A Review of Integrated Control Technology of Tension Stringing Equipment in Transmission Line Erection

ABSTRACT

The comprehensive control technology of tension stringing equipment for transmission line erection is a method that uses modern information technology, communication technology, automation technology and other means to remotely control and monitor the state of the tensioning equipment, and realize the acquisition and control of the main working state of the tensioner, as well as real-time monitoring and control. This method has important roles and values in improving the operation efficiency and reliability of the tensioning equipment, reducing the construction cost and risk, ensuring the quality and safety of the erection construction, etc. This paper reviews the research status and progress in this field, mainly introduces the research achievements in three aspects: online monitoring and intelligent control system of tensioning equipment, control strategy based on nonlinear control technology, and control strategy based on fuzzy logic, as well as their roles in improving the machine performance and safety. This paper also analyzes the problems and challenges in this field, and puts forward the future development direction. This paper provides a valuable reference for the researchers and engineers in this field, and also provides some inspiration and suggestions for the future research or exploration in this field.

Keywords: Tension stringing equipment; integrated control technology; nonlinear control strategy; fuzzy logic control strategy; Online monitoring, intelligent control system.

1. INTRODUCTION

Transmission lines are important components of the power system, they are responsible for delivering the electric energy generated by the power plants to various load centers. Transmission line construction is an important and complex link in the power grid construction, it involves multiple professional fields, such as civil engineering, mechanical engineering, electrical engineering, etc. The most critical and difficult step in the transmission line construction process is the erection construction.

The tensioning equipment for erection construction refers to the puller and tensioner used in the transmission line construction process. [1] The puller is used to pull the conductor, making it align along the tower, the tensioner is used to apply a certain tension to the conductor, making it reach the prescribed tightness. The control technology of the tensioning equipment is an important factor affecting the quality and efficiency of the transmission line erection construction, it involves the coordinated control of multiple subsystems such as the puller, tensioner, conductor, etc., as well as the precise control of the state parameters such as conductor tension, speed, position, etc.

According to the China Electric Power Development Report 2020, China’s total electricity consumption reached 7.14 trillion kWh in 2019, an increase of 4.5% year-on-year, of which industrial electricity consumption accounted for 67.5%. To meet the electricity demand of various regions, industries and levels, China’s power grid construction scale is expanding, and the total length of transmission lines reaches 1.206 million kilometers. To improve the quality and efficiency of power grid construction, State Grid Corporation of China proposed the “intelligent, digital and platform” construction development strategy, requiring the extensive application of information technology, communication technology, automation technology and other modern scientific and technological means in transmission line erection, to achieve intelligent management and control of the construction process. Integrated control of tensioning equipment is an innovative technology that meets this strategic requirement and has important application value in transmission line erection.

In order to understand the research status and progress of the comprehensive control technology of tensioning equipment, this paper reviews the related literature. This paper mainly focuses on the following three aspects of literature: (1) online monitoring and intelligent control system of tensioning equipment; (2) control strategy based on nonlinear control technology; (3) control strategy based on fuzzy logic. This paper classifies the literature into four categories according to their content and contribution: (1) literature that designed and implemented the online monitoring and intelligent control system of tensioning equipment; (2) literature that proposed and verified the control strategy based on nonlinear control technology; (3) literature that proposed and verified the control strategy based on fuzzy logic; (4) literature that comprehensively applied various control technologies and methods. This paper briefly introduces each category of literature, and gives their main features and advantages. This paper also compares and analyzes each category of literature, and gives their main differences and limitations. This paper finally summarizes the results of the literature review, and points out the problems and challenges in this field.

2.ONLINE MONITORING AND INTELLIGENT CONTROL SYSTEM OF TENSIONING EQUIPMENT

The online monitoring and intelligent control system of tensioning equipment is a method that uses network, controller, state monitoring, signal processing and other technologies and theories to remotely control [2]and monitor the state of the tensioning equipment, and realize the acquisition and control of the main working state of the tensioner, as well as real-time monitoring and control. This method can improve the operation efficiency and reliability of the tensioning equipment, reduce manual intervention and misoperation, and lower the construction cost and risk.

There have been many research achievements in this aspect. For example, Wang Shiyang et al. [3] designed a remote control system for power grid tensioning equipment based on intelligent control, analyzed the main characteristics of power grid tensioning equipment data, processed the data in power grid tensioning equipment by adaptive wavelet denoising method, effectively eliminated the noise and oscillation phenomenon of the equipment. The system not only has good data preprocessing ability, but also has fast response speed and high precision control results[3]. Li Yuanming [4] designed a SAQ-250 traction machine remote controller, which consists of wireless communication module, single-chip microcomputer module, display module, key module, etc. The wireless communication module is used to realize data transmission and communication with the traction machine, the single-chip microcomputer module is used to realize the function logic control of the remote controller, the display module is used to display the working state and parameter setting of the remote controller, and the key module is used to realize the operation input of the remote controller. The remote controller realizes the remote control of the traction machine functions such as speed, steering, braking, etc. by wireless communication technology, and has functions such as automatic cruise, speed lock, fault detection, etc. The remote controller verified its effectiveness and reliability by simulation and experiment, and can improve the operation efficiency and safety of the traction machine[4].

In addition to the above two examples, there are some other researchers who have also made contributions in this aspect. For example, Liu Jianfeng et al. [5] designed a centralized intelligent tensioning field integrated system, which realized the coordinated control of various subsystems of tensioning equipment (such as wire rope tensioner, traction machine, etc.) by using a control strategy based on nonlinear dynamic control technology[5]. Hong Qiaozhang [6] conducted a research on intelligent upgrade of automatic control of tensioner, and proposed a low-risk, high-efficiency and economical technical route. The route includes the following steps: (1) intelligently transform the existing tensioner, add wireless communication module, sensor module, controller module, etc.; (2) develop a remote monitoring system for tensioner based on cloud platform, realize remote data acquisition, analysis, display and control of tensioner; (3) develop an optimization control algorithm for tensioner based on artificial intelligence, realize adaptive adjustment and optimization of tensioner; (4) develop a fault diagnosis and early warning system for tensioner based on big data, realize fault detection, diagnosis, early warning and recovery of tensioner. The route verified its feasibility and effectiveness by implementation, and can improve the intelligence level and operation performance of tensioner[6]. Gao Youliang et al. [7] designed a remote state monitoring system for tensioning equipment based on multi-scale convolutional network. The system realized the construction of hardware execution environment by setting terminal processor and wireless communication module. In terms of software, it realized the construction of software execution environment by protocol porting processing and serial communication subroutine. The experimental results show that the monitoring system can effectively reduce the difference between valley electricity degree and flat electricity degree values of tensioning equipment and standard electricity output results, which plays a great role in maintaining the long-term stable operation of equipment structure[7] . Hou Jianming et al. [8] developed a “tensioner collaborative intelligent control system”, which combines dual-machine position and wireless video surveillance system and other components, and uses Profibus bus connection. It is applied to transmission line conductor tension laying construction. It can transmit data within 50m range, thus achieving the goal of remote control[8].

These research achievements show that online monitoring and intelligent control system of tensioning equipment is an effective method that can improve operation efficiency and reliability of tensioning equipment reduce construction cost and risk ensure quality and safety of erection construction. However there are still some problems and challenges in this area such as how to improve coordination compatibility among various subsystems how to develop more advanced more intelligent more flexible more robust more adaptive more energy-saving more environmentally friendly control strategies algorithms how to develop more concise more efficient more stable more reliable more safe more easy-to-use more easy-to-maintain more easy-to-expand more easy-to-integrate control systems how to develop more practical more convenient more friendly more intuitive more interactive more intelligent more personalized more diverse human-machine interfaces how to develop more advanced more comprehensive more accurate more real-time more fault diagnosis more fault early warning more fault recovery systems that can intelligently deeply analyze optimize various data of tensioning equipment. These problems challenges require researchers engineers in this field to constantly explore innovate to improve level application scope of comprehensive control technology of tensioning equipment.

3. MAIN CONTROL STRATEGIES AND METHODS OF INTEGRATED CONTROL OF TENSIONING EQUIPMENT

3.1 Control Strategies Based on Nonlinear Control Technology

Nonlinear control technology refers to the control methods that design and implement effective, stable, robust and reliable performance indicators for nonlinear dynamical systems, such as feedback linearization, variable structure control, adaptive control and so on. Nonlinear control technology has the advantage of overcoming the nonlinear characteristics and uncertainties of the system, and realizing the precise tracking and adjustment of the system state and output in the integrated control of high-voltage line traction and tensioning machine. This method can improve the dynamic response and anti-interference ability of the tensioning equipment, reduce the fluctuation and overshoot of the line tension, and ensure the quality and safety of the line erection.

At present, many research achievements have been made in this aspect. For example, Xue Hua [9] proposed a decoupling control method based on robust disturbance observer for ACES feedback linearization. Aiming at the nonlinear characteristics of ACES, the exact feedback linearization control method was adopted to design the state transformation matrix, the feedback linearization control law and the ACES nonlinear model were jointly observed, which could be equivalent to a completely linearized object, and simple linear control was adopted. The experimental results show that the proposed method has the characteristics of simple structure, good dynamic performance, wide stability domain and strong robustness[9] . Ding Ming et al. [10] introduced radial basis function neural network (RBFNN) identification for the control system and proposed an adaptive feedback linearization control strategy. First, the nonlinear model of the system was established. Then, based on RBFNN identification, an adaptive controller was designed by using feedback linearization. Finally, simulation analysis under external force disturbance was carried out by using MATLAB/Simulink. The results show that compared with the classical proportional coefficient-integral coefficient-differential coefficient (PID) and sliding mode control, the new controller has significantly improved control accuracy and anti-interference ability[10]. Lu Yi et al. [11] combined the characteristics of variable structure controller such as strong anti-disturbance performance, fast adjustment speed and simple structure, and proposed a second-order self-disturbance rejection controller based on variable structure controller. First, a system phase trajectory and a variable structure control law were designed, which made the system have stronger anti-disturbance ability and faster adjustment speed. Under the condition of nearly constant bandwidth, the parameters can be adjusted to change the anti-disturbance performance and adjustment time of the system. The stability of the system was proved. The experimental results show that compared with the standard self-disturbance rejection controller using PD control for tensioning equipment, the controller is better in adjustment time, anti-disturbance performance and parameter tuning[11]

These research members mainly focused on how to propose and verify control strategies based on nonlinear control technology to overcome the nonlinear characteristics and uncertainties of tensioning equipment dynamic model, and realize coordinated control of various subsystems of tensioning equipment (such as traction machine, tensioner, conductor, etc.). Their research methods usually adopt feedback linearization, variable structure control, adaptive control and other methods to realize accurate tracking and adjustment of tensioning equipment state and output. Their main feature is to use mathematical theory and simulation experiment to prove the effectiveness and robustness of control strategy. The results show that the main advantages of these methods are that they can improve the dynamic response and anti-interference ability of tensioning equipment, reduce conductor tension fluctuation and overshoot phenomenon, ensure erection construction quality and safety.

3.2 Control Strategies Based on Fuzzy Logic

Fuzzy logic is a mathematical theory based on fuzzy sets and fuzzy inference, which can deal with uncertainty, fuzziness and imprecision, and has the advantages of natural language description, knowledge representation and reasoning ability. The advantage of fuzzy logic in the comprehensive control of high-voltage line traction tensioner is that it can use expert experience and human language to establish fuzzy control rules for tensioning equipment, and realize fuzzy inference and control of system state and output. This method can improve the adaptability and flexibility of tensioning equipment, reduce the dependence on the accurate model of the system, and ensure the quality and safety of erection construction. There have been many research achievements in this aspect.

For example, Zhang Xiaoyan et al. [12] proposed a comprehensive control scheme for high-voltage line traction tensioner based on fuzzy logic, by simplifying the dynamic model of high-voltage line traction tensioner into a second-order system, and using fuzzy logic controller to realize fuzzy inference and control of system state and output. The scheme verified its effectiveness and flexibility by simulation and experiment, which can ensure that the high-voltage line traction tensioner reaches the expected goal in the erection process, and improves the safety of erection construction[12] . Zhang Zongming [13] applied fuzzy logic control theory to the method of traction machine control system and verified the effectiveness of control algorithm. Based on MATLAB, he first established the model of fuzzy controller, obtained the spatial mapping relationship between input and output. Then he established the model, connected to form a closed-loop control loop, and carried out simulation calculation on this basis, analyzing the influence of control algorithm on vehicle power performance. The simulation results show that the fuzzy logic control algorithm has good response characteristics and robustness[13].

These research members mainly focused on how to propose and verify control strategies based on fuzzy logic, to use expert experience and human language to establish fuzzy control rules for tensioning equipment, and realize coordinated control of various subsystems of tensioning equipment (such as traction machine, tensioner, conductor, etc.). They usually use fuzzy logic controller to realize fuzzy inference and control of tensioning equipment state and output. Their main feature is to use fuzzy sets and fuzzy inference to deal with uncertainty, fuzziness and imprecision, etc., and have the advantages of natural language description, knowledge representation and reasoning ability. The results show that their main advantages are that they can improve the adaptability and flexibility of tensioning equipment, reduce the dependence on the accurate model of the system, ensure erection construction quality and safety.

3.3 Comprehensive application of multiple control technologies and methods

These control methods usually use multiple methods such as nonlinear control technology, fuzzy logic control technology, neural network control technology, genetic algorithm optimization technology, etc., to realize the coordinated control of multiple state parameters such as speed, position, tension, temperature, etc. of tensioning equipment, as well as the optimization control of multiple performance indicators such as stability, robustness, reliability, energy saving, etc. of tensioning equipment.

There have been many research achievements in this aspect. For example, Tan Longbiao [14] proposed an improved particle swarm algorithm to optimize the PID tension controller parameters for improving the stability of the tension control system, and analyzed and improved the tension controller algorithm of the system. Aiming at the “premature” phenomenon, poor local search ability and poor population diversity of particle swarm algorithm, he introduced crossover operator and mutation operator and linearly decreasing inertia weight to enhance the global search ability of the algorithm. In order to enhance the anti-disturbance ability of the tension control system, he used self-disturbance rejection controller (ADRC) as the tension controller. He used an improved sparrow search algorithm to optimize the self-disturbance rejection controller (ADRC) parameters. Aiming at the shortcomings of sparrow search algorithm that it searches for optimal solution by jumping, easily converges to origin and “premature”, he proposed to introduce the velocity operator of particle swarm algorithm, improve the iteration formula of sparrow search algorithm and improve the optimization ability of the algorithm. He also used crossover operator and mutation operator to enhance population diversity. The results show that this research method has good effects in online speed and control tension[14]. Zhu Qiangqiang [15] carried out a more in-depth study on pure feedback nonlinear control system based on neural network. He combined nonlinear intelligent control technology, practical finite/fixed time intelligent tracking control algorithm and predefined time intelligent tracking control algorithm for pure feedback nonlinear system. Furthermore, he solved the adaptive tracking control problem of pure feedback nonlinear multi-agent system under event-triggered mechanism, and proposed an intelligent tracking control algorithm based on heterogeneous Laplacian matrix design method[15].

Their main feature is to use the advantages of various technologies and methods to complement each other and improve the system’s comprehensive performance. The main advantage of these control methods is that they can realize comprehensive management and control of tensioning equipment, and meet different working environment and task requirements.

4. RESULTS AND DISCUSSION

According to the analysis of the research status and progress of the comprehensive control technology of tensioning equipment, it is divided into four categories according to their content and contribution, and their main features and advantages are given. It also compares and analyzes each category, and gives their main differences and limitations. The results of the literature review are shown in Table 1.

Table 1. Summary of literature review on comprehensive control technology of tensioning equipmen

Category	**Content**	**Advantage**	**Difference**	**Limitation**
Online monitoring and intelligent control system	Use network, controller, state monitoring, signal processing and other technologies and theories to remotely control and monitor the state of the tensioning equipment, and realize the acquisition and control of the main working state of the tensioner, as well as real-time monitoring and control.	Improve the operation efficiency and reliability of the tensioning equipment, reduce manual intervention and misoperation, lower the construction cost and risk.	Compared with other categories, it focuses more on the hardware design and software development of the control system, rather than the control strategy or algorithm.	There may be problems such as complexity and uncertainty of the system, as well as delays and instability of the network, which affect the performance and efficiency of the system.
Control strategy based on nonlinear control technology	Use feedback linearization, variable structure control, adaptive control and other methods to overcome the nonlinear characteristics and uncertainties of tensioning equipment dynamic model, and realize accurate tracking and adjustment of tensioning equipment state and output.	Improve the dynamic response and anti-interference ability of tensioning equipment, reduce conductor tension fluctuation and overshoot phenomenon, ensure erection construction quality and safety.	Compared with other categories, it focuses more on the theoretical analysis and verification of the control strategy, rather than the practical application or implementation of the control system.	It still needs to simplify or approximate the system model or parameters, which may cause errors or deviations in the actual operation.
Control strategy based on fuzzy logic	Use expert experience and human language to establish fuzzy control rules for tensioning equipment, and realize fuzzy inference and control of system state and output.	Improve the adaptability and flexibility of tensioning equipment, reduce the dependence on accurate model of system, ensure erection construction quality and safety.	Compared with other categories, it focuses more on the knowledge representation and reasoning ability of the control strategy, rather than the mathematical rigor or precision of the control algorithm.	It still needs to determine the membership function or fuzzy rule base of the system, which may be subjective or ambiguous in some cases.
Comprehensive application of multiple control technologies and methods	Use multiple methods such as nonlinear control technology, fuzzy logic control technology, neural network control technology, genetic algorithm optimization technology, etc., to realize coordinated control of multiple state parameters such as speed, position, tension, temperature, etc., as well as optimization control of multiple performance indicators such as stability, robustness, reliability, energy saving, etc.	Realize comprehensive management and control of tensioning equipment meet different working environment task requirements.	Compared with other categories it integrates multiple technologies methods rather than using single one.	It still needs to deal with complexity compatibility coordination among various technologies methods which may increase difficulty cost implementation maintenance.

6. CONCLUSION

This paper reviews the research status and progress of the comprehensive control technology of tensioning equipment, mainly introduces the research achievements in three aspects: online monitoring and intelligent control system of tensioning equipment, control strategy based on nonlinear control technology, and control strategy based on fuzzy logic, as well as their roles in improving the operation efficiency and reliability of tensioning equipment, reducing the construction cost and risk, ensuring the quality and safety of erection construction.

This article also compares and analyzes various types of literature, and points out the problems and challenges in this field, providing research directions for researchers who want to study the control of tensioning devices in the future. It also emphasizes that the comprehensive control technology of tensioning devices is an innovative technology with important significance and value, and has a broad application prospect in the construction of transmission line erection. However, there are still some problems and challenges in this aspect, which require the researchers and engineers in this field to constantly explore and innovate, to improve the level and application scope of the comprehensive control technology of tensioning devices. Here are some possible development directions and challenges:

Integrate multiple control technologies and methods to realize comprehensive control of tensioning equipment with multiple objectives, multiple levels, multiple scenarios, and multiple constraints. For example, combine nonlinear control technology, fuzzy logic control technology, neural network control technology, genetic algorithm optimization technology, etc., to realize coordinated control of multiple state parameters such as speed, position, tension, temperature, etc., as well as optimization control of multiple performance indicators such as stability, robustness, reliability, energy saving, etc.

Develop more advanced, more intelligent, more flexible, more robust, more adaptive, more energy-saving, more environmentally friendly control strategies and algorithms to realize accurate tracking and adjustment of tensioning equipment. For example, use artificial intelligence technologies such as deep learning, reinforcement learning, transfer learning, etc., to realize autonomous learning and self-adjustment of tensioning equipment to adapt to different working environments and task requirements.

Develop more concise, more efficient, more stable, more reliable, more safe, more easy-to-use, more easy-to-maintain, more easy-to-expand, more easy-to-integrate control systems to realize efficient management and control of tensioning equipment. For example, use VoIP performance in wireless networks [16] to realize remote voice communication and command transmission of tensioning equipment to improve the collaboration efficiency and safety of construction personnel.

Develop more practical more convenient more friendly more intuitive more interactive more intelligent more personalized more diverse human-machine interfaces for control systems to realize convenient operation and monitoring of tensioning equipment. For example use human-computer interaction technologies such as voice recognition image recognition gesture recognition touch screen etc. to realize natural language description graphical display gesture manipulation etc. functions for tensioning equipment to improve the usability and user experience of the control system.

Develop more real-time more comprehensive more accurate more real-time more fault diagnosis more fault early warning more fault recovery systems that can intelligently deeply analyze optimize various data of tensioning equipment to realize efficient monitoring maintenance of tensioning equipment. For example use data technologies such as data mining data analysis data visualization etc. to realize various functions such as collection storage processing analysis display etc. for various data (such as working state data operation parameter data environmental factor data etc.) of tensioning equipment to improve the monitoring ability fault handling ability of the control system.

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