A Multi-index Comprehensive Analysis Method for Waveform Consistency of Single-Phase Ground Fault of Power Source Output

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***Abstract*—A multi-index comprehensive analysis method is proposed for the consistency of the output signal and the input signal of the power source about single-phase ground fault. Compared with the traditional single-index waveform similarity comparison method, this method combines the time-domain characteristics of the steady-state waveform, the time-domain ,frequency-domain and time-frequency domain characteristics of the transient state.The consistency of power source grounding fault waveform is comprehensively evaluated. On the basis of investigation and analysis of the field identification method of short-circuit and grounding faults in distribution network, the key characteristic parameters including the voltage amplitude changes of steady-state signals , harmonic distortion rate and amplitude of transient zero-sequence voltage, or the other characteristic parameters that cover the essential characteristics of transient signal waveform.All the parameters are divided into their importance grades. At the same time, the weight rank of each parameter is determined by the combination of the analytic hierarchy process (AHP) and the correlation coefficient method. Finally, the waveform of field grounding fault from the power grid and two power sources is extracted, and a comprehensive evaluation model of transient signal output consistency is established.**

Keywords:Power Source, Single-phase Ground Fault, Waveform Consistency, Analytic Hierarchy Process (AHP)

I. INTRODUCTION

As an important instrument in electronic information system, current and voltage power source is widely used in measurement and control, medical treatment, education, scientific research, measurement, navigation and so on. The current and voltage power source can not only provide the output of voltage and current, but also serve as the reference source of instrument calibration.With the further development of scientific research, more and more strict requirements are put forward for the precision and dynamic performance of current and voltage standard source.But at present, the research on the consistency test method of output waveform and input waveform of power source is relatively single in the current field. In [1] ,the total harmonic distortion of the output standard sine signal is extracted to verify the similarity of the waveform and the precision of the output of the power source. The correlation coefficient and Total harmonic distortion (THD) are used to evaluate the similarity of input and output waveforms and the output quality of power sources. A method of waveform consistency analysis by using correlation coefficient is introduced in detail in [3] , and the waveform consistency is evaluated synthetically by combining the spectrum of waveform. The consistency of transient waveform is analyzed by using correlation coefficient in [5].And [4] used the mean square error to test the waveform similarity of zero sequence current, and proposes a method of earthing fault location based on the waveform similarity. To sum up, the current consistency comparison methods have the problem of single index and incomplete judgment. Aiming at the consistency of output signal and input signal of power source, combined with the method of grounding fault diagnosis which is widely used in distribution network and academic circles, several parameters which can effectively characterize the characteristics of grounding fault waveform are extracted in this paper, based on three-phase voltage waveform, a multi-index comprehensive analysis method for waveform consistency of single-phase ground fault of power source is proposed.

At present, single-phase ground fault accounts for the heaviest proportion in the grounding fault of the distribution network. The domestic and foreign research on single-phase ground fault gradually focuses on the electrical information research after the fault, which changes the previous trend of establishing complex distribution network mathematical trend model to study the fault type. Because today's distribution network is very different from the traditional distribution network, its structure is more complex, a wider area, a wide variety of loads, but also face more uncertain fault factors. Therefore, it is difficult to establish a unified, standard and wide-ranging mathematical model of the distribution network. By studying the characteristics of electrical information after the fault, without complex system modeling, only after obtaining the electrical information of the corresponding fault, the classification and identification of single-phase fault can be realized. With the large-scale application of big data and artificial intelligence in the distribution network, the analysis method of electrical information after failure is more and more efficient and widely used in the fault analysis of the distribution network.

Single-phase ground fault can be divided into permanent ground fault, intermittent ground fault and transient ground fault according to the duration of the fault, high resistance fault and low resistance fault. By judging whether there is arc burning at the fault point, it is divided into arc grounding fault and resistance grounding fault. In addition, according to the neutral grounding mode, its fault characteristics are not the same.

For single-phase ground faults in inter-phase short circuit and high current grounding systems, the over-current method is used to identify faults in distribution networks and academic circles. The detection methods for single-phase ground fault of small current grounding system are more diversified. The methods of fault identification by using transient characteristics are transient zero sequence current comparison method, transient reactive power direction method, attenuated DC component method, wavelet analysis method, parameter identification method, first half wave method, etc. , the steady-state characteristics of faults can be identified by using zero-sequence current amplitude comparison method, zero-sequence current phase comparison method, zero-sequence active power method, zero-sequence reactive power direction method, fifth-order harmonic method, zero-sequence admittance method and negative-sequence current method.

II. KEY PARAMETERS FOR CONSISTENCY ANALYSIS

Based on the investigation of the parameters used in line selection and identification of single-phase ground fault commonly used in the power gird and academic literatures.The parameters are extracted and redundant parameters are eliminated, the final parameters and gradients are as follows:

1)Because the phase voltage amplitude of steady state changes when there is a fault, the steady-state amplitude before and after the fault is extracted and the differences are calculated

2)Because the power sources used in this paper are voltage power sources, so three-phase voltage parameters are used for analysis, current parameters are not analyzed.

3)For the transient parameters, the transient characteristics in the first cycle after fault are more obvious, so the parameters in the first cycle after fault are extracted uniformly for consistency analysis.

A. Parameters that express features of fault effectively

TABLE I. EFFECTIVE PARAMETERS

Parameters	*Steady state*	***Transient state***
Time Domain	Amplitude change of three-phase voltage	Polarity of zero-sequence voltage
	Amplitude of zero-sequence voltage in fault	

B. Parameters that express a part of features of fault

TABLE II. IMPRORENT PARAMETERS

Parameters of zero-sequence voltage in transient state	
Time Domain	Peak-to-peak value
Frequency domain	Total Harmonic Distortion
Time-frequency domain	The proportion of low frequency energy
	Standard deviation of low frequency component reconstruction
	Wavelet Singular Entropy

C. Parameters of the transient waveform.

TABLE III. PARAMETERS OF WAVEFORM

Parameters of zero-sequence voltage in transient state	
Time Domain	Standard Deviation
	Peakedness
	Skewness
	Root Mean Square
	Waveform Factor
	Peak Factor
	Peak
Frequency domain	Gravity Frequency
	Standard Deviation
	The largest three value

III. A MULTI-INDEX COMPREHENSIVE ANALYSIS METHOD

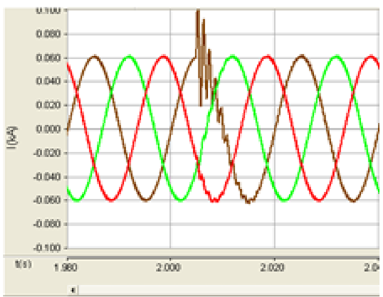
As for the input waveform and the output waveform,their starting point and ending point and their sampling rates(The input waveform is much larger than the output waveform) may be diffrernt.Therefore,in order to analyze the consistency of the output waveform, we can not simply compare and analyze by means of waveform superposition alignment, we need to determine waveform consistency by waveform pretreatment and feature.

For the comparison of the similarity between the input (standard) waveform and the output waveform, the following two waveforms are taken as examples:

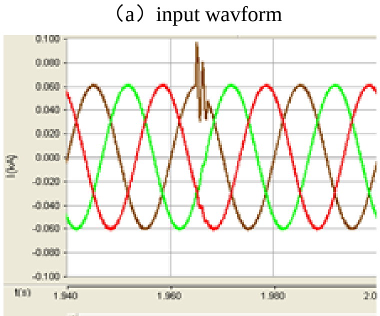
In view of the different sampling rates of the two waveforms (the standard waveforms are much larger than the recorded waveforms) , the following methods are proposed to compare their similarity:

1) Pretreatment of waveform:

Align the output waveform and the standard waveform by aligning the fault points of two sets of waveforms. Then, the corresponding parts of the standard waveform are truncated according to the time length of the output waveform, and two waveforms with the same time length are obtained



（a） input wavform



（b） output wavform

Fig. 1. Comparison schematic of waveform consistency(Pretreated)

2) Parameters which can express the waveform consistency.

a) Hard index: polarity of zero-sequence transient voltage.

b) Frist gradient:

The parameters that effectively represent the characteristics of grounding faults or waveform consistency are showed in TABLE I.They are in frist gradient of AHP.

c) Second gradient:

The parameters that can represent the characteristics of grounding faults are showed in TABLE II.They are in second gradient of AHP.

d) Third gradient:

The other transient parameters of the zero-sequence voltage which can represent the characteristics of waveform are showed in TABLE III. They are in third gradient of AHP.

3) Pretreatment of data:

a) Reverse parameters

Since the parameter differences are used to judge the waveform consistency in this paper, they are negative parameters.

b) Undimensionalization of parameters

This paper studies the consistency between the output waveform of power source and the standard waveform, and the parameters of the standard waveform are all known or determined, so we use threshold of comparative law to process the parameters,the threshold is the standard value for each waveform parameter.For example:

$$y_1 = \frac{|U_{Aac} - U_{sAac}|}{U_{sAac}} \tag{1}$$

4) The construction of index weight

The rationality of evaluation index setting for waveform consistency of single-phase ground fault of power source output has a great influence on the correctness of judgment, a set of scientific, reasonable and complete index system must be formed. By retrieving a large amount of data and listening to the suggestions of many experts and scholars in the power industry, a scheme for determining the evaluation index weight of waveform consistency is formed.

The analytic hierarchy process (AHP) , is one kind of synthetic multi-index importance appraisal method.

In 2), the importance rank between indicators has been ranked, which will not be described here. Construction method of index weight system is as follows:

a) Construct the judgment matrix to determine the weight of each layer.

For parameters, a matrix with 22 rows and 22 columns can be constructed.Compare an element in pairs with all the elements in this layer, and conduct hierarchical ranking.The hierarchy of importance in matrix is showed in TABLE IV.

b) Weight by AHP

$$\overline{W_i} = \sqrt[n]{\prod_{j=1}^{n} a_{ij}} \tag{2}$$

c) Normalization of subjective weight.

$$W_i = \frac{\overline{W_i}}{\sum \overline{W_i}} \tag{3}$$

d) consistency checking.

$$C.I. = \frac{\lambda_{\max} - n}{n-1} = 0.061 \tag{4}$$

It is a consistency index used to test the judgment.

$$C.R. = \frac{C.I.}{R.I.} = 0.038 < 0.1 \quad (5)$$

The consistency of the matrix is acceptable. That is, the obtained weights meet the consistency criteria. The final gain weight is showed in TABLE V:

TABLE IV. MEAN OF JUDGMENTMATRIX

Hierarchy of importance in matrix	
Ratio（A:B）	***Mean***
1	A is as important as B
3	A is more important than B
5	A is more important than B significantly

TABLE V. WEIGHT OF PARAMETERS

Weight of Parameters	
Gradient of parameters	***weight***
Frist gradient	0.1059
Second gradient	0.0486
Third gradient	0.0190

e) The coefficient of correlation method for assignment

Construct a correlation coefficient matrix for multiple index to obtain the multivariate correlation coefficient for each index.The matrix is obtained by sampled data.After normalization of objective weight,we can obtain the objective weight of each index.

f) Composite weight.

$$W_j = \frac{\sqrt{W_{Cj}W_{Dj}}}{\sum_{j=1}^{22}\sqrt{W_{Cj}W_{Dj}}} \quad (6)$$

5) Comparison of the waveform consistency.

The evaluation process of waveform consistency is based on the weight gained in 4).

The polarity of the maximum of the zero-sequence transient signal is first examined.If the polarity of two waveforms is the same, calculate error of other parameters.

$$E_T = w_1 \bullet |R-1| + \sum_{j=2}^{22} w_j y_j \quad (7)$$

Waveform consistency parameter:

$$Z = \frac{1}{1+E_T} \quad (8)$$

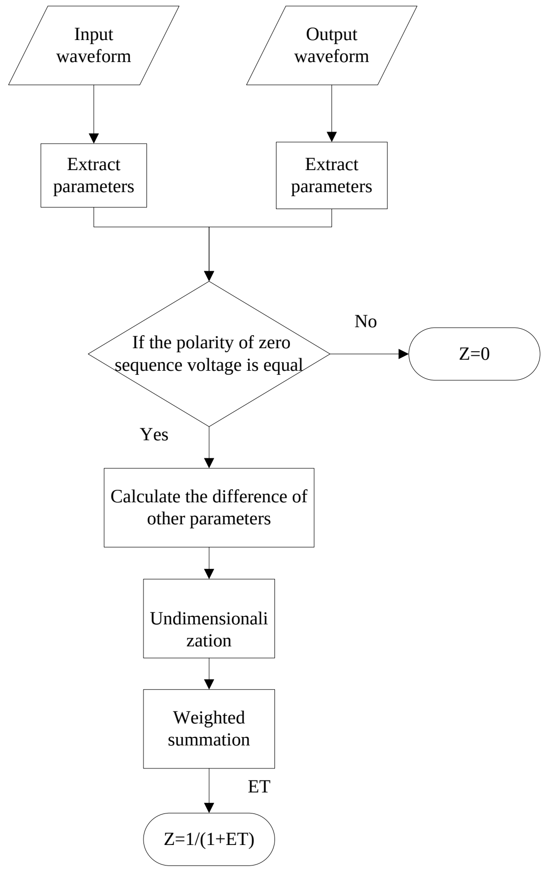


Fig. 2. Evaluation process of waveform consistency

IV. SIMULATION AND VERIFICATION

To verify the effectiveness of the comprehensive evaluation method, a multi-index algorithm based on MATLAB for parameter extraction and comparison and consistency calculation is constructed. The experimental data use five sets of field fault recording waveforms of the distribution terminal and the corresponding waveforms of three power source inversion.

Among all parameters, the transient parameters are gained from the data of a circle after the fault, the fault point is gained when the zero-sequence voltage increase to a value, the parameters in frequency domain are gained by Fourier transform, and parameters in time-frequency domain are extracted by wavelet packet transform, using DB10 wavelet for the appropriate number of Wavelet packet decomposition. The weight coefficient is extracted from five groups of sample data to judge the correlation of each index, and finally determined by combining the analytic hierarchy process. The input (reference) waveform is sampled at 50000 Hz.

The A power source output five sets of waveform.The sampling frequency of A power source is 5000Hz.Since the judgment of the correlation coefficient requires that the two sets of data have the same length,the input waveform is sampled with a interval, which is the ratio of the sampling frequency of the input waveform to that of the output waveform. For the accuracy of extracting parameters by wavelet transform, the input waveform data also need to be sampled with the same interval.

The final results of the frist set of waveform by A power source are showed(input waveform in blue, output waveform in red) .

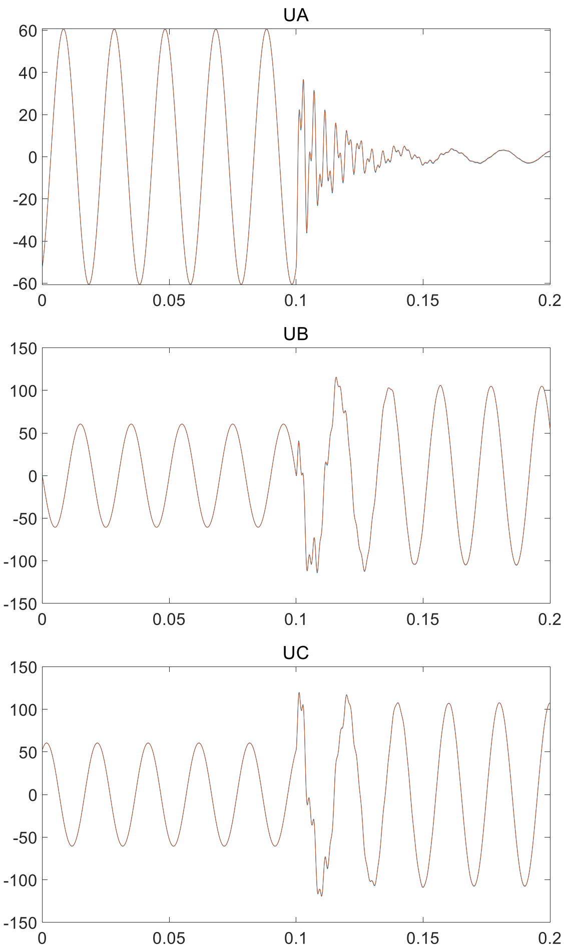


Fig. 3. Comparative diagram of overall voltage

From Fig.3, it can be seen that the steady-state consistency of the waveform in time-domain is very high, the waveforms almost overlaps, but from Fig.4,there is a small amplitude fluctuation of the zero-sequence voltage before fault, and there are small errors in the peak value part of the transient time-domain,which will reduces the value of *Z*.

From Fig.5,the value of peak part of the transient output waveform is a little smalller than the input waveform.

As can be seen in the Fig.6, there are deviations between the amplitudes in frequency domain from input waveform and output waveform.The value of output waveform is smaller. Especially when the frequencies are 50Hz,200Hz and 500Hz,which are the frequencies with the maximum amplitude.

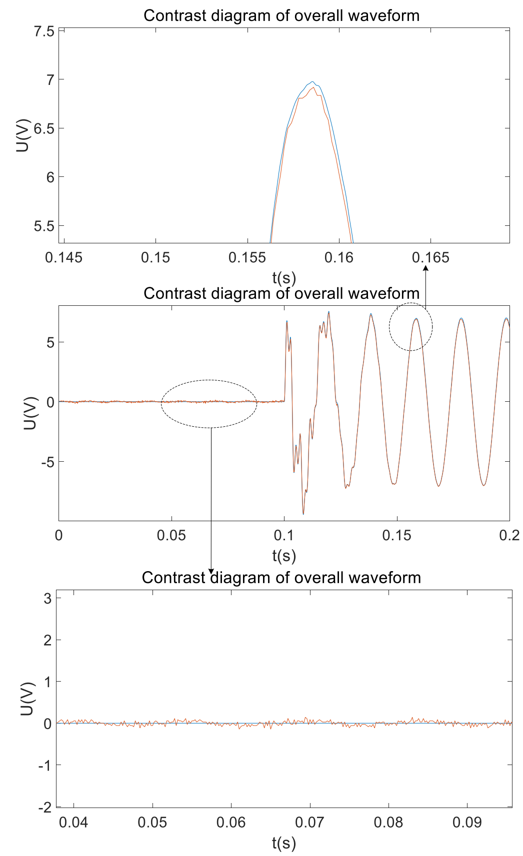


Fig. 4. Details of waveform in steady state

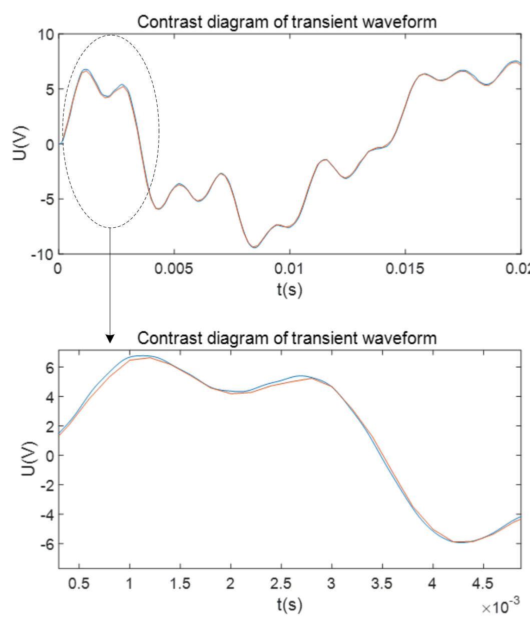


Fig. 5. Details of waveform in transient state

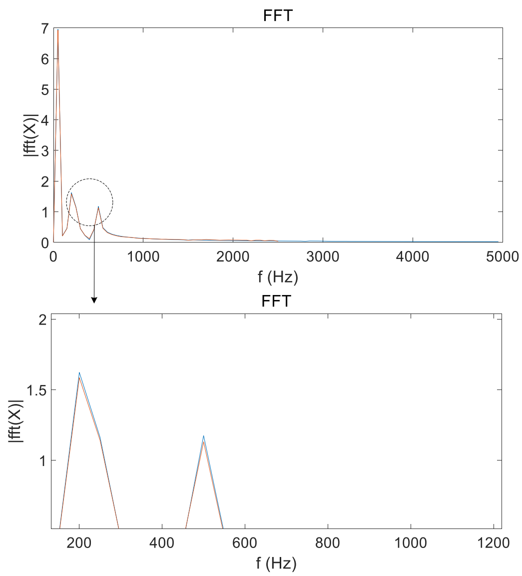


Fig. 6. Comparative diagram of FFT

The final results by A power source which including the correlation coefficient *R* and waveform consistency coefficient *Z* are showed in TABLE VI.

TABLE VI. RESULTS OF COMPARISON

Results	R	Z
A01	0.9890,	0.9787
A02	0.9968	0.9783
A03	0.9987	0.9752
A04	0.9974	0.9778
A05	0.9998	0.9857

The results show that the waveform consistency coefficient *Z* proposed in this paper can effectively reflect the transient output consistency of the waveform.

V. CONCLUSION

In this paper,a multi-index comprehensive analysis method is proposed for the consistency of the output signal and the input signal of the power source about single-phase ground fault. Comparing with the traditional single-index waveform similarity comparison method, this method combines the characteristics of the waveform in steady-state and transient state. The parameters in time-domain,frequency-domain and time-frequency domain are also used. By giving every parameters a weight determined by its hierarchy rank and its correlation with others,more comprehensive characterization of the detailed differences in waveform is expressed by the consistency coefficient *Z*.Besides,the results of the simiulation show the high consistency of the input waveform in power gird and output waveform that power source A generates.

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