Remote testing and trial of new energy grid-connected power generation for complex data

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Abstract. For the data monitoring, diagnostics and evaluation of new energy grid-connected power generation, multi-source complex data such as real-time operation data and characteristic test data are synchronized into the new energy grid-connected power generation system. And multi-source information fusion technology and online data evaluation method are used to analyze and process the data. On this basis, the establishment of a new energy grid-connected power generation remote test diagnostics system is designed. The real-time curve, test curve and fusion data curve’s simulation waveform and the parameters of simulation credibility were analyzed. The experiment proves the feasibility and rationality of multi-source information fusion and online evaluation method. The system runs stably. And the test data is accurate. It provides the system platform for comprehensive grasp of the grid-connected operation characteristic and the grid-connected test diagnostics information.

1. Introduction

In recent years, the world has responded positively to the concept of "global energy internet". The new energy grid-connected generation has become a hot issue in the power industry. The location of wind power and photovoltaic power generation is mainly located in grasslands, barren hills, deserts, seaside and so on. Although DG units have their own ability to grid-connected, they still need to test whether their grid-connected capability is up to standard. The installation sites of the DG units are scattered, and the testing personnel are not enough. Therefore, it is difficult to realize the grid-connected ability detection, operation characteristic test and equipment state monitoring of wind farm or photovoltaic power plant. With the continuous development of computer technology, network communication technology, testing and diagnostics technology, as well as the continuous improvement of test demand, a test diagnostic method based on these technologies is developed-remote test and diagnostics \cite{1}. The remote test and diagnostics system realizes the separation of field test equipment and diagnostic resources in geospatial space. The test equipment can exchange information with remote diagnostics resources through network communication, and can send on-site data to the test center and diagnostic experts in different places in time.

During the performance test of wind farms and photovoltaic power plants, it is necessary to accurately and synchronously measure the relative performance parameters. However, the differences in device structure, operating conditions and testing environment have increased the uncertainty in the test information \cite{2}. In order to avoid the uncertainty and correlation between many characteristic
parameters influence the final test results, it is necessary to ensure the efficiency and accuracy of the remote testing and diagnostics system of new energy grid-connected power generation in complex environment. How to deal with the multi-source parameter information effectively is an urgent problem to be solved in the remote testing and diagnostics system.

At present, on-line monitoring technology plays an important role in ensuring safety and stable operation of power grid [3, 4]. The new energy grid-connected power generation system has introduced on-line monitoring technology. The real-time on-line evaluation and diagnostics of operating parameters is an important link to ensure the accuracy and reliability of the experimental results of the new energy grid-connected characteristics [5]. At present, the research on on-line data evaluation mainly aims at the detection and identification of bad data, usually using the Supervisory Control And Data Acquisition data to estimate the performance parameters, such as the extended parameter estimation [6], however, this kind of method is not easy to meet the principle conditions, which often leads to the problem of deviation in the parameter evaluation. This puts forward higher requirements for monitoring information acquisition, on-line evaluation of test and diagnostic data and design of test system.

To make up for the uncertainty and unreliability of the single source data and the real-time validity of the running data, this paper presents the remote testing of new energy grid-connected power generation for complex data. The collected complex data can be processed through multi-source information fusion technology [7-9]. And the on-line data evaluation technology is used to evaluate and check the processed data. The real-time on-line running status monitoring and running characteristics test of the new energy grid-connected power generation system is realized. Combining with practical engineering application, a remote test and diagnostics system for new energy grid-connected power generation is designed and developed. The system greatly reduces the number and intensity of field testing personnel. And the test efficiency is improved.

2. Theoretical method for monitoring and on-line data evaluation of new energy grid-connected generation based on multi-source information fusion technology

2.1. Monitoring and analysis method of new energy grid-connected generation characteristics based on multi-source information fusion technology

In the remote testing and testing system for new energy grid-connected power generation, the data collected by each sensor include real time and non-real-time, time-varying and non-time-varying, precise and fuzzy, definite and random, mutual exclusion and complementarity [10]. Information fusion technology through the analysis and utilization of information characteristics, grasps the general characteristics and general trend of the overall data [11-13]. It can get the fusion result and situation assessment with higher accuracy, completeness and effectiveness compared with single data source [14, 15].

D-S evidence theory is the most commonly used algorithm to study the uncertainty in fusion technology. The main methods are: The data collected by each sensor is analyzed, then the support for each possible event is calculated respectively. The support probability is expressed by constructing the basic probability distribution function, it is expressed as the evidence provided by the sensor. The Dempster combination rule is used to arrange different evidence bodies, to calculate the support degree of the joint evidence to each possible event. A total reliability distribution function is obtained. Through this formula, the results of information data fusion can be obtained, and the decision is classified according to the given rules. The detailed analysis of the algorithm is as follows:

Assumed recognition framework Θ, when the function m: $2^\Theta \rightarrow [0,1]$ is satisfied

\[
m(\emptyset) = 0 \tag{1}
\]

\[
m(A) \geq 0, \text{ and } \sum_{A \in \Theta} m(A) = 1 \tag{2}
\]
where \( m \) is the basic trustworthiness allocation of the corresponding recognition framework, which generates the confidence of the \( A \), \( m(A) \) is the basic probability assignment of \( A \), in which the \( A \) represents the focus element, \( \phi \) is an empty set.

In order to calculate the overall trust degree of \( A \), all the subset \( B \) of \( A \) are extracted and the basic probability assignment is calculated. Thus, the trust measure of the evidence to \( A \) can be obtained.

\[
Bel(A) = \sum_{B \subseteq A} m(B)
\]

(3)

When calculating trust for \( A \), in order to make the result more comprehensive, we should add the degree of skepticism to \( A \), write it as \( Dou(A) \). And \( Bel \)'s suspect function is \( Dou \). If \( \forall A \subseteq \Theta \), it can be obtained:

\[
Dou(A) = Bel(\overline{A})
\]

(4)

The rest is called uncertain probability, that is, it may support or not support \( A \), record it as \( m(\theta) \).

As for \( A \subseteq \Theta, \ A \neq \Theta \), The general form of the fusion rules with D-S evidence theory is:

\[
m(A) = \frac{\sum_{A_1 \cdots A_k \subseteq \Theta} m_1(A_1) \cdots m_k(A_k)}{1 - \sum_{A_1 \cdots A_k \subseteq \Theta} m_1(A_1) \cdots m_k(A_k)}
\]

(6)

2.2. On-line evaluation and analysis of multi-source data

The accuracy of the performance parameter simulation data depends on the comparison of the performance parameters. Therefore, this paper carries out residual cross alignment around test data, on-line real-time collection data and fusion data. Then, the residual analysis method and multi-source parameter alignment method are used to realize on-line parameter evaluation [16, 17].

First, the residual analysis method is introduced. After subtracting the measured signal sequence from the simulation signal series, the residual sequence is obtained. The proper mathematical model of residual sequence is established and the corresponding data are given. The specific expressions are as follows:

\[
\gamma_i = \frac{\sum_{j=1}^{n} |y_j|}{\sum_{j=1}^{n} |\hat{y}_j|}
\]

(7)

\[
x_i = 1 - \frac{|y_i - \hat{y}_i|}{\max_{j} \left( |y_j|, |\hat{y}_j| \right)}
\]

(8)

\[
\varphi = \sum_{i=1}^{n} \gamma_i x_i
\]

(9)

where: \( y_i \)—The simulation of the signal sequence, specifically for the fusion of data, \( i \in (1, n) \); \( \hat{y}_i \)—Measured signal sequence, specifically for real-time acquisition of data, that is, Supervisory Control And Data Acquisition data, \( i \in (1, n) \); \( x_i \)—Reliability of point \( i \) of data points; \( \gamma \)—The weight of point \( i \) is the ratio of the amplitude of the point \( i \) in the data to the sum of all the sampling points; \( \varphi \)—Residual reliability index of \( \hat{y}_i \) and \( y_i \).
In the method of multi-source parameter comparison, real time acquisition and test data are integrated into the set of parameter problems by mapping multi-source data. Comparing the two parameter sets, the parameters are adjusted and the results are fed back to the fusion data. The expression of specific index is:

$$\alpha_i = \frac{p_i}{P}$$  \hspace{1cm} (10)

$$Y = \sum_{i=1}^{n} \left[ \alpha_i \left( y_i - \hat{y}_i \right) / y_i \right]$$  \hspace{1cm} (11)

where: $p_i$—Active power of equipment; $P$—Total load of the system; $y_i$—Acquisition of data parameters in real time; $\hat{y}_i$—Test data parameters.

3. Design and construction of remote test and diagnostics system for new energy grid-connected generation

3.1. Overview of the overall structure of the system

![Architecture diagram of the system](image)
The new energy remote testing and diagnostics system designed and constructed is composed of 3 parts, the field test data acquisition layer, the network remote test data center and the application display layer. The system provides service from bottom to top. Figure 1 shows the architecture diagram of the system.

The remote test and diagnostics system for new energy grid-connected power generation is divided into two levels. The first level is deployed in the new energy remote testing center of the Academy of electricity. The second level is deployed in all regional wind farms and photovoltaic power plants. It is composed of distributed test data acquisition device, field test centralized monitoring [18] and data analysis system.

The distributed test data acquisition device uploads the test data to the field test centralized monitoring and data analysis system through WIFI wireless communication. The system transmits the control instructions to the field test device through LORA communication. Through the INTERNET public network and 4G wireless network, the test data is uploaded from the scene to the data platform deployed in the remote testing center of the Electric Power Research Institute. The data platform fuses the test data with the real-time data collected by Supervisory Control and Data Acquisition. The fusion data is further simulated, processed and analyzed. Finally, the test results are obtained and uploaded to the user side.

3.2. Design of distributed test data acquisition device

The system adopts the core concept of virtual instrument to design the distributed test data acquisition device of wind farm and photovoltaic power plant test site. Through different software programming, the user's custom instrument function can be realized. It can also achieve collection and wireless transmission for different test data.

The test standards of power quality, reactive power compensation and power control for new energy grid-connected test are applicable to different test data of wind farms and photovoltaic power plants. The design of the distributed test data acquisition device is shown in figure 2. The layout of test data acquisition points is shown in figures 3 and 4.

![Figure 2. Architecture diagram of wind farm /photovoltaic power plant distributed test data acquisition device.](image-url)
3.3. **System function**
- Test monitoring. It includes map navigation, real-time monitoring of regional wind farms, photovoltaic power plant on-site test units, real-time monitoring of test equipment transit status and so on.
- Test management. It includes test project, testers, test process and test data management to realize the test management of multi-source information fusion. And it also has remote test control function.
- Fault diagnostics and state evaluation. It can display the health status of the device in real time and automatically generate physical examination reports and diagnostic reports.
- Technical Supervision. It includes new energy grid-connected power generation test and test index evaluation, comprehensive evaluation, test report generation, data statistics report output and chart analysis functions.
- Large capacity data storage [19-21] and monitoring. According to different test items, the offline storage, management and real-time monitoring of large capacity storage data in field test are carried out.

4. **Rationality of multi-source data and reliability analysis of on-line parameter evaluation**
The distributed test data acquisition device installed in various regional wind farms and photovoltaic power plants is used to collect the characteristic test data. It is compared with the real time data collected in Supervisory Control and Data Acquisition system. Because of the large number of performance parameters, this paper only takes the wind farm as an example to analyze and compare the three measured values of voltage, active power and reactive power. The test point is shown as 5 points for figure 3.

Taking 12 hours as a sampling period and collecting data once every 1 hours, the operational characteristics parameters and real-time acquisition parameters of the new energy grid-connected generation system are measured—active power, reactive power, voltage. The information fusion technology is used to process the real-time and test data. The fusion data, real-time data and test data are compared and analyzed. The active power analysis is shown in table 1. The reactive power analysis is shown in table 2. Voltage analysis is shown in table 3.

Compared with the Supervisory Control and Data Acquisition system, the characteristic test device has higher accuracy of measurement data. By comparing the values of each column in tables 1-3, it
can be seen that the fusion data is closer to the test data, indicating that the information fusion technology can get more accurate data processing results. The feasibility and rationality of data processing method of remote test and diagnostics system based on information fusion technology are proved.

Table 1. Analysis of the active power of the node.

| time/h | 1    | 2    | 3    | 4    | 5    | 6    | 7    | 8    | 9    | 10   | 11   | 12   |
|--------|------|------|------|------|------|------|------|------|------|------|------|------|
| real   | 13.2 | 8.4  | 4.7  | 7.5  | 3.0  | 9.7  | 6.8  | 9.2  | 15.4 | 14.6 | 13.6 | 8.5  |
| test   | 14.0 | 7.8  | 3.9  | 8.2  | 3.8  | 9.3  | 6.0  | 8.4  | 14.5 | 13.7 | 12.6 | 7.8  |
| fuse   | 13.7 | 7.9  | 4.1  | 8.0  | 3.6  | 9.4  | 6.2  | 8.6  | 14.7 | 13.8 | 12.9 | 8.0  |

Table 2. Analysis of reactive power.

| time /h | 1    | 2    | 3    | 4    | 5    | 6    | 7    | 8    | 9    | 10   | 11   | 12   |
|---------|------|------|------|------|------|------|------|------|------|------|------|------|
| real    | 1.0  | 3.8  | -0.7 | -2.2 | 0.4  | 0.6  | 7.5  | 3.1  | 4.9  | 4.6  | 0.2  | -3.2 |
| test    | 1.7  | 3.3  | -0.2 | -2.9 | -0.1 | -0.2 | 8.1  | 3.8  | 4.0  | 3.8  | -0.5 | -4.2 |
| fuse    | 1.5  | 3.4  | -0.4 | -2.6 | 0.0  | -0.1 | 8.0  | 3.6  | 4.3  | 3.9  | -0.3 | -4.0 |

Table 3. Analysis of point voltage (Per-unit value).

| time /h | 1    | 2    | 3    | 4    | 5    | 6    | 7    | 8    | 9    | 10   | 11   | 12   |
|---------|------|------|------|------|------|------|------|------|------|------|------|------|
| real    | 1.026| 1.019| 1.021| 1.023| 1.003| 1.029| 1.02 | 1.024| 1.033| 1.021| 1.035| 1.018|
| test    | 1.021| 1.023| 1.027| 1.018| 1.009| 1.034| 1.024| 1.027| 1.04  | 1.026| 1.029| 1.025|
| fuse    | 1.023| 1.022| 1.025| 1.02 | 1.008| 1.032| 1.023| 1.026| 1.038| 1.025| 1.031| 1.023|

The curves of real time data and test data for three parameters of active power, reactive power and voltage are given respectively. The on-line data evaluation technology is used to adjust the fusion data and make the fusion simulation curve. The measured curves, test curves and fusion simulation curves are placed in the same coordinate system for comparison and analysis. Figures 5-7 is a comparison diagram of each parameter curve. At the same time, by calculating the reliability of the simulation curve from three indexes of frequency reliability, amplitude reliability and residual reliability, the difference between simulation wave and test waveform is analyzed objectively. And the results are shown in table 4 as shown below.

**Figure 5.** Comparison of active power simulation and actual waveform.

**Figure 6.** Simulation of reactive power and comparison of actual waveform.
Figure 7. Voltage simulation and actual waveform comparison.

Table 4. The reliability index of the simulation of each parameter of the wind farm and the network.

| parameter   | frequency similarity | amplitude similarity | residual similarity |
|-------------|----------------------|----------------------|---------------------|
| active power| 96.34                | 95.92                | 98.66               |
| reactive power| 97.51            | 95.37                | 95.11               |
| voltage     | 95.26                | 94.47                | 96.08               |

From figures 5-7, we can see that the trend of the convergence curve is almost the same as that of the test data. And the numerical difference is smaller. From the data in table 4, we can see that the reliability of the simulation curves of each parameter is as high as 94%, which shows that the simulation curve has high accuracy. It is proved that the parameter simulation method based on on-line evaluation technology is feasible for long-term waveform simulation of grid-connected parameters and credibility of simulation data. To a certain extent, it makes up for the problem that the test equipment can not run for a long time and the accuracy of real-time monitoring data of Supervisory Control and Data Acquisition system is poor.

5. Application example and effect for system

The remote test and diagnostics system for new energy grid-connected generation has been tested on May 2018 at the New Energy Laboratory of the Power Science Research Institute of Shandong electric power company of national network. Figure 8 is a part of the test data monitoring and analysis interface that is captured during the operation of the system. At present, the system runs steadily and the test results are accurate.

Figure 8. Interface display of partial characteristic test data analysis.
6. Conclusions
The new energy grid-connected generation system has complex operation environment and the reliability of test results is the most basic and important requirement for remote test and diagnostics system. The accuracy of data collection is directly related to the accuracy and credibility of characteristic testing and safety monitoring. In this paper, the multi-source information fusion technology and on-line evaluation method are successfully applied to the new energy remote testing and diagnostics system. The reliability of the simulation data is verified by the comparison of the curve waveform and the reliability analysis. And the accuracy of the characteristics analysis and safety monitoring is improved. The design and successful application of the system have accumulated a large amount of data for the research of parameter monitoring under the complex environment. And it provides a system platform and technical support for the field characteristic testing of new energy grid-connected.

References
[1] Ge E L 2014 Design and implementation of remote fault diagnostics center for equipment based on cloud computing (Nanjing: Nanjing University of Science and Technology)
[2] Chen Y Y 2012 Fault diagnostics method of wind turbine based on information fusion (Shanghai: East China University of Science and Technology)
[3] Bai Y 2014 Research on state monitoring information aggregation of power equipment for large data (Kunming: Kunming University of Science and Technology)
[4] Xi Fang, et al 2012 Smart Grid the new and improved power grid: A survey IEEE Communications Surveys and Tutorials 14 944-80
[5] Wu T 2013 Research and implementation of on-line data assessment for multi section flow control (Baoding: North China Electric Power University)
[6] Qiu J, Niu L L and Yu H C 2013 Online data evaluation technology based on multi source data Power Sys Techno 37 2658-62
[7] Blasch E, Llinas J and Lambert D 2010 High level information fusion developments, issues, and grand challenges: Fusion 2010 panel discussion Proc. of the 13th International Conference on Information Fusion (Edinburgh, UK) pp 1-8
[8] Solano M A, Ekwaro-Osire S and Tanik M M 2012 High-level fusion for intelligence applications using recombinant cognition synthesis Information Fusion 13 79-98
[9] Li X-D, et al 2011 Evidence supporting measure of similarity for reducing the complexity in information fusion Information Sciences 181 1818-35
[10] Li H 2014 Research on state monitoring of wind turbine based on information fusion (Baotou: Inner Mongolia University of Science and Technology)
[11] Xin W 2010 Model-based and data-driven fault diagnostics for wind turbine hydraulic pitching system (Milwaukee: The University of Wisconsin-Milwaukee)
[12] Zhao B Y 2017 Research on fault diagnostics method of power grid based on multi information fusion (Nanjing: Nanjing University of Science and Technology)
[13] Chen K W, Zhang Z P and Long J 2013 The key problems, research progress and new trend of multi-source information fusion Computer Science 40 6-13
[14] Roy J 2011 From data fusion to situation analysis Proc. of the 4th Int. Conf. on Information Fusion (Montreal) pp 335-42
[15] Khaleghi B, Khamis A and Karray F O 2013 Multi-sensor data fusion: A review of the state-of-the-art Information Fusion 14 28-44
[16] Gao F, Kang J D and Xue X H 2017 On-line simulation data quality evaluation and automatic calibration method for power grid Ningxia Electric Power 1 1-5
[17] Jia X D, Li G Y and Zhao C Y 2010 Research on the method of evaluating the reliability of power system simulation Proceedings of the CSEE 30 51-7
[18] Zhang Y, Wang Y J and Yu P 2017 Design and application of an integrated test device for new energy grid testing Shandong Electric Power 44 1-7
[19] Zikopoulos A C, et al 2012 Understanding Big Data (USA: The McGraw-Hill Companies)
[20] Baker J, et al 2011 Megastore: Providing scalable, highly available storage for interactive services Proc. of the CIDR (Asilomar, California , USA) pp 223-34
[21] Tatemura J, et al 2012 Partiql: An elastic SQL engine over key-value stores Proc. of the SIGMOD (New York: ACM Press) pp 629-32