller through the network. Then the remote controller executes the motor control instructions according to the control signal sent by the master controller and returns the sensor measurement data to the master controller [21, 22]. In the process of permanent magnet synchronous motor servo control, it is found that the motor speed is greatly affected by the current. In view of this high sensitivity, a scheme with faster information transmission speed should be chosen as a response. Based on this consideration, the choice of the control structure of networked permanent magnet synchronous motor is more inclined to the hierarchical structure. Block diagram of a conventional networked servo control system. Under the hierarchical network control framework, the system can be roughly divided into the following parts: (1) Remote unit: including remote controller and remote motor; (2) main controller; and (3) data network [23].

Each remote unit comprises a remote controller and an induction motor. The remote controller is responsible for relatively simple control work, such as receiving the control signal of the master controller transmitted through the data network, carrying out simple control of the IDIQ flow of the induction motor, and finally converting the control signal into PWM signal to drive the induction motor.

At the same time, the detection data of induction motor, such as motor speed and current, are also transmitted to the main controller through the network. The master controller has powerful data processing capability and can process and calculate the control information of several remote units, so it is not convenient to be installed on the remote site. At the

same time, the master controller can also provide an advanced real-time control algorithm, and even have fault detection and network status monitoring, and other functions.

In the process of network communication, due to the limitation of its structure and function, it often causes information congestion and even data packet loss. When data packet loss occurs, it is generally chosen to ignore the loss of old data and keep sending the latest data. In fact, the lost data will lose its reference value due to the long waiting time.

For the convenience of modeling, the following assumptions are made for the networked induction synchronous motor servo control system: (1) The sensor is event-driven and the sampling period is H. The sampled PMSM data are packaged and sent to the central controller through the network. (2) The central controller is event-driven. Each time the packet arrives at the controller, the control signal is calculated and the result is sent to the actuator over the network. (3) the actuator is event-driven. It is assumed that the actuator and the sensor are synchronous and have the same sampling period h $(h > 0)$.

The transmission delay from the master controller to the PMSM and the transmission delay from the sensor to the master controller is τ_a and τ_{sc}, respectively, so the total delay of the system is as follows:

$$\tau_k = \tau_{ca} + \tau_{sc}. \tag{15}$$

When there is network delay in the system, the state value collected by the controller at the moment of kh will reach the controller at the moment of $kh + \tau k$. The state feedback controller can be designed as follows:

$$u(t) = Kx(kh), \quad \forall t \in [kh + \tau_k, (k+1)h + \tau_{k+1}]. \tag{16}$$

Let $d(t) = $ t-kh, then

$$kh = t - d(t). \tag{17}$$

where $d(t)$ is the time delay.

Time delay nominal system is as follows:

$$\begin{cases} x = \mathrm{A}x(t) + A_d x(t - d(t)), \\ x(t) = \Phi(t), t \in [-h, 0]. \end{cases} \tag{18}$$

where $x(t) \in R^{n \times n}$ is the state vector, and A_d is the appropriate dimension matrix. $D(t)$ is to satisfy the following conditions:

$$0 \le d(t) \le h. \tag{19}$$

3. Simulation Test of Induction Motor Based on Network Control System

3.1. Simulation of Networked AC Induction Motor Control System Based on True-Time Toolbox. True-time toolkit is a real-time network control system based on the MATLAB simulation toolbox, the toolkit is ideal for network control system of virtual simulation tools, according to different network protocols, can study all kinds of network environment change on the influence of the closed-loop control

system, especially the effect of network delay on the system performance [24].

In networked control systems, an improved Smith estimator fuzzy control method is proposed to solve the problem that the network-induced delay worsens the system performance. Firstly, an improved Smith predictive controller is introduced at the controller side to solve the problem of mismatch between the controlled object model and the controlled object model. Meanwhile, the cut-off frequency of the system is increased to obtain faster system response. Then, the controller is designed as a fuzzy controller by using fuzzy control algorithm, which can achieve better control effect and has strong robustness.

3.2. Simulation Test Parameters. Given that the core of the internal model control strategy lies in the design of the dynamic inverse of the controlled object, accurate motor parameters are needed in the simulation design so as to design a fully matched dynamic inverse. The motor parameters used in the simulation design are the actual experimental motor parameters obtained through parameter identification. As shown in Table 1, all parameters of the induction motor in the simulation experiment are set.

4. Simulation Test Results of Induction Motor Based on Network Control System

4.1. Closed-Loop Response State of the Robust Controller When d2 Is 0.1355

4.1.1. Closed-Loop Response State of a Robust Controller with No Disturbance. When $d1 = 0$, $\mu = 1$ and $d2 = 0.1355$, the parameter selection is $\alpha = 0.5$, and after two iterations, $\sigma 1 = \sigma 2 = 0$. In this case, the controller gain can be obtained. Without considering the disturbance, the initial value of the state vector is: $X(0) = [5, 10, 15, 20]$, and the closed-loop state response is: $X(0) = [5, 10, 15, 20]$.

As shown in Table 2 and Figure 2, the system with parameter perturbation can be asymptotically stable under the action of the controller. The state of $X1$, $X2$, and $X3$ approaches and stabilizes when the time reaches 15, while the time of $X4$ closed-loop response state fluctuates greatly. The system state does not approach 0 until the time approaches 20 from the highest—55. Its main feature can be expressed as oscillation divergence, and the oscillation amplitude decreases with time.

4.1.2. Closed Loop Response State of Robust Controller with Disturbance. As shown in Figure 3 and Table 3, the initial value of state vector is $x(0) = [5, 10, 15, 20]$ for the random number sequence with $w(t)$ variance of 0.05 and the average value of 0 when considering disturbance. It can be seen that the system with parameter perturbation can be asymptotically stable under the action of the controller, and can still achieve asymptotic stability in the case of external disturbance, which verifies the effectiveness and feasibility of the method. Therefore, the nonlinear control method of the induction motor based on the network control system

TABLE 1: Induction motor parameters.

Parameter	Numerical value	Parameter	Numerical value
Rated power P_N	3 kW	Polar logarithm n_p	2
Rated voltage U_N	370 V	Stator resistance R_s	1.794 Ω
DC bus voltage U_{dc}	530 V	Rotor resistance R_r	1.583 Ω
Rated current I_N	6.4 A	Mutual inductance L_m	0.379 H
Rated frequency f_N	50 Hz	Stator inductance L_s	0.3952 H
Given speed n	1350 r/min	Rotor inductance L_r	0.3956 H

TABLE 2: Closed loop state response of robust controller without disturbance.

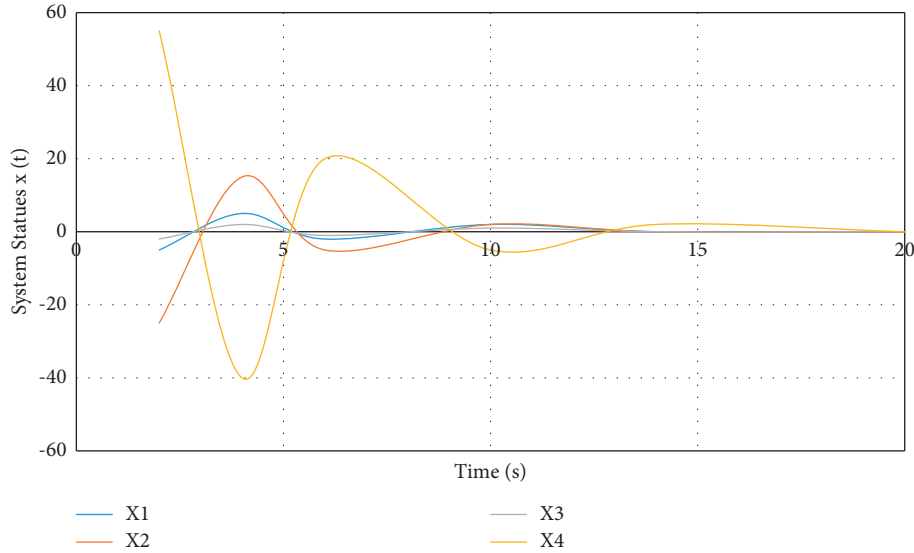|	2	4	6	10	14	20
X1	−5	5	−2	2	0	0
X2	−25	15	−5	2	0	0
X3	−2	2	−1	1	0	0
X4	55	−40	20	−5	2	0

FIGURE 2: Closed loop state response of robust controller without disturbance.

achieves the predetermined performance index and ensures the stability of the closed-loop system.

4.2. Closed Loop Response State of Robust Controller When d2 Is 1.1355

4.2.1. Closed-Loop Response State of a Robust Controller with No Disturbance.
When $d1 = 0$, $\mu = 1$ and $d2 = 1.13555$, the parameter selection is $\alpha = 0.5$, and after two iterations, $\sigma 1 = \sigma 2 = 0$. In this case, the controller gain can be obtained. Without considering the disturbance, the initial value of the state vector is: $X(0) = [5\ 10\ 15\ 20]$, and the closed-loop state response is: $X(0) = [5, 10, 15, 20]$.

As shown in Table 4 and Figure 4, when D2 value is 1.1355, the closed-loop response state of robust controller achieves asymptotic stability faster than that when $D2$ value is 0.1355. Among them, $X1$ tends to 0 after 3 times; $X2$ and $X3$ tend to 0 after 6 times; $X4$ tends to 0 faster than $D2$ when the value is 0.1355.

4.2.2. Closed Loop Response State of Robust Controller with Disturbance.
As shown in Table 5 and Figure 5, the trend of the closed-loop response state of the robust controller in the presence of disturbance is close to that in the case of no disturbance. It can be concluded from the above diagram that the system with parameter perturbation can be asymptotically stable under the action of the controller, and the asymptotic stability can be achieved in the case of external disturbance, which verifies the effectiveness and feasibility of the method.

4.3. No Load Low-Speed Starting Performance.
The same as the previous two statistical indicators of patients, the maximum, minimum, and median values of postoperative total fluid recovery time of patients in the three groups were still selected.

As shown in Table 6, Figures 6 and 7, comparing the three different control strategies under no-load conditions, it can be seen that the speed waveform of control strategy 1
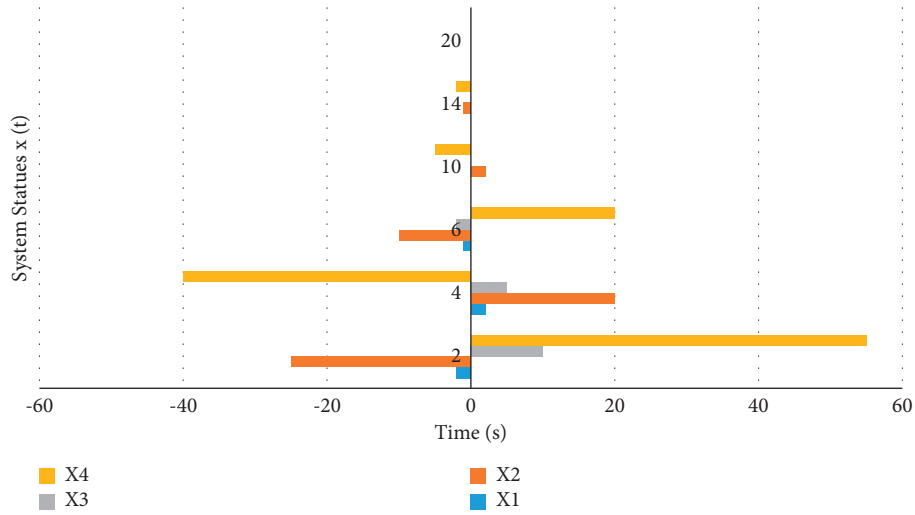
Figure 3: Closed loop response state of robust controller with disturbance.

Table 3: Closed loop response state of robust controller with disturbance.

	2	4	6	10	14	20
X1	−2	2	−1	0	0	0
X2	−25	20	−10	2	−1	0
X3	10	5	−2	0	0	0
X4	55	−40	20	−5	−2	0

Table 4: Closed loop response state of robust controller when $d2$ is 1.1355.

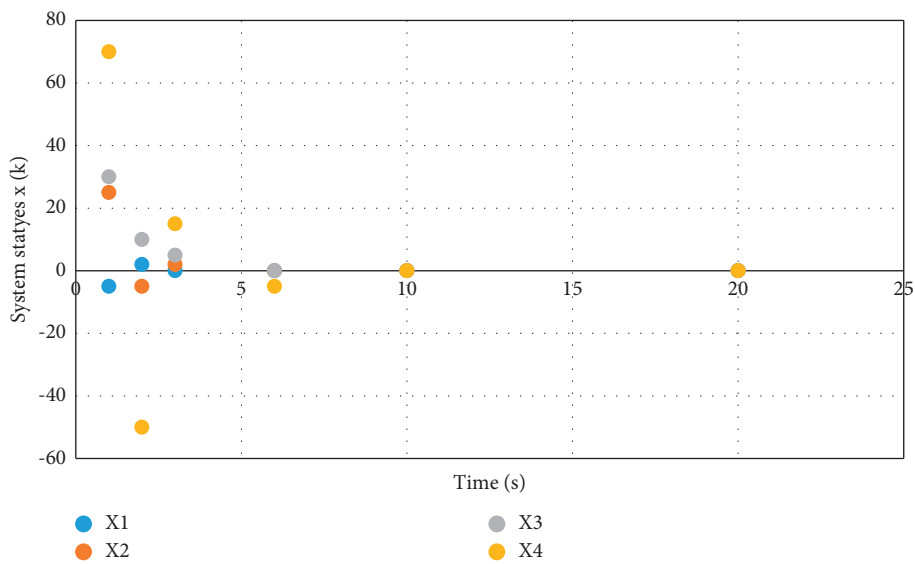|	1	2	3	6	10	20
X1	−5	2	0	0	0	0
X2	25	−5	2	0	0	0
X3	30	10	5	0	0	0
X4	70	−50	15	−5	0	0

Figure 4: Closed loop response state of robust controller when $d2$ is 1.1355.

TABLE 5: Closed-loop response state of robust controller in the presence of disturbance with $D2$ value of 1.1355.

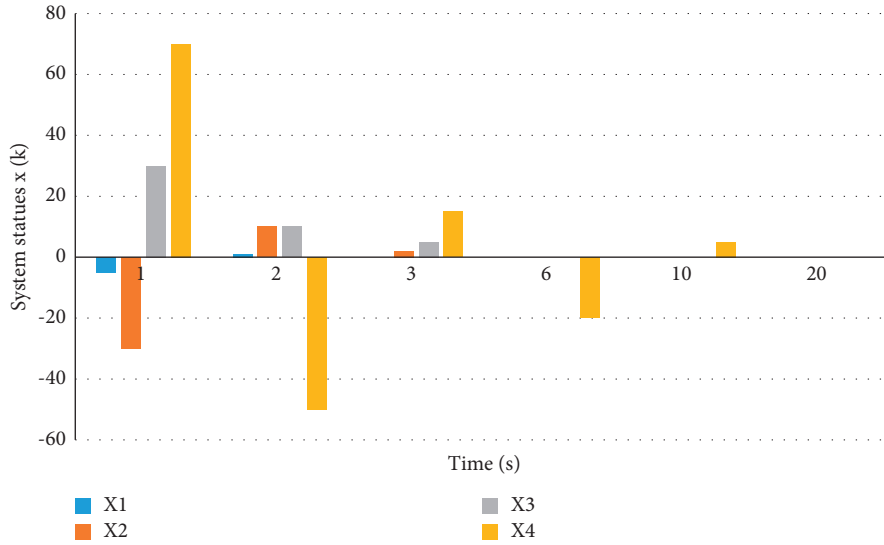|	1	2	3	6	10	20
$X1$	−5	1	0	0	0	0
$X2$	−30	10	2	0	0	0
$X3$	30	10	5	0	0	0
$X4$	70	−50	15	−20	5	0

FIGURE 5: Closed-loop response state of robust controller in the presence of disturbance with $D2$ value of 1.1355.

TABLE 6: Speed waveform under no load and low-speed start.

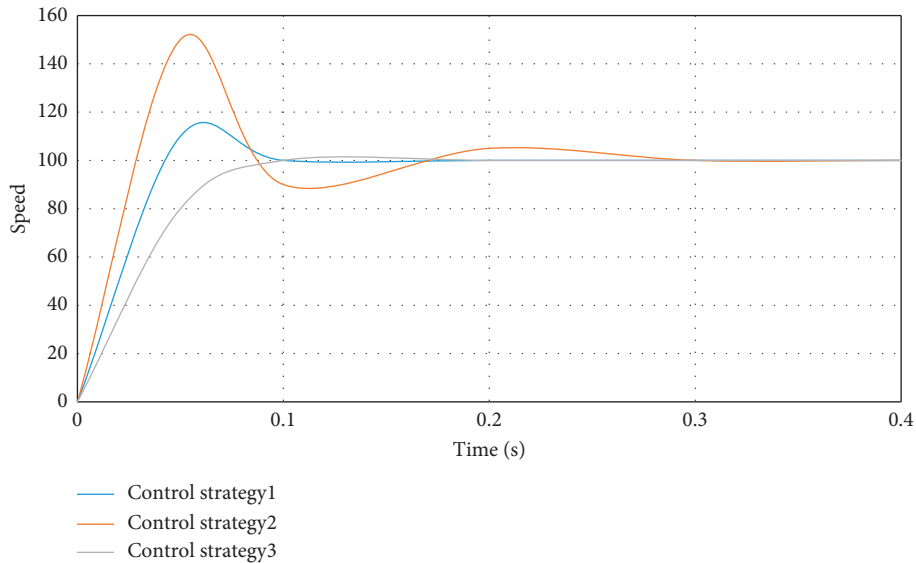|	0.01	0.02	0.03	0.1	0.2	0.3
Control strategy1	60	120	110	110	100	100
Control strategy2	70	150	85	100	100	100
Control strategy3	80	90	95	100	100	100

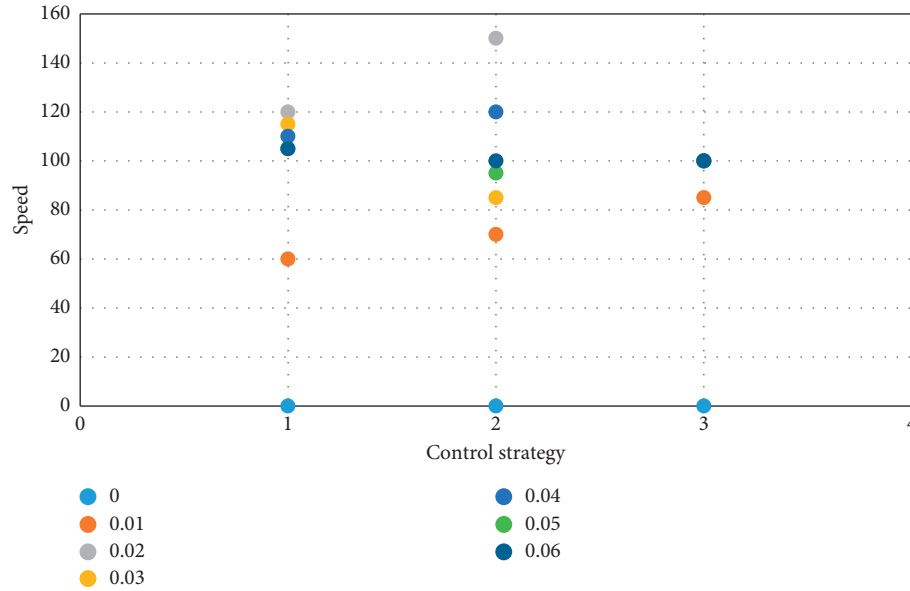FIGURE 6: Speed waveform under no load and low-speed start(1).

FIGURE 7: Speed waveform under no load and low-speed start(2).

and control strategy 2 has an obvious overshoot phenomenon under the condition of low-speed start-up of the system, and the adjustment time is about 0.18 s and 0.26 s. It can be seen that control strategy 2 shortens the regulating time, but increases the overshoot of the system under the condition of low-speed starting, which indicates that the ideal speed regulation effect cannot be achieved at low-speed. The adjusting time of the control strategy proposed in this paper is 0.06 s, which verifies that the starting performance of the control strategy is better than that of control strategy 1 and control strategy 2 under no load and low-speed conditions.

5. Conclusions

Network control system is a new type of control system which combines computer networks, communication technology, and control theory. It has the advantages of remote control, resource sharing, easy maintenance, and high flexibility. It has a wide application prospect in industrial control and other fields. It is one of the hot topics in communication and control.

In this paper, based on the existing AC induction motor model, the mathematical model of networked AC induction motor is established, and it is subdivided into discrete networked AC induction motor mathematical model with controller parameter perturbation and external disturbance, and continuous networked AC induction motor mathematical model with system parameter perturbation and external disturbance. Based on the coordinate transformation method, the three-phase dynamic model of PMSM Based on physical meaning is transformed into the two-phase decoupling motor model in a rotating coordinate system The simulation module is built on the MATLAB experimental platform; aiming at the problems of parameter perturbation and network induced delay in networked AC induction motor control system, the robust stabilization problem of networked AC induction motor control system is studied, and the time-varying delay is divided by the method of time-delay division.

Due to the limitation of my knowledge level and research time, there are some shortcomings in this paper: in the modeling of networked AC induction motor system, the simplified modeling method is adopted, and many assumptions are made in the modeling. Therefore, how to establish a more realistic model to reflect the characteristics of the network or to establish a more general network control system model is also one of the research hotspots in the next step.

Data Availability

This article does not cover data research. No data were used to support this study.

Conflicts of Interest

The author declares that there are no conflicts of interest.

Acknowledgments

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