Artificial Intelligence Technology in Flexible DC Transmission Monitoring System

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Abstract. The flexible DC transmission system is a grand project being practiced by the State Grid Corporation of China and China Southern Power Grid. The flexible DC transmission monitoring system is particularly important, and the use of artificial intelligence related technologies to solve such problems is considered an effective solution. This article mainly introduces the application analysis of artificial intelligence technology in the flexible DC transmission monitoring system. This paper uses artificial intelligence technology to perform real-time detection on the flexible DC transmission monitoring system and establishes the SC-HVDC system model. The model is solved by neural network, and the status of the transmission system is evaluated, and the model is revised using historical data to improve the accuracy of the evaluation of the transmission safety status. The experimental results of this paper show that the SC-HVDC system model reduces the accident rate of flexible HVDC transmission by 16%. Finally, artificial intelligence technology has a good effect on improving the stability and safety of the flexible DC transmission monitoring system.

Keywords: Artificial Intelligence, Flexible Direct Current Transmission, SC-HVDC System Model, Neural Network

1. Introduction
In today's world, almost all human needs, food, shelter and transportation are inseparable from electricity. The flexible DC transmission system has become an important energy source to support social development [1-2]. With the increasing depletion of traditional petrochemical energy, electric energy is replacing traditional petrochemical energy. This has also led to a sharp increase in the current society’s demand for electrical energy [3-4]. In order to ensure economic growth and ensure the production and life of the people, the power grid must be continuously expanded and strengthened. While ensuring the power supply capacity, the quality of power supply is guaranteed [5-6].

With the depletion of traditional petrochemical energy and air pollution caused by petrochemical energy, people are increasingly developing and using clean energy such as electricity. Akerkar R believes that traditional petrochemical energy vehicles are gradually being replaced by electric vehicles, and today's electric vehicle products (such as Tesla and BYD) have been deeply recognized by consumers [7]. Levy feels that in order to cope with the depletion of petrochemical energy,
developed countries such as Europe, the United States and Japan have announced that they will stop manufacturing traditional health vehicles after 2030. This impact will be visible and will be replaced by traditional energy vehicles. Energy is increasing [8]. At present, the supply and consumption of most power sources in the world is based on the AC method, and the generation, transmission and distribution of AC-based power is also the main current [9-10]. However, at the end of electrical appliances, the final voltage of most electrical appliances is direct current, such as computers, communication equipment, etc., and various electrical chips in them usually use direct current. When converting AC to DC, there is still conversion efficiency, so most of the electrical energy is lost. Under the current loop, the power loss caused by this AC-DC conversion is unavoidable, and the loss is also very large [11-12]. The innovation of this paper is to put forward the application analysis of artificial intelligence technology in flexible DC transmission monitoring system. According to the monitoring system of flexible HVDC transmission, the ideal straight line and safety threshold range of HVDC transmission are calculated, which are used as the basis for judging the safety of transmission channels, and the calculation of SC-HVDC system model is established by neural network algorithm. There have been many researches on the additional damping control of traditional HVDC flexible transmission, but from the experience of actual engineering feedback, it is often limited due to insufficient reactive power support of the receiving end system.

2. Artificial Intelligence Technology in Flexible Dc Transmission Monitoring System

2.1. Flexible Dc Transmission Monitoring System

In response to the new situation of large-area DC transmission grid interconnection, China's power industry should closely follow the pace of scientific and technological development and actively use new technologies, new equipment, and new control ideas, in order to form a combined force to ensure the dynamic security and stability of the grid. Traditional energy management the system EMS enables dispatchers to understand the current conditions of the system and plays a pivotal role in production practice. However, the SCADA system has a slow data update rate and the most fatal defect of the time scale is that it cannot obtain real-time performance reflecting the dynamic characteristics of the system. Indicators, operators need to rely on accumulated experience to make judgments about the state of the system. With the development of advanced technologies such as the Global Position System (GPS), optical fiber communication technology, and microprocessors in recent years, it is possible to measure phasors across the entire network. Many power grid companies around the world have extensively carried out wide area measurement system (WAM) engineering practice, and have achieved preliminary results. The wide-area measurement system brings new development opportunities for the damping monitoring technology of large-scale interconnected power grids. Real-time synchronized phasor information makes the operating status of the power system more intuitive. Based on online monitoring, the dynamic analysis of the power system can be It is hoped to move from traditional "offline" simulation to "online" real-time analysis and control.

The active power modulation control method of flexible direct current transmission uses wide-area signals as feedback control input to form an inter-regional low-frequency oscillation damping controller. The wide-area signal selection uses the extended damping ratio method proposed in Chapter 2, and the pole configuration method is used to tune the parameters of the damping controller. The results of this chapter prove that it is feasible to use the flexible DC transmission resistance to oscillate.

Compared with traditional HVDC, flexible DC transmission has the following technical characteristics

1. Connect scattered small power plants
2. Replace regional small power plants and supply power to remote loads.
3. Build a DC distribution network to supply power to large cities with rapidly increasing power consumption
The standard per unit system reference value of the DC part is selected according to the following principles

\[ V_B \cdot I_B = 3V_B^* \cdot I_B^* \]  

(1)

The relationship between the reference DC voltage and the AC reference voltage is as follows;

\[ V_B^* = V_B^- \cdot \frac{3\sqrt{2}}{m} \]  

(2)

DC transmission line current model;

\[ I_d = \frac{V_{ds} \cos \alpha - V_{ds} \cos \gamma}{R_c + R_L - R_i} \]  

(3)

2.2. Control Principle of Flexible Direct Current Transmission Monitoring System

Multi-terminal DC transmission is connected in parallel. The characteristic of parallel connection is that the adjustment and distribution of power between converter stations is mainly realized by changing the DC current of the converter stations. The adjustable trigger angle of the tap converter is used to change the DC current. The core of MTDC is the voltage source converter. Its basic control methods can be divided into three categories: constant DC control voltage, DC bus voltage control and reactive power transmission to AC Side; constant DC current (power) control, DC current (or power) control and reactive power delivered to the AC side: constant AC voltage control, AC voltage control. The most significant feature of multi-terminal DC transmission is that it can achieve multi-power supply and multi-point power reception, thereby providing a more flexible and fast power transmission method.

The main components of multi-terminal DC transmission include: voltage source converter (VSC), DC transmission line, AC filter, DC filter, control system and control protection system. Since the multi-terminal system adopts the parallel network mode, the power balance and distribution of the entire system are maintained by the DC current of each terminal. Compared with the traditional converter controller, the neural network controller has better dynamic performance, robust adaptive learning ability and other characteristics, which enables the system to obtain better stability and dynamic response characteristics.

3. SC-HVDC System Model of Flexible Dc Transmission Monitoring System

3.1. SC-HVDC System Model

In all DC transmission projects, traditional DC transmission still accounts for the majority, especially in long-distance, high-power transmission, which still has absolute advantages. The establishment of the SC-HVDC system model is of great significance for DC transmission. After a small disturbance occurs in the DC parallel operation system, an increased low-frequency oscillation may occur. The essence of this oscillation phenomenon can be understood from the power imbalance on the generator set rotor. The modulation effect of the HVDC parallel to the AC system is actually to use its fast responsiveness to add a modulation signal that responds to the unbalanced power of the rotor of the unit to its main control, and achieve the effect of reducing the unbalanced power of the rotor through a small modulation of the DC power. In order to suppress the low frequency oscillation, the WFSC control additional signal is applied to the modulation signal input point of the DC main control.

When building the SC-HVDC system model, due to the limitations of the operating principle and operating characteristics of the VSC, the parameters of the main circuit and the design of the controller need to consider some constraints, specifically the following types: (1) Converter reactor The design of the converter reactor is the core component of the system. It is used for the energy exchange
between the converter station and the AC system. Its size is determined by the power operating range, AC current waveform quality and current harmonic limits. (2) Design of the coupling transformer The leakage reactance of the coupling transformer and the phase reactor together provide the commutation reactance, so the leakage reactance of the coupling transformer is also limited by the constraints mentioned above.

DC-side capacitor The DC-side capacitor plays a role in supporting the DC voltage. Its design principles are: (1) Suppress DC voltage fluctuations, that is, when the system has an asymmetric fault, avoid DC voltage fluctuations beyond the given voltage fluctuation range; (2) It can be the rated power of the system Operation provides a certain length of energy storage based on the above principles.

3.2. SC-HVDC System Model for Flexible DC Transmission
(1) Analysis of SC-HVDC system model. Although the existing literature has done certain research on the mathematical models of SC-HVDC system model, such as high frequency and low frequency, these models have not analyzed the dynamic and static characteristics of SC-HVDC system model in detail. In addition, the analysis of transient operating characteristics of the SC-HVDC system model still needs in-depth study.

(2) Research on the control strategy of SC-HVDC system model steady-state operation. A lot of research work has been done in this area, which are basically divided into three categories: linear control, robust control based on linear systems and nonlinear control. Most of these methods consider the mathematical model to be accurate in design, and do not consider the impact of system parameter changes or unmodeled dynamics, so there is a certain lack of robustness of the control system, so research in this area which you can go deep. Research on SC-HVDC system protection strategy, research in this area is relatively weak. Due to the lack of high-voltage DC circuit breakers, the system protection after SC-HVDC system disturbances or faults has become more complicated than AC protection. However, because SC adopts PWM control, its high-speed switching characteristics also enable us to control Means to achieve the purpose of system protection. The key to the problem is what kind of control steps are used to protect the system, that is, the protection strategy. Today, when the issue of renewable energy and power quality is getting more and more attention, DC networks have more advantages than AC networks in connecting renewable energy and power distribution. SC-HVDC system model technology provides technical possibilities for DC networking, so it is meaningful to study multi-terminal VSC-HVDC systems. The current research on this aspect has just started, and its connection structure and control strategy need to be studied in depth. Specific performance is shown in Table 1.

| Working condition | Identify the object | Oscillation frequency | Oscillation damping | Residual amplitude |
|-------------------|---------------------|-----------------------|---------------------|-------------------|
| 100MW             | 1,3 speed difference| 0.623                 | 0.0247              | -1.038            |
| 100MW             | 8, 9 power          | 0.627                 | 0.0262              | -89.501           |
| 100MW             | 1,3 power angle difference | 0.623 | 0.0261 | -92.46 |

4. Neural Network Flexible HVDC Transmission under Artificial Intelligence

4.1. Neural Network Control Analysis
The concepts and principles of intelligent control are mainly proposed for the complexity of controlled objects, environments and tasks, and are closely related to traditional control or conventional control. Intelligent control has different forms and different application fields. Regarding its composition principle, it can be divided into the following categories:

(1) The rule-based intelligence control system uses hidden knowledge in the form of strategies or frames or semantic networks, and uses membership functions in statistics or fuzzy mathematics to deal with uncertainty and knowledge burning, and adopts forward, reversible and Non-monotonic
reasoning or fuzzy reasoning mechanism. According to certain conditions and inputs of the system, formulate the control rules required by the target control system

(2) Control systems based on intelligent neural networks are widely used in the identification, modeling and control of complex systems due to their powerful learning capabilities, self-flexibility and nonlinear neural network processing capabilities.

(3) Intelligent control system based on the combination of fuzzy controller and neural network. The combination of the two will be the direction of the development of intelligent systems. According to the different combination of the two, this type of intelligent control system also has modular intelligent control. The system includes an embedded neural network expert control system and a simulation dedicated neuron system.

Comprehensive consideration of the controllability and observability of the speed difference signal is better than the power angle difference and the branch power difference amplitude-frequency, phase-frequency characteristic identification results and the comparison of the measured results are shown in Figure 1. It can be seen from the figure that when the frequency reaches 0.7hz, both the measured result and the identification result reach the peak.

![Figure 1. Comparison of frequency characteristics](image)

4.2. SC-HVDC System Model Analysis Based on Neural Network

The intelligent control system based on the neural network is also called the intelligent control system based on the connection mechanism. With the development of artificial neural networks (AN), neural networks are increasingly used in all aspects of control. The research of neural network has a history of more than 30 years. Compared with traditional control technology, it has the following characteristics.

Non-linear, neural networks are promising in solving non-linear control problems. The neural network can approach any nonlinear function in theory, and modeling is more economical; parallel distributed processing. The neural network has a highly parallel structure. Due to the distribution and parallel implementation, it has greater fault tolerance and fast processing speed; learning and adaptability. Using the past data records of the system, the network can be trained, the network is capable of identification, and online training can be performed.

Although many SC-HVDC projects have been put into commercial operation around the world, the exploration of science and technology is endless. Research on SC-HVDC technology is still in the ascendant. In the future, the following directions still need in-depth research. Techniques to increase the capacity of SC-HVDC systems; methods to reduce VSC switching losses; research on SC-HVDC system protection strategies. That is, how to use control methods to achieve the purpose of SC-HVDC system protection; the study of multi-terminal SC-HVDC system coordination strategies; the study of SC-HVDC system operation control problems under the condition of asymmetric power grid; the interaction between SC-HVDC system and AC power grid Role of research. The specific results are
shown in Table 2.

**Table 2.** Comparison of Interarea Oscillatory Mode in Different Operation with WFSC

| Trends of communication lines | Disturb | Inter-area oscillation mode | Inter-area oscillation mode(WFSC) |
|-------------------------------|---------|----------------------------|----------------------------------|
|                               |         | Frequency                  | Damping ratio                    | Frequency | Damping ratio |
| 200                           | 8       | 0.547                      | -0.49                           | 0.595     | 8.05         |
| 200                           | 8-9     | 0.545                      | -0.50                           | 0.568     | 7.25         |
| 200                           | 8       | 0.545                      | -0.48                           | 0.579     | 7.51         |

The results in Table 2 show that no matter whether the system is working at the initial operating point or the operating point has a small deviation (transmission power increased by 30MW), the additional WESC control designed shows a good damping effect. Changes in working conditions still maintain good damping characteristics, Which shows that the robust performance of the controller is excellent.

From a control theory point of view, the ability of neural networks to deal with nonlinearities is the most meaningful. The variety and complexity of nonlinear systems have made it impossible to establish a systematic and general theory of nonlinear control system design. For special types of nonlinear systems, there are some traditional methods, such as phase plane method, linearization method, and velocity function method, but they are not enough to solve the nonlinear difficulties faced. Therefore, neural networks will play an important role in modeling nonlinear systems. Neural network can be regarded as a special form of adaptive controller. Through the learning process of the neural network, the combined weight of the network is gradually changed to minimize the error signal between the expected value of the dynamic system and the actual response. Use Fourier analysis tools to analyze the above quantities. The specific results are shown in Figure 2. The DC component reaches the peak value at 75 Hz, and the double component reaches the peak value at 25 Hz. The interphase circulating current is dominated by the DC component and the double frequency component, which is consistent with the composition of the circulating current expressed by the double component.

![Figure 2. Spectral diagram of interphase circulation](image)

**5. Conclusions**

Although this paper has made some research results on the application analysis of artificial intelligence technology in flexible DC transmission monitoring system, there are still many shortcomings. Based on the analysis of the application of artificial intelligence technology in the flexible DC transmission monitoring system, there is still a lot of in-depth content worthy of study. The SC-HVDC system model has many steps that have not been covered due to space and personal
ability. In addition, the actual application effects of neural network algorithms can only be compared with traditional models from the theoretical and simulation levels.

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