Research on time delay compensation method of distributed generation system in active distribution network

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Abstract. In order to solve the problems of low compensation accuracy and long compensation time in traditional time delay compensation methods for active distribution network distributed generation system, a new time delay compensation method for active distribution network distributed generation system is proposed. Firstly, the cause of time delay in active distribution network distributed generation system is determined, and then the global characteristics of time delay in active distribution network distributed generation system are extracted by frequency domain method. On this basis, the time delay characteristics of active distribution network distributed generation system are discretized, and the time delay characteristics set of active distribution network distributed generation system is obtained. The continuous function in Banach space is determined by the element method. On this basis, it is discretized, and the time delay compensation model of distributed generation system in active distribution network is constructed. The Lagrange coefficient is used to correct the model to complete the time delay compensation of distributed generation system in active distribution network. The experimental results show that the proposed method has the highest accuracy of 98% and the shortest compensation time of 0.1 s.

1. Introduction

With the continuous development of China's industry, China's power grid construction is becoming more and more complex. There are large units, large-scale complex power grid, ultralong-distance hybrid transmission projects, and these projects are increasingly difficult, marking a new stage of full speed development of China's power industry [1]. In this context, a variety of power systems emerge as the times require. In order to meet the needs of the power market, many kinds of power systems adapted to the development of power grid are designed to ensure the stable operation of power grid. The design of these power systems is mainly to improve the effect of power transmission and distribution and the role of safe power transmission of power grid [2-3]. However, the operation of ultra-long distance or complex large-scale power grid is prone to oscillation of different frequencies, which leads to the instability of power grid operation. Due to the influence of various external signals, the time delay problem of power system occurs, which leads to the delay of power system signal transmission and makes it a time-delay system. The key to solve this problem is to compensate the time delay of distributed generation system in active distribution network. To this end, researchers in related fields have done a lot of research on it, and achieved some results.

In reference [4], an active disturbance rejection control strategy based on time delay compensation is proposed. This method mainly focuses on the time delay problem of permanent magnet synchronous generator. The time delay of signal transmission is compensated by Smith predictor, which is
controlled in the state without time delay. The feed forward channel is used for real-time compensation to eliminate the interference factors in the internal system. Then the nonlinear extended state observer is used to observe and track the interference factors, and the delay compensation strategy is realized. This method can effectively compensate the time delay in permanent magnet synchronous generator, and the compensation speed is fast, but it cannot suppress all interference privacy, resulting in low accuracy of time delay compensation, which still needs to be further improved. In reference [5], an additional damping control method for large-scale doubly fed wind power generation system with time-varying delay is proposed. This method analyzes the output power of power system and the influence probability in long-distance transmission. A wind power generation model is constructed and linearized. According to the characteristic root of the model, the spatial state of the power system is processed. A wide area damper with time delay is designed according to the phase offset compensation method. The parameters of the damper are designed according to the actual needs of the application, and the time delay is compensated. This method mainly compensates the time delay of power system through the damper, which has high accuracy, but the anti-interference ability of the analysis is poor, which has some limitations. In reference [6], a multi time delay compensation method for decentralized control systems is proposed. This method analyzes the limitations of traditional time-delay control and determines the necessity of compensating the time-delay problem. This method takes the control effect of the system as the final optimization objective, and the system is decentralized. The time delay problem in each subsystem is analyzed. The formula of time delay compensation is constructed by recursive response method, and the time delay in each subsystem is compensated. This method has high accuracy for power system compensation, but it takes a long time and has some limitations.

Based on the above problems, this paper proposes a new time delay compensation method for distributed generation system of active distribution network. Firstly, the cause of time delay in active distribution network distributed generation system is determined, and then the global characteristics of time delay in active distribution network distributed generation system are extracted by frequency domain method. On this basis, the time delay characteristics of active distribution network distributed generation system are discretized, and the time delay characteristics set of active distribution network distributed generation system is obtained. The continuous function in Banach space is determined by the element method. On this basis, it is discretized, and the time delay compensation model of distributed generation system in active distribution network is constructed. The Lagrange coefficient is used to correct the model to complete the time delay compensation of distributed generation system in active distribution network.

2. Time delay causes and feature extraction of distributed generation system in active distribution network

In the distributed generation system of active distribution network, the change of the system state is directly related to the current grid operation state, and also has a certain correlation with the previous operation state. At this time, the state of the power system is the time-delay state. This phenomenon is common in every link of the power system, which directly affects the stable operation of the power system [7-8]. In order to determine its impact on the performance of distributed generation system in active distribution network, it is necessary to analyze the characteristics and causes of time delay.

2.1. Causes of Time Delay in Distributed Generation System of Dynamic Distribution Grid

Distributed generation system of active distribution network is a typical networked control system. Due to the influence of bus and generation power, there are many kinds of time delay phenomena in the process of signal exchange.

(1) When the power system equipment is running, the time delay occurs in the process of converting the signal in the process of power transmission into digital signal.

(2) When the power terminal receives the digital signal transmitted by the power equipment, it converts the signal. In this process, the data conversion has a certain delay.
(3) In the process of power data transmission, the channel selected for data transmission is inconsistent, which leads to the influence of power data transmission medium and channel medium, and the influence of channel medium. The simultaneous interpreting of the delay time in different transmission media is shown in Table 1.

Table 1 simultaneous interpreting of different transmission medium signals

| transmission channel         | time-lag/ms |
|-----------------------------|-------------|
| Digital microwave           | 100-150     |
| fiber optic network         | 100-150     |
| Satellite transmission      | 500-700     |

2.2. Time-delay feature extraction for distributed generation system of active distribution network

Based on the analysis of the causes of the time delay of the active distribution network distributed generation system, in order to realize the time delay compensation of the active distribution network distributed generation system, it is necessary to extract the time delay characteristics of the active distribution network distributed generation system. Firstly, the global characteristics of time delay in active distributed generation system are extracted by frequency method [10]. In this method, the stability of distributed generation system in active distribution network is analysed and extracted by formula (1)

\[ C(a, b) = \sum_{a=1}^{m} \sum_{b=1}^{n} x_i \phi^a e^b \]  

In the formula, C represents the active distribution network distributed generation system time delay characteristic set, \( a, b \) represents the components of the system delay feature set, \( x_i \) represents the \( x \)-axis component of active distribution network distributed generation system, \( \phi \) represents the active power component of distributed generation system in active distribution network.

In the global feature extraction of the time-delay feature of the active distribution network distributed generation system, it can be regarded as a feature that cannot be completely determined. At this time, the uncertainty feature is determined by constructing the system matrix [11-12], that is:

\[ f(t) = P_0f(t) + U(f(t - g)) \]  

In the formula, \( P_0 \) represents AC power, \( U \) represents the cut-off frequency, \( g \) represents the resistance of the active distribution network distributed generation system.

Among them,

\[ \begin{align*}
  f(t) &= P_0f(t) + PY(t) \\
  x(t) &= Y(t) \\
  Y(t) &= \Delta x(t)
\end{align*} \]  

Because it is regarded as an uncertain feature, the global feature is extracted deeply through the [13] of freedom matrix, that is:

\[ R = 2[\int f(t)U_1 + f(t-g)U_2]/\int f(t) - f(t-g)]_{g-1}^g \int f(t) \]  

Where, \( U_1 \) and \( U_2 \) the representation matrix. Its value is arbitrary.

After extracting the global characteristics of distributed generation system in active distribution network, in order to make the time delay compensation more accurate, the local characteristics also need to be extracted. Firstly, the voltage of distributed generation system in active distribution network is determined, and then according to the voltage value, the micro factors of influencing factors are analysed.

It is assumed that the voltage of distributed generation system in active distribution network can be expressed as:
In the formula, \( W \) representing the voltage of the active distribution network distributed generation system, \( R' \) represents the active distribution network distributed generation system interference factor, \( \theta \) represents the delay value of signal transmission in active distribution network distributed generation system.

According to the voltage value of distributed generation system of active distribution network determined above, the relationship between time delay and voltage in generation system is considered [14]. Based on this analysis, the nonlinear control method is used to construct the [15] of time delay feature extraction model to realize the local feature extraction of time delay, that is:

\[
\begin{align*}
    f(t) &= P_d f(t) + P_d f(t - h(t)) \\
    g(t) &= \phi(t)
\end{align*}
\]  

(6)

In the formula, \( g(t) \) represents a delay state vector, \( P_d \) represents a common exponential matrix, \( h(t) \) represents the time-delay eigenvector function.

3. Time-delay compensation method for distributed generation system of active distribution network

After obtaining the time delay characteristics of distributed generation system in active distribution network, it is compensated. In this paper, the infinitesimal generator discretization method is used to supplement the time-delay of active distribution network distributed generation system. The method discretizes the overall and local characteristics of the time-delay of active distribution network distributed generation system [16], and further analyzes the time-delay characteristics, so as to realize the time-delay compensation of active distribution network distributed generation system.

In the infinitesimal generator method, let \( E: [0,1] \) represents the time interval response to the real interval \( Q^{n+1} \), Consider it as the Banach space of a continuous function and set its boundaries. Set the infinitesimal generator to:

\[
Q^{n+1} = \frac{\partial E}{\partial t} \alpha', \alpha' \in D
\]  

(7)

In the formula, \( \alpha' \) defined as dense space.

\[
D(t) = \{ \alpha' \in E | \alpha' \in X \}
\]  

(8)

Converts an infinitesimal generator to:

\[
\begin{align*}
    E(t) &= \eta \frac{e(t)}{\partial t} \times \gamma \\
    e(0) &= \alpha'
\end{align*}
\]  

(9)

In the formula, \( e(t) \) represents a continuous function, \( \eta \) represents the eigenvalues of the object of study, \( \gamma \) represents a set of features.

Based on the infinitesimal generator method [17], it is discretized to realize the time delay compensation of distributed generation system in active distribution network.

Suppose that \( N \) represents any of the time delay characteristics of the distributed generation system of active distribution network, \( N + 1 \) discrete point a is determined in its feature set

\[
K_N = \{ \theta_N', J = 1, \ldots, N + 1 \}
\]  

(10)

Where \( K_N \) is the discrete function space.

In this case, the normalized node of n-stage polynomial is determined as an element.
\theta_N = \frac{\mu_{\max}}{3} [\cos\left(\frac{h-1}{N} \chi\right) - 1] \quad (11)

On this basis, the time delay characteristic elements of distributed generation system in active distribution network are discretized:

\[ L_N = \left[ \frac{T_N}{B_N \otimes I_N} \right] \quad (12) \]

Where \( \otimes \) is the kronrcker product of the time delay of the distributed generation system of the active distribution network.

At this time, a time delay compensation model [18-20] for distributed generation system of active distribution network is constructed to realize time delay compensation

\[
\begin{align*}
L_{N+1}(1,1) & = \frac{3N^2 + 1}{5} \\
L_{N+1}(N+1,N+1) & = -\frac{3N^2 + 1}{5} \\
L_{N+1}(N+1,1) & = \frac{(3N^2 + 1)}{2(1 - \theta_N^2)} \\
L_{N+1}(1,N+1) & = \frac{3N^2 + 1}{2(1 - \theta_N^2)}
\end{align*}
\]

(13)

In the formula, \( L_{N+1} \) represents the sequence of time-delay compensation elements, \( N^2 \) represents a highly sparse matrix.

In this paper, the Lagrange coefficient is used to correct the time delay compensation model

\[ \Phi_N(i,j) = \begin{cases} 1 & i = j \\ 0 & i \neq j \end{cases} \quad (14) \]

After discretizing the time-delay characteristics of distributed generation system of active distribution network, the time-delay characteristic set of distributed generation system of active distribution network is obtained, and the Banach function of continuous function is determined by infinitesimal generator method. On this basis, it is discretized to construct the active distribution network distributed generation system time delay compensation model, and the Lagrange coefficient is used for correction to complete the active distribution network distributed generation system time delay compensation. The process of time delay compensation for distributed generation system of active distribution network is shown in Figure 1.
4. Experimental analysis

4.1. Experimental environment
In order to verify the advantages of this method, a simulation experiment is carried out. The experiment is mainly carried out by comparing the methods of this paper, literature [4] and literature [5]. In the experiment, the distributed generation system of an active distribution network of an electric power enterprise is taken as the experimental object. The rated voltage of the generation system is 220 V, and its operating frequency is 100 Hz. The frequency of time delay in the operation process of the generation system is analysed, and three methods are used to compensate it. The test structure of the power generation system is shown in Figure 2.
4.2. Design of Experimental Parameters

In order to ensure the smooth progress of the experiment, the relevant experimental parameters are set up, as shown in Table 2.

Table 2 Design of Time Delay Compensation Parameters for Generation Systems

| Parameter                              | Short-cut process |
|----------------------------------------|-------------------|
| Voltage generation system / V          | 220               |
| Frequency / kHz                        | 8                 |
| Characteristic noise / dB              | -2-2              |
| Number of iterations / times           | 200               |

4.3. Analysis of Experimental Indicators

(1) Time-delay compensation accuracy: The time-delay compensation accuracy of distributed power generation system in active distribution network is an important index to measure the method in this paper. The formula is as follows:

$$ F = \frac{2 \times \text{precision} \times \text{recall}}{\text{precision} + \text{recall}} $$  \hspace{1cm} (15)

(2) Time-consuming of time-delay compensation: On the basis of ensuring the precision of time-delay compensation, the time-consuming of time-delay compensation can reflect the speed of the method.

4.4. Discussion

4.4.1. Precision Analysis of Time Delay Compensation in Different Methods. To verify the validity of this method, the experimental analysis of the accuracy of this method, the literature [4] method and the literature [5] method to compensate the delay of the active distribution network distributed generation system is carried out many iterations to ensure the accuracy of the experiment. The experimental results are shown in Figure 3.
Figure 3 Precision Analysis of Time Delay Compensation by Different Methods

By analyzing the experimental results in Figure 3, the accuracy of the proposed method, the method in reference [4] and the method in reference [5] is different. Among them, the method of this paper, the method of reference [4] and the method of reference [5] have the highest compensation accuracy of about 98%, while the compensation accuracy of the other two methods is lower than the method of this paper. This is because the proposed method obtains the active distribution network distributed generation system by discretizing the time delay characteristics of the active distribution network distributed generation system. Based on the characteristic set of time delay of generation system, the infinitesimal generator method is used to determine the Banach space of continuous function. On this basis, it is discretized, and the time delay compensation model of active distribution network distributed generation system is constructed, and the Lagrange coefficient is used for correction. The time delay compensation of active distribution network distributed generation system is completed, and the accuracy of compensation is improved.

4.4.2. Time consuming analysis of different time delay compensation methods. While ensuring the accuracy of time delay compensation for distributed generation system of active distribution network, the method of this paper, the method of reference [4] and the method of reference [5] are also analysed in the experiment. The shorter the time is, the faster the compensation speed is, and the more outstanding the performance of the method is. The experimental results are shown in Figure 4.
It can be seen from the analysis of Figure 4 that under the same experimental environment, there are some differences in the time-consuming of the three methods. When the number of iterations is 60, the delay compensation time of this method is about 2 s, the delay compensation time of reference [4] method is about 5.2 s, the delay compensation time of reference [5] method is about 7.2 s, when the number of iterations is 100, the delay compensation time of this method is about 2 s, and the delay compensation time of reference [4] method is about 2.3 s. The delay compensation time of the method in reference [5] is about 2.4 s. In contrast, the delay compensation time of the proposed method is the shortest, which indicates that the delay compensation speed of the proposed method is the fastest.

5. Conclusion
This paper presents a time delay compensation method for distributed generation system of active distribution network. The cause of time delay in active distribution network distributed generation system is determined, and the global characteristics of time delay in active distribution network distributed generation system are extracted by frequency method. On this basis, the time delay characteristics of active distribution network distributed generation system are discretized, and the time delay characteristic set of active distribution network distributed generation system is obtained, which is confirmed by infinitesimal generator method. On this basis, the distributed generation system is treated as a discrete time-delay compensation system, and the time-delay compensation of the distributed generation system is carried out by using the Lagrangian function. Compared with the traditional method, it has some advantages, such as higher compensation accuracy and faster humidity compensation. Although this method has achieved some results, there are still some errors.

ACKNOWLEDGEMENTS
This work is supported by the Sichuan Science and Technology Project (No.: 2019YJ0646); Chengdu Science and Technology Project (No.: 2019-YF05-00224-SN); Research Platform Foundation of Chengdu Polytechnic (No.: 19KYPT01); Research and Innovation Team of Chengdu Polytechnic (No.: 20KYTD02, 20KYTD03 and 20KYTD07).

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