A novel detection method for signal disturbances in the ship distribution network based on morphological gradient

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Abstract. Aiming at the deficiencies of the current detection methods for signal disturbances in the ship distribution network, such as low accuracy and slow detection speed, a new detection method for signal disturbances in the ship distribution network based on morphological gradient is proposed. The effectiveness of the proposed method is verified by comparing its detection accuracy and speed with an existing method on five typical signal disturbances in the ship distribution network. The comparison results show that the proposed method can detect the signal disturbances in the ship distribution network quickly and accurately.

1. Introduction
With the rapid development of electric power technology and intelligent technology, every ship has its own power system. As the main power mode of a ship, the power system plays a significant role in the process of ship navigation [1]. Ship distribution network (SDN) is an important part of the ship power system. SDN must have high stability and reliability to ensure the safety of ship power system. In the working process of a SDN, electricity consumption of large loads is time-varying and fluctuation with high probability of random, which may lead to large disturbances in the SDN signals [2]. Therefore, for the purpose of taking certain preventive measures in advance to reduce the appearance probability of signal disturbances in the SDN as much as possible, effectively detecting signal disturbances in a SDN has become a significant research direction for the current ship power system.

In a SDN, there are many factors causing signal disturbances with complicated changing features. In addition, many disturbances may be appeared in a SDN signal simultaneously. At present, there are many researches on the detection of signal disturbances in the SDN, such as, signal disturbance detection methods based on instantaneous reactive power analysis, signal disturbance detection methods based on short-time Fourier transform, signal disturbance detection methods based on entropy calculation, and signal disturbance detection methods based on neural network [3]. All these methods can effectively detect the signal disturbances in the SDN by effectively extracting the disturbance characteristics of these signal disturbances.

However, signal disturbances in the SDN are usually affected by noise, and most of these detection methods have limited anti-noise capability in the detection of signal disturbances in the SDN. As a result, the signal disturbance detection accuracy of most existing methods is not high enough, and the detection speed of most existing detection methods is so slow that their real-time detection is seriously insufficient.

To overcome the shortcomings of the existing signal disturbance detection methods, such as low accuracy and slow detection speed, a new detection method for signal disturbances in the SDN based
on morphological gradient is proposed, and the simulation verification of the proposed method is conducted in the section IV.

2. Signal Disturbance Detection in The Ship Distribution Network Based on Morphological Gradient

2.1. Mathematical morphology
Mathematical morphology is a signal analysis and processing technique in which a signal is measured by a structural element with a certain shape. Mathematical morphology includes two basic operations: expansion and corrosion, through which a variety of combined operations are formed [4].

Let \( f(x, y) \) be the original signal to be processed and \( S(\alpha, \beta) \) be a structural element, with \( x \) and \( \alpha \) respectively representing the abscissa values of \( f \) and \( S \), and \( y \) and \( \beta \) being the Y-coordinate values of \( f \) and \( S \). The corrosion and expansion of \( S(\alpha, \beta) \) with respect to \( f(x, y) \) are expressed as \( \Theta S \) and \( f \oplus S \), respectively [5].

In order to realize the corrosion and expansion of \( S(\alpha, \beta) \) with respect to \( f(x, y) \), structural element \( S(\alpha, \beta) \) is applied to each pixel of \( f(x, y) \) from top to bottom and from left to right simultaneously. The minimum value of the overlapping part is the result of corrosion and the maximum value being the result of expansion. \( \Theta S \) and \( f \oplus S \) are respectively defined as [6]

\[
(\Theta S)(x, y) = \min_{\alpha, \beta} [f(x + \alpha, y + \beta) - S(\alpha, \beta)] \\
(f \oplus S)(x, y) = \max_{\alpha, \beta} [f(x - \alpha, y - \beta) + S(\alpha, \beta)]
\]

(1) (2)

If the structural element \( S(\alpha, \beta) \) is flat, corrosion and expansion expressed in (1) and (2) can be rewritten as

\[
(\Theta S)(x, y) = \min_{\alpha, \beta} [f(x + \alpha, y + \beta)] \\
(f \oplus S)(x, y) = \max_{\alpha, \beta} [f(x - \alpha, y - \beta)]
\]

(3) (4)

For corrosion, the center point of \( S(\alpha, \beta) \) is compared with the points in \( f(x, y) \). If all the points in \( S(\alpha, \beta) \) are within the range of \( f(x, y) \), the compared point will be retained; otherwise, the compared point will be removed. Expansion is made by comparing the center of \( S(\alpha, \beta) \) with the points in \( f(x, y) \) and around \( f(x, y) \). If one or more points in \( S(\alpha, \beta) \) are within the range of \( f(x, y) \), these compared points will be retained; otherwise, these compared points will be removed.

2.2. Morphological gradient
Morphological gradient can effectively filter out the noise in the SDN disturbance signals while retaining the useful information in these signals [4].

The classical morphological gradient, called the basic morphological gradient (BMG), is the difference between the expansion output of a signal and the corrosion output of this signal. BMG can be utilized to extract the outside contour part of the processed signal.

\[
BMG(x, y) = (f \oplus S)(x, y) - (\Theta S)(x, y)
\]

(5)

Inside morphological gradient (IMG) is the difference between the original signal and its corrosion output.

\[
IMG(x, y) = f(x, y) - (\Theta S)(x, y)
\]

(6)

External morphological gradient (EMG) is the difference between the original signal and its expansion output.

\[
EMG(x, y) = (f \oplus S)(x, y) - f(x, y)
\]

(7)
In this study, a combination form of IMG and EMG (combined morphological gradient) is constructed to detect the signal disturbances in the SDN:

$$c_{\text{msg}}(x,y) = \frac{I_{\text{msg}}(x,y) - I_{\text{msg}}(x,y)}{2} = \frac{(f \odot S)(x,y) + (f \odot S)(x,y) - 2f(x,y)}{2}$$ (8)

3. five Typical Signal Disturbances in The Ship Distribution Network

five typical signal disturbances in the SDN shown in Table 1 are selected to verify the effectiveness of the proposed method.

| Serials | Signal disturbances       |
|---------|---------------------------|
| 1       | voltage swell             |
| 2       | voltage dip               |
| 3       | transient oscillation     |
| 4       | momentary interruption    |
| 5       | harmonics                 |

Table 2 presents the mathematical expressions of these five typical signal disturbances shown in Table 1 [7].

| Disturbance signals | Mathematical expressions | Parameters |
|---------------------|--------------------------|------------|
| voltage swell       | $x(t) = [1 - \alpha(\alpha(t) - u(t))] \sin(\epsilon t)$ | $0.1 < \alpha < 0.9, T \leq t_2 - t_1$ |
| voltage dip         | $x(t) = [1 + \alpha(\alpha(t) - u(t))] \sin(\epsilon t)$ | $0.1 < \alpha < 0.9, T \leq t_2 - t_1$ |
| transient oscillation | $x(t) = [1 - \alpha(\alpha(t) - u(t))] \sin(\epsilon t)$ | $0.1 < \alpha < 0.9, T \leq t_2 - t_1$ |
| momentary interruption | $x(t) = \sin(\epsilon t) + \alpha e^{-(\epsilon t - \beta)} \sin(\beta t)\{u(t_2) - u(t_1)\}$ | $0.1 < \alpha < 0.8, \beta > 7, 0 \leq t_2 - t_1 \leq 2T$ |
| harmonics           | $x(t) = \sin(\epsilon t) + \sum_{i=2}^{N} \alpha_{2i} \sin[(2i-1)\epsilon t]\{u(t_2) - u(t_1)\}$ | $0.1 < \alpha_{i} < \alpha_{i-1} < 0.9, T \leq t_2 - t_1$ |

4. Case Studies

To verify the performance of the proposed detection method based on morphological gradient, a detection method based on neural network (Method 1) is selected for simulation comparison with the proposed method.

In the following case study, 30 dB Gaussian white noise is added to each original disturbance signal to verify the effectiveness of the provided method under noise. The sampling frequency is set at 4000 Hz.

4.1. Detection accuracy comparison for five typical signal disturbances in the ship distribution network

Fig. 1 (a) shows the original signal of voltage dip who starts at the 801 sampling point and ends at the 2002 sampling point. Fig. 2 (a) shows the original signal of voltage swell who also starts at the 801 sampling point and ends at the 2002 sampling point. Fig. 3 (a) shows the original signal of momentary interruption who starts at the 432 sampling point and ends at the 1649 sampling point. Fig. 4 (a) shows the original signal of transient oscillation who starts at the 626 sampling point and ends at the 790 sampling point. Fig. 5 (a) shows the original signal of harmonics who starts at the 510 sampling point and ends at the 3027 sampling point.
Taking voltage dip as an example, the signal disturbance detection results of Method 1 and the proposed method are analyzed. Fig.1 (b) and Fig.1 (c) are the detection results of Method 1 and the proposed method on the original voltage dip signal depicted in Fig.1 (a), respectively.

After the original signal of voltage dip being processed by Method 1, the output signal are still seriously affected by Gaussian white noise, which affects the locating of disturbances. Through the processing of the original disturbance signal by the method proposed in this research, the peak pulses corresponding to the starting and ending positions of the disturbance signal can be enhanced on the basis of filtering the influence of Gaussian white noise, which ensures the disturbance detection effect of the proposed method is more accurate than Method 1.

Figure 1 Voltage dip detection: (a) Original disturbance signal; (b) output of Method 1; (c) output of the proposed method.

Figure 2 Voltage swell detection: (a) Original disturbance signal; (b) output of Method 1; (c) output of the proposed method.
Figure 3  Momentary interruption detection: (a) Original disturbance signal; (b) output of Method 1; (c) output of the proposed method.

Figure 4  Transient oscillation detection: (a) Original disturbance signal; (b) output of Method 1; (c) output of the proposed method.

Figure 5  Harmonics detection: (a) Original disturbance signal; (b) output of Method 1; (c) output of the proposed method.
The detected starting and ending disturbance pulses in Fig. 1 (c) accurately correspond to the starting and ending points in the original disturbance signal shown in Fig. 1 (a). The detection and analysis of the other three signal disturbances are similar to the process of voltage dip.

Detection accuracy comparison results of five typical signal disturbances in the ship distribution network are presented in Table 3.

Table 3  Detection accuracy comparison results of five typical Signal disturbances in The ship distribution network (%)

| Serials | Disturbance Signal   | Method 1 | The proposed method |
|---------|----------------------|----------|---------------------|
| 1       | Voltage swell        | 90       | 98                  |
| 2       | Voltage dip          | 90       | 98                  |
| 3       | Transient oscillation| 88       | 97                  |
| 4       | Momentary interruption| 92     | 99                  |
| 5       | Harmonics            | 89       | 97                  |

As shown in Table 3, the detection accuracy of signal disturbances in the ship distribution network based on the combined morphological gradient is higher than that of Method 1. Therefore, the proposed method can effectively improve the detection accuracy of signal disturbances in the SDN.

4.2. Detection speed comparison for five typical signal disturbances in the ship distribution network

Detection speed comparison results of five typical signal disturbances in the SDN are presented in Table 4.

As shown in Table 4, the detection speed of the proposed method is faster than that of Method 1.

Table 4  Detection speed comparison results of five typical signal disturbances in the ship distribution network (second)

| Serials | Disturbance Signal   | Method 1 | The proposed method |
|---------|----------------------|----------|---------------------|
| 1       | Voltage swell        | 12       | 7                   |
| 2       | Voltage dip          | 10       | 7                   |
| 3       | Transient oscillation| 10       | 7                   |
| 4       | Momentary interruption| 10     | 7                   |
| 5       | Harmonics            | 10       | 7                   |

5. Conclusions

To solve the problems existing in the current detection methods of signal disturbances in the ship distribution network, such as low detection accuracy and slow detection speed, a new detection method based on morphological gradient is proposed in this research. The effectiveness of the proposed method is verified by comparing the detection accuracy and speed of the proposed method for five typical signal disturbances with that of a detection method based on neural network. Comparison results prove that the proposed method can detect signal disturbances in the ship distribution network faster and more accurate than the detection method based on neural network.
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