Research on Advanced Power System Analysis and Control Based on Big Data Technology

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Abstract. The continuous development of big data technology has brought many new ideas and challenges to power system analysis and control. With the development of distributed power sources, energy storage, monitoring, and protection devices, the traditional distribution network has gradually evolved into much Active distribution networks with control ability. At present, the power quality of the power system is a hot issue in power system research. There are many types of power quality disturbances, mainly including single type and compound type disturbances. The thesis first uses Matlab to model and simulate the power quality disturbance signal and then obtains a complex number matrix through S transform, then calculates its modulus, and extracts the corresponding characteristic parameters to form the characteristic vector. Secondly, the thesis uses a simple and efficient decision tree to correctly classify and identify power quality disturbance signals. Finally, the thesis's simulation analysis results show that this research method combining S transform and decision tree has high recognition accuracy and strong anti-noise ability, which is a very suitable method.

Keywords: Power system, big data technology, power quality disturbance, decision tree, feature extraction.

1. Introduction

The construction of the national functional power grid directly promotes the development of the power industry. The big data in the power industry refers to the electricity consumption of individuals and companies and includes the data generated during the operation of the entire grid. Because the data is different, based on these data, screening, exploration, and speculation are used to select more Value meaning information [1]. The characteristic of big data is that it has a large quantity and a wide range of types, so the correct handling of big data can improve the industry's quality, and it has also been well promoted in various industries.

The basic requirements of power system operation are: (1) to ensure reliable and safe power supply; (2) qualified power quality level; (3) good economy. Electricity is an energy that cannot be separated from the paper. Its application directly reflects a country's economic level and scientific and technological strength. As a particular commodity that enters the market, electric energy, like other commodities and services, also has quality attributes. To this end, the power sector should provide high-quality electrical energy for safe production and efficient life for the people. High-quality electric
energy is of great significance for ensuring the power grid’s safe and economical operation, improving product quality, and ensuring residents’ everyday lives.

As mentioned above, changes in the power grid structure and the input of a large number of power electronic equipment have disturbed the power quality, which in turn led to many power quality problems. Because they are mostly impulsive, nonlinear, and unbalanced loads, they can easily cause a series of disturbance phenomena such as voltage waveform distortion and voltage fluctuation. At present, sensitive devices such as microelectronic computers and PLC are gradually increasing, which has stricter requirements for power quality. Faced with so many power quality problems, the thesis should pay more attention to power quality and increase efforts to truly implement the research [2]. This paper introduces the mathematical model of the power quality disturbance signal and the simulation waveform model. Feature extraction of power quality disturbance signals: According to the modulus matrix of the complex number matrix after S transformation, a simulation diagram and a real-time frequency statistical information diagram are obtained, and 5 characteristic parameters are extracted and drawn into a characteristic parameter table. Classification and recognition of power quality disturbance signals: According to the characteristic parameter table, a decision tree classification and recognition model is obtained to verify the simulation classification results’ correctness.

2. Mathematical model and simulation of power quality disturbance signal

2.1. Voltage sag

Voltage sag refers to the voltage or current change phenomenon in which the root means square value of voltage or current drops to between 0.1-0.9p.u. and the duration is 0.5 cycles to 1 minute under power frequency conditions. Voltage sags can be caused by system failures, large motors starting, or large loads charging. Voltage sags can cause sensitive loads to fail to operate normally and cause electrical equipment to stop running. The mathematical model of voltage sag can be represented by a sine function or a cosine function. Here the paper uses the cosine function to express as follows:

\[ v(t) = A[1 - k[u(t_2) - u(t_1)]] \cos(\omega t) \]  

In this formula, \( A \) represents the amplitude \( A = 1 \); \( 0.1 \leq k \leq 0.9 \); \( T \leq t_2 - t_1 \leq 9T \). The mathematical model of the disturbance signal of the voltage sag is simulated by Matlab, as shown in Figure 1.

![Figure 1. Voltage sag disturbance signal.](image-url)
2.2. Voltage Surge
Voltage swell refers to the voltage or current change phenomenon in which the root mean square value of voltage or current increases to 1.1-1.8 p.u. under power frequency conditions, and the duration is 0.5 cycles to 1 minute. It is basically due to the failure of the power system [3].

The mathematical model of voltage swell can be represented by a sine function or a cosine function. Here the paper uses the cosine function to express as follows:

\[ v(t) = A \{1 + k[u(t_2) - u(t_1)]\} \cos(\omega t) \]  

(2)

In this formula, \( A \) represents the amplitude \( A = 1 \); \( 0.1 \leq k \leq 0.8 \); \( T \leq t_2 - t_1 \leq 9T \). The mathematical model of the disturbance signal of the voltage swell is simulated by Matlab, shown in Figure 2 below.

![Voltage swell disturbance signal](image)

**Figure 2.** Voltage swell disturbance signal.

2.3. Voltage interruption
Voltage interruption refers to the phenomenon of voltage or current changes when the voltage of the power supply or the current flowing through the load drops below 0.1 p.u., and the duration is less than 1 minute. Voltage interruption may be caused by electrical equipment failure, power system failure, control failure, and so on. The mathematical model of voltage interruption can be represented by a sine function or a cosine function. Here the paper uses the cosine function to express as follows:

\[ v(t) = A \{1 - k[u(t_2) - u(t_1)]\} \cos(\omega t) \]  

(3)

In this formula, \( A \) represents the amplitude \( A = 1 \); \( 0.9 \leq k \leq 1 \); \( T \leq t_2 - t_1 \leq 9T \). The mathematical model of the disturbance signal of voltage interruption is simulated by Matlab, as shown in Figure 3 below [4].
2.4. Voltage flicker
Voltage flicker is caused by voltage fluctuations. These two words are usually linked together in power quality standards. It is the subjective sensation of the contrast of the human eye, an extremely uncomfortable feeling. Voltage fluctuations can be caused by electric arc furnaces, rolling mills, and electric motors. Voltage flicker can cause the lights to flicker and cause the malfunction of the protection device, the paralysis of the control system, and the malfunction of the servo motor [5].

The mathematical model of voltage flicker can be represented by a sine function or a cosine function. Here the paper uses the cosine function to express as follows:

\[ v(t) = A[1 + \alpha \cos(\beta \omega t)] \cos(\omega t) \] (4)

In this formula, \( A \) represents the amplitude, \( A=1; \) \( 0.1 \leq \alpha \leq 0.2; \) \( 5 \leq \beta \leq 20 \). The mathematical model of the disturbance signal of voltage flicker is simulated by Matlab, as shown in Figure 4 below.

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**Figure 3.** Voltage interruption disturbance signal.

**Figure 4.** Voltage flicker disturbance signal.
3. Introduction to the principle and nature of S transformation

S transform is a time-frequency analysis method proposed by American geophysicist Stockwell and other scholars in 1996 based on the predecessors' time-frequency analysis method. S transform is the inheritance and development of a short-time Fourier transform and wavelet transform in the paper. It is a lossless and reversible time-frequency analysis method. The S transform overcomes the shortcomings of the two and has its own advantages while having the two's respective characteristics. It is a commonly used analysis method [6]. First, the S transform overcomes to a certain extent the short-term Fourier transform Gaussian window height and width do not change with frequency; secondly, the S transform also overcomes to a certain extent the wavelet transform's weak anti-noise Not enough, its anti-noise ability is powerful.

3.1. One-dimensional continuous S transformation formula

The one-dimensional continuous S transformation formula of signal h(t) is as follows:

\[ S(\tau, f) = \int_{-\infty}^{\infty} h(t)w(\tau - t, f)\exp(-i2\pi ft)dt \]  

Among them \( w(\tau - t, f) \) is the Gaussian window function, and its calculation formula is as follows:

\[ w(\tau - t, f) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left(-\frac{(\tau - t)^2}{2\sigma^2}\right) \]  

Among them \( \tau \) is the translation factor, \( \sigma \) is the scale factor, and the calculation formula \( \sigma \) is as follows:

\[ \sigma = \frac{1}{|\tau|} \]  

3.2. One-dimensional discrete S transform formula

The paper let \( f \to \frac{n}{NT} \), \( \tau \to kT \), where \( T \) is the sampling interval, and \( N \) is the total number of sampling points. The paper can get the one-dimensional discrete S transformation formula as follows:

\[ S[\frac{n}{NT}, kT] = \sum_{m=0}^{N-1} H\left(\frac{m+n}{NT}\right)\exp\left(-\frac{2\pi^2m^2}{n^2}\right)\exp\left(-\frac{i2\pi mk}{N}\right) \]  

When it \( n = 0 \), substituting into the above formula (8) can get the following formula:

\[ S[0, kT] = \frac{1}{N} \sum_{m=0}^{N-1} H\left(\frac{m}{NT}\right) \]  

4. Feature extraction of disturbance signal of power quality

4.1. Briefly introduce the complex number matrix after S transformation

After performing S transformation on the disturbance signal of power quality, a corresponding complex matrix is obtained. The characteristic of the complex matrix is that the rows correspond to the frequency, the columns correspond to the time, and the elements in the matrix correspond to the corresponding frequency and the amplitude of the time after the S transformation [7]. I have to say that S transform brings a lot of time-frequency information to the paper, and the paper should be used and
analysed. Taking voltage sag as an example, the complex number matrix obtained after the S transformation is shown in Figure 5 below.

![Figure 5. Complex number matrix after voltage sag disturbance signal S transformation.](image)

4.2. Briefly introduce the modulus matrix of the complex number matrix

After performing S transformation on the disturbance signal of power quality, a corresponding complex matrix is obtained. The complex matrix can indeed bring a lot of time-frequency information to the paper. Still, the feature extraction of the power quality disturbance signal directly on the matrix will quickly make the disturbance signal's characteristics overlooked, and the classification system that this brings is too much. It is enormous, and undoubtedly, the correct rate of classification and recognition of the final power quality disturbance signal is not high, and the paper's task cannot be effectively completed. The thesis has done many tasks and a lot of labour, but there is almost no gain, labour, and no work [8].

To avoid this situation, the paper should find ways to solve the problem. For this reason, the thesis can first find the modulus matrix of the complex number matrix after S transformation so that the extracted characteristic parameters can first remove some unnecessary, redundant information. This makes classification and recognition simple and dramatically improves classification and recognition accuracy, and obtains the paper's desired results [9]. Taking voltage sag as an example, calculate the modulus matrix of the complex matrix after S transformation shown in Fig. 5, and the modulus matrix is shown in Fig. 6 below.

![Figure 6. Modulus matrix after voltage sag disturbance signal S transformation.](image)
4.3. Simulation of various disturbance signals of power quality and its time-frequency statistical information graph

This part of this thesis is an explanation of the research content of other scholars. I studied this part carefully through simulation and wrote a simulation program myself, but it was slightly different from theirs. The total number of sampling points here is 3200, the sampling frequency is 1600HZ, and the rated frequency is 50HZ, so the number of sampling points per cycle is 32, a total of 100 cycles.

The paper draws four types of simulation diagrams of 7, 8, 9, 10 for each power quality disturbance signal. Figure 7 is a simulation diagram of various power quality disturbance signals, but this is different from the simulation diagram of various power quality disturbance signals mentioned above. The diagram's abscissa is the sampling point instead of time, and the ordinate has not changed. Still the amplitude. Fig. 8 is a simulation diagram of the spectral standard deviation curve of the S transform. The figure's abscissa is frequency, and the ordinate is each row vector of the amplitude matrix obtained after S transform of various power quality disturbance signals, that is, the standard deviation at each frequency. Figure 9 is a simulation diagram of the maximum spectral amplitude curve of the S transform. The figure's abscissa is the frequency, and the ordinate is the amplitude matrix obtained after the S transform of various power quality disturbance signals. Each row vector is the maximum value of each row [10]. Figure 10 is a simulation diagram of the power frequency amplitude curve of the S transform. The figure's abscissa is the sampling point, and the ordinate is the row of the amplitude matrix obtained after the S transform of various power quality disturbance signals. The frequency is 50HZ.

Figure 7. Simulation diagram of voltage sag and its time-frequency statistical information diagram.

Figure 8. Simulation diagram of voltage swell and its time-frequency statistical information diagram.
4.4. Characteristic analysis of various disturbance signals of power quality

The paper can extract some characteristic parameters for classification and recognition through the analysis and comparison of the above figures. Feature extraction is very critical because it is related to the correct rate of classification and recognition. If the selected feature parameters are not good enough, then the decision tree classification and recognition method cannot produce good classification results. The extraction of the paper's feature quantity should reduce its number as much as possible under the premise of ensuring the correct recognition rate, but it contains most of the original, useful information. After extracting the characteristic parameters, the paper designs a characteristic parameter table based on the above simulation diagram, the extracted characteristic quantities, and the definition of various power quality disturbance signals, as shown in Table 1 below.
Table 1. Characteristic parameter table.

| Type of disturbance       | $F_1$ | $F_2$ | $F_3$ | $F_4$ | $F_5$ |
|---------------------------|-------|-------|-------|-------|-------|
| Voltage dip               | 1     | 1     | Less than 0.5 | 0.1 ≤ $F_4$ ≤ 0.9 | -     |
| Voltage swell             | 1     | 1     | Greater than 0.5 | 1.1 ≤ $F_4$ ≤ 1.8 | -     |
| Voltage interruption      | 1     | 1     | Less than 0.5 | $F_4$ < 0.1 | -     |
| Transient oscillation     | 0     | 2     | -     | -     | 1     |
| Harmonic                  | 0     | 2     | -     | -     | 0     |
| Harmonic plus voltage sag | 1     | 2     | Less than 0.5 | -     | -     |
| Harmonic plus voltage swell| 1     | 2     | Greater than 0.5 | -     | -     |

5. Conclusion

This paper proposes and implements a power quality disturbance classification and recognition method based on generalized S transform and PSO-PNN. This method uses generalized S transform with better time-frequency resolution for feature extraction and uses PSO to select smoothing parameters of PNN, which overcomes the shortcomings of smoothing parameters that need to be selected by experience. First, perform generalized S transform on 6 kinds of disturbance signals, analyse and compare the information in generalized S transform modulus matrix of different disturbance signals, and propose 6 kinds of time-frequency characteristic quantities that can effectively distinguish different disturbances. Finally, the extracted features are sent to PSO. Training and testing are performed in the PNN classifier. A large number of simulation experiment results show that this paper's method can accurately and reliably realize the classification and recognition of power quality disturbance signals, with high recognition accuracy and strong anti-noise ability, which is worthy of popularization and application.

6. References

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