Fault Diagnosis Method of AC Transmission Controller Based on PLC Technology

Liping Zhang*
Wuhan Railway Vocational College of Technology, Wuhan, Hubei 430205, China

*Corresponding author e-mail: zhangliping@wru.edu.cn

Abstract. In recent decades, as a clean and efficient secondary energy source in modern society, electricity has unique advantages, is easy to convert, and is suitable for other forms of energy for centralized mass production. This article introduces a special diagnostic technology through PLC technology, which is one of the most eye-catching technologies in today's new technologies, especially the plan to solve operational problems through radio and electrical system controllers. According to the standard and modulate the parameters of the controller system. The experiments in this paper show that the use of particle swarm algorithm for fault diagnosis of the controller can greatly simplify the complexity of the power grid, and can well control the power flow of the power grid; it can increase the transmission capacity of the network 30%; Avoid the overload phenomenon of parallel operation lines; improve the static and transient stability of the AC transmission controller system.

Keywords: PLC Technology, AC Transmission Controller, Fault Diagnosis, Particle Swarm Algorithm

1. Introduction

1.1. Background and Meaning
It is well known that the ability to provide AC transmission control is more difficult than power generation and distribution. The natural power flow in the network changes with the load, which leads to excessive power loss or endangers safe operation [1, 2]. The reduction of transmission power increases the load on the existing transmission line, and the contradiction of insufficient transmission capacity becomes more and more common [3, 4]. At the same time, due to various social, environmental and economic reasons, the construction of new power plants and transmission networks for the power grid is limited, which has led to one of the main problems of the power system in the twentieth century; how to maximize its potential. The transmission rate is increasing in the use of equipment transmission network [5, 6].

1.2. Related Work
According to different research ideas, fault diagnosis research is usually divided into two categories [7, 8]. One is to use fault detection equipment or detection tools to detect the object to be tested and
determine whether its working state is abnormal [9, 10]. If the working state of the object under test is abnormal, the source of the fault of the object under test needs to be locked. The other is to judge the working status of the target object by means of analytical redundancy. If the working status of the target object is abnormal, it is necessary to further distinguish the fault category of the target object to determine the source of the fault [11, 12].

1.3. Innovation of PLC Technology Fault Diagnosis Method

In the past 30 years, fault diagnosis research has always been a hot research direction of control theory. Scholars from different countries have published their research results on fault diagnosis in academic conferences or journals with significant influence. Generally speaking, according to the different technical characteristics of fault diagnosis, fault diagnosis methods can be roughly classified into the following three categories

(1) Fault diagnosis method based on signal processing

The fault diagnosis method based on signal processing is to analyze and calculate the mean value, frequency, variance and other characteristic values of the signal on the basis of mastering the detected signal, and judge whether the actual characteristic parameter value of the signal exceeds the threshold value of the normal system parameter.

(2) Fault diagnosis method based on analytical model

The fault diagnosis method based on the analytical model is based on the complete or partially complete dynamic model of the established system, calculates the characteristic parameter residuals between the expression results of the model and the actual state of the system, and defines the current work of the system according to the characteristics of the residuals status. The dynamic model can usually be expressed by linear or nonlinear differential equations. If the residual value of the characteristic parameter between the expression result of the model and the actual state of the system is too high, indicating that the actual operating state of the system does not match the model, it means that the system is malfunctioning.

(3) Knowledge-based fault diagnosis method

For some specific systems, people usually have established a more systematic prior knowledge based on their understanding. By comparing the inference result based on prior knowledge with the actual operation result of the system, it can be judged whether the system has failed. Knowledge-based fault diagnosis methods mainly include neural network-based fault diagnosis methods and pattern recognition-based fault diagnosis methods. Generally speaking, knowledge-based fault diagnosis methods do not rely on the mathematical model of the system. This method is used in fault diagnosis. Different from the method based on analytical model, it has extremely high robustness and is especially suitable for solving the fault diagnosis problem of complex system.

2. AC Transmission Controller

Fault data location and mining methods in AC transmission controllers mainly include clustering algorithm-based location and mining methods, ant colony algorithm-based location and mining methods, and genetic algorithm-based location and mining methods. The most commonly used method is the fault data location and mining method in the flexible AC transmission controller based on the clustering algorithm.

2.1. Fault Location of PLC Technology

The fault data location and mining method of the AC transmission controller is because it has important application value in improving product quality and reducing operating costs. The algorithm has the flexibility of an AC conversion controller and can find fault data. The linear control system has Features of small overshoot and high control accuracy.

The simulation results show that the improved algorithm can improve the accuracy and efficiency of fault data location and mining in the flexible AC transmission controller, and it has good application value.
when the AC transmission controller is in normal operation, the AC current is equally distributed among the three phase units, and the AC current of each phase unit is $I_{dc}/3$. In addition, the reactor values of the upper and lower arms of each unit are equal, so the AC current $i$ is equally divided between the upper and lower bridge arms, and the current of the j-th phase upper and lower bridge arms is.

$$\{J_{pu} = \frac{I_{dc}}{3} + \frac{i_{vj}}{2}, \ j = a, b, c \}$$

### 2.2. Failure Data Analysis

A new method of fault diagnosis based on plc. Considering that when measuring the actual system output, random noise interference may be introduced into the system, so before fault diagnosis, the measured system output needs to be denoised. In this paper, a new plc method is used to filter the system output, and the process of proof of stability is given. Then use the extended state observer ESO in plc to observe the system state, and finally construct a new residual equation for fault diagnosis. The fault diagnosis method based on the ESO idea in the plc proposed in this paper can not only detect the faults in the system, but also effectively estimate the fault function.

This can be said to be a great innovation in the field of fault diagnosis. A signal can not only be used for diagnosis and fault estimation, but also has high real-time performance.

### 2.3. Fault Diagnosis Sensor Design

In order to clarify the fault diagnosis method designed in this paper, without loss of generality, here is a single-input single-output system as an example. In order to detect the change of the system output measurement value, we use n sensors to measure the system output. Construct n state observers of the following form:

$$\hat{y}(t) = C \hat{X}_r(t)$$

For a class of nonlinear stochastic systems, a new fault detection method based on plc technology is proposed. We use a nonlinear observer to estimate the state of the system and generate residuals for detecting faults. If the measured value output by each sensor is disturbed by noise, the estimated state of the system will also be affected. Therefore, we use a sensor to filter out disturbances in the estimated state of the disturbed system. This method is used in the fault detection of nonlinear stochastic systems. The simulation results in this article prove the effectiveness of this improved method.

### 3. PLC Technology Detection Failure Experiment

Because each node of AC power transmission has corresponding requirements for data collection, communication and processing, it uses a distributed I/O network composed of s7-300 series PLC. In this kind of network, the main control PLC can perform periodic data exchange with distributed peripherals through high-speed serial lines; the main control PLC can read or output the equipment information in each carriage.

#### 3.1. Fault Diagnosis Organization Block

The S7-300 series PLC has a set of OB blocks with complete functions, including multiple interrupt OB blocks that provide error and fault self-diagnosis functions. When the system detects a certain type of error, it will automatically call the OB block related to that type of error. According to the return parameters of these OB blocks, you can know the specific information of the fault, such as the type
and location, and execute it. The programmed program commands alarm or processing; PROFIBUS-DP network has 3 levels of diagnostic functions: station level, module level, channel level, that is, specific error information of these 3 levels can be obtained through diagnosis. At the same time, when an error is detected, the system can maintain the running mode by calling the interrupt organization block. This provides a convenient and effective way for users to query and troubleshoot, and also ensures the safety of the system during the entire process of detecting and eliminating the fault. Specific modules are shown in Table 1

Table 1. Parameters of single phase experimental platform

| parameter                          | application fields of developing | value   |
|------------------------------------|---------------------------------|---------|
| DC Bus Voltage                     | U                               | 450V    |
| Bridge arm inductance              | L                               | 12mH    |
| Turn ratio capacitance value of sub module | N                               | 12:80   |
| Sub module capacitor voltage       | C                               | 4.7mF   |
| Rated frequency                    | F                               | 50Hz    |

3.2. PLC Fault Diagnosis Organization Investigation

These organization blocks can be divided into three types: hardware interrupt response to signals from input and output modules; synchronous response to program instruction execution errors; asynchronous response to CPU operation or abnormal module status. Among them, asynchronous errors have the highest priority; while synchronous errors remain the same as the interrupted OB block and can be interrupted by high-priority events.

In most cases, if the system needs to call a specific function block, and this function block has not been downloaded by the user or no effective program is written in it to deal with the fault, the system will switch to STOP mode and will not recover until the fault is eliminated and restarted.

Therefore, before using interrupt organization blocks, you must copy them from the system library to the corresponding project and ensure that they are downloaded to the processor of the corresponding station. It should be noted that the type and number of OB blocks supported by each CPU are not same, so we must first know which OB blocks are supported by the CPU model used. In the maglev train system, the CPU315-2DP used can support the following OB blocks: OB40, OB80, OB81, OB82, OB85, OB86, OB87, OB121 and OB122.

4. Technical Analysis of Particle Swarm Optimization Algorithm for AC Transmission Controller

4.1. Particle Swarm Algorithm

The Particle Swarm Optimization (PSO) optimization algorithm is a global optimization algorithm proposed by Eberhart et al. to simulate the predation behavior of a flock of birds. The idea is to treat each individual as a particle; the information carried by each individual as the particle's own attributes and state, and uses the information sharing between particles to obtain the optimal solution within the entire problem solving space.

As a simple, effective and easy-to-implement swarm intelligence algorithm, particle swarm algorithm has attracted wide attention worldwide. At present, the particle swarm algorithm is mainly used to optimize the parameters of the system model and has penetrated into various engineering fields. Figure 1 shows the trend of particle swarm optimization in the iteration.
4.2. Principle of Particle Swarm Optimization
The particle swarm algorithm is designed based on the predation behavior of birds. In this algorithm, each particle represents a group of feasible solutions, and the activity range of each particle in the particle swarm constitutes a multi-dimensional particle search space. Table 2 shows the particle acceleration level, the number of particles and the inertia weight.

Table 2. Performance comparison of the two models

| DC line | DC line resistance | audio Preset active current at sending end |
|---------|--------------------|-------------------------------------------|
| Level 1 | 3000               | 1500                                      |
| Level 2 | 1800               | 900                                       |
| Level 3 | 1800               | 800                                       |
| Level 4 | 1800               | 700                                       |
| Level 5 | 1800               | 600                                       |

4.3. Main Parameters of Particle Swarm Algorithm
The main parameters of the particle swarm algorithm include: the number of particle swarm particles, particle acceleration coefficient and inertia weight.

Different parameter values will cause the performance of the algorithm to vary greatly. In order to design the algorithm parameters reasonably, this article refers to a large number of relevant documents and materials, and on the basis of repeated experiments, summarizes certain parameter value standards.

1) Number of particles in particle swarm
   According to the actual use experience of the particle swarm algorithm, if the number of particles in the particle swarm is too small, the particle swarm algorithm is prone to instability, and there is a risk of falling into a local minimum; if the number of particles in the particle swarm is too large, it will increase the complexity of the algorithm. Thereby increasing the iteration cost and reducing the convergence efficiency. Considering the lack of a theoretical basis for determining the number of particles in a particle swarm at this stage, in the actual application of the algorithm, the number of particles in a particle swarm is generally determined according to the use experience and actual needs.

2) Particle acceleration coefficient

Figure 1. The curve of optimal individual fitness
When calculating the speed update value of the particles, the acceleration coefficients $c_1$ and $c_2$ of the particles need to be used. Both indicate that the acceleration weights when the particles are close to their optimal position and close to the global optimal position are two non-negative constants. When the acceleration coefficient is set to a small value, the particles can only search in an area far away from their optimal position and the global optimal position, resulting in low algorithm iteration efficiency; when the acceleration coefficient is set to a large value, the particles will be It has a faster speed and there is a risk of crossing the optimal position.

(3) Inertia weight

The size of the inertia weight has a significant impact on the optimization ability of the particle swarm algorithm. Related experiments show that if the inertia weight is larger, the algorithm's global optimization ability is stronger, if the inertia weight is smaller, the algorithm's local optimization ability is stronger, but it is about how to find the balance between local optimization and global optimization Point, choose the most appropriate inertia weight, so far there is no mature theoretical guidance. The result is shown in Figure 2:

![RMS waveform of AC bus voltage at merging point](image)

**Figure 2.** RMS waveform of AC bus voltage at merging point

When the time is between 0.3 and 0.5, the inertia weight reaches its peak value, and when it is less than 0.3 and greater than 0.5, it decreases sequentially.

5. Conclusions

The interrupt organization block provided in this experiment can realize the diagnosis and processing of most faults, which is of great significance for ensuring the reliability and safety of the system; moreover, if the system has more detailed requirements, integrate this function with other diagnostic methods application can be more complete; the particle swarm method is used to analyze the faults that cannot cause the interruption of the organization block call. This ensures the accuracy of the diagnosis of the AC transmission controller P to a greater extent, and can be detected and eliminated in time when the failure occurred. Combining plc technology and particle algorithm has great advantages for the failure analysis of AC transmission controllers.

References

[1] Wang S, Wang J B. Robust sensor fault diagnosis and validation in HVAC systems. Transactions of the Institute of Measurement and Control, 2016, 24(3):269-370
[2] Jiang W, Wei B, Xie C, et al. An evidential sensor fusion method in fault diagnosis. Advances in Mechanical Engineering. 2016;83(4):77-299.

[3] Lu C, Wang Z Y, Qin W L, et al. Fault diagnosis of rotary machinery components using a stacked denoising autoencoder-based health state identification. Signal Processing. 2017;130(Jan):377-388.

[4] Li Y, Xu M, Wang R, et al. A fault diagnosis scheme for rolling bearing based on local mean decomposition and improved multiscale fuzzy entropy. Journal of Sound and Vibration. 2016;360:277-299.

[5] Wen J, Chunhe X, Miaoyan Z, et al. Sensor Data Fusion with Z-Numbers and Its Application in Fault Diagnosis. Sensors (Basel, Switzerland). 2016;16(9):287-299.

[6] Ruddy J, Meere R, Terence O’Donnell. Low Frequency AC transmission for offshore wind power: A review. Renewable and Sustainable Energy Reviews. 2016;14-15.

[7] Bhattacharyya B, Raj S, Swarm intelligence based algorithms for reactive power planning with Flexible AC transmission system devices. International Journal of Electrical Power & Energy Systems. 2016;78:158-164.

[8] Liu J, Liu D, Scott J K, et al. Global Solution Strategies for the Network-Constrained Unit Commitment Problem with Flexible AC transmission. IEEE Transactions on Power Systems. 2018:1-1.

[9] Liang H, Liu Y, Wan L, et al. Power characteristics of half-wavelength AC transmission in point-to-grid system. Journal of Modern Power Systems and Clean Energy. 2019;77(10):1-8.

[10] Arioua L, Marinescu B. Robust grid-oriented control of high voltage DC links embedded in an AC transmission system. International Journal of Robust Nonlinear Control. 2016;26(9):1944-1961.

[11] Krishnan B, Ramakrishnan M, Velamuri S. Evolutionary Programming-Based Diagnosis ofNetwork-Constrained AC Transmission System. International Journal of Modern Power Systems. 2011;10(9):1944-1961.

[12] Datta L, Contagion Analysis: Electric Machines & Power Systems. 2016;44(7):806-819.