Transformer for Single-phase Line Break Fault in Low Voltage Three-phase Distribution System

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Abstract. Single-phase line break fault is becoming more and more frequent in low voltage three-phase distribution system. Therefore, once the single-phase line break fault occurs, three-phase loads cannot work, which will cause unnecessary economic loss. This paper proposed a transformer that can transfer power from two-phase to three-phase for single-phase line break fault in low voltage three-phase distribution system. The proposed transformer can solve the problem that these three-phase loads cannot work due to single-phase line break fault. At the same time, the principle that the transformer transfers power from two-phase to three-phase is analyzed. Finally, simulation results verify that the proposed transformer can transfer power from two-phase to three-phase.

1. Introduction
At the end of the power system, the low voltage three-phase distribution system plays an important role in supplying the power to user. In recent years, the single-phase line break fault has attracted more and more attention from the power sector and user.

The single-phase line break fault is usually caused by meteorological disasters or wire overload or mechanical disruption or some other reasons [1, 2]. In the low voltage distribution network, the single-phase line break fault will cause the three-phase loads, such as the flue-cured tobacco plants and refrigeration plants, to fail to draw three-phase power, which will cause serious economic losses. Some scholars have focused on the analysis and location of the single-phase line break fault [3, 4]. However, these studies do not address the issue of how to supply power to three-phase loads when the single-phase line break fault occurs. Reference [5] analyzes the solution of single-phase line break fault in low voltage distribution network. However, the solution is to disconnect the corresponding circuit breaker, which does not meet the power demand of low voltage three-phase loads. The technology that two-phase voltage transformers to three-phase voltage is studied in railway power distribution system in China [6], the two-phase voltage is balanced (the amplitude are equal and the phase difference is 90 degrees) in railway power distribution system. However, the technology applied in railway power distribution system cannot be used to solve the single-phase line break fault in low voltage three-phase distribution system.

In this paper, a transformer which can transfer power from two-phase to three-phase for single-phase line break fault is proposed in low voltage three-phase distribution system. And the principle of two-phase power conversion to three-phase power is analyzed. Finally, the simulation model of the proposed transformer is established to verify the correctness and the validity of the theoretical analysis.
2. The proposed transformer

2.1. Configuration of the proposed transformer

The structure of the proposed transformer is shown in Fig. 1. It consists of a single-phase transformer and a reverse YNd11 transformer. In Fig. 1, the primary and secondary turns of the single-phase transformer and the reverse YNd11 transformer are \( \omega_1 \) and \( \omega_2 \), respectively. The ratio \( K \) of the single-phase transformer and the reverse YNd11 transformer is \( \omega_1/\omega_2 \). In this paper, \( K=1 \).

![Figure 1. Structure of the proposed transformer.](image)

2.2. Principle Analysis of the proposed transformer

We suppose the single-phase line break fault occurs on phase B, and the analysis method is similar when the single-phase line break fault occurs on other phase. As shown in Fig. 1, the primary side voltage of the single-phase transformer is \( U_A \), and the secondary side voltage of the single-phase transformer is \(-U_A\). According to the schematic diagram of the reverse YNd11 transformer, the relationship of current and magnetic balance can be expressed as

\[
\begin{align*}
    i_a + i_b + i_c &= 0 \\
    \omega_2 i_a &= -\omega_1 i_{Aa} \\
    \omega_2 i_b &= -\omega_1 i_{Ab} \\
    \omega_2 i_c &= -\omega_1 i_{Ac} \\
    -i_A &= i_{Aa} - i_{Ab} \\
    i_c &= i_{Ac} - i_{Ab}
\end{align*}
\]

Where \( i_a, i_b \) and \( i_c \) represent the secondary three-phase current of the reverse YNd11 transformer, respectively; \( i_{Aa}, i_{Ab} \) and \( i_{Ac} \) denote the primary winding current of the reverse YNd11 transformer, respectively; \( i_A \) and \( i_c \) represent the primary side current of the proposed transformer, respectively.
From (1), the current relationship on the primary and secondary side of the proposed transformer is as follows:

\[
\begin{bmatrix}
I_a \\
I_c
\end{bmatrix} = \frac{1}{K} \begin{bmatrix}
1 & -1 & 0 \\
0 & 1 & -1
\end{bmatrix}
\begin{bmatrix}
I_A \\
I_B
\end{bmatrix}
\tag{2}
\]

According to the schematic diagram of the reverse YNd11 transformer shown in Fig. 1, the relationship of voltage balance can be expressed as

\[
\begin{align*}
\frac{-\hat{U}_a}{\hat{U}_a} &= \frac{\alpha_1}{\omega_2} \\
\frac{-(-\hat{U}_c - \hat{U}_A)}{\hat{U}_b} &= \frac{\omega_1}{\omega_2} \\
\frac{-\hat{U}_c}{\hat{U}_c} &= \frac{\alpha_1}{\omega_2}
\end{align*}
\tag{3}
\]

Where \( \hat{U}_A \) and \( \hat{U}_c \) represent the primary side voltage of the proposed transformer, respectively; and \( \hat{U}_a \), \( \hat{U}_b \), and \( \hat{U}_c \) denote the secondary side voltage of the proposed transformer, respectively.

From (3), the voltage relationship on the primary side and secondary side of the proposed transformer is as follows:

\[
\begin{bmatrix}
\hat{U}_a \\
\hat{U}_b \\
\hat{U}_c
\end{bmatrix} = \frac{1}{K} \begin{bmatrix}
-1 & 0 \\
1 & 1 \\
0 & -1
\end{bmatrix}
\begin{bmatrix}
\hat{U}_A \\
\hat{U}_B \\
\hat{U}_C
\end{bmatrix}
\tag{4}
\]

According to (4), the primary and secondary voltage phasor diagram of the proposed transformer is illustrated in Fig. 2.

**Figure 2.** The primary and secondary voltage phasor diagram.

3. **Simulation verification**

In order to verify the proposed transformer, the simulation based on MATLAB/Simulink has been established. The simulation parameters are: the phase voltage (RMS) is 220V, and the grid frequency is 50Hz, and the ratio of the single-phase transformer and the reverse YNd11 transformer is 1:1.
### 3.1. Single-phase line break fault occurs on phase A

This situation will be considered through the following two wiring cases:

1) Case 1: Phase B connected to the single-phase transformer, and the phase C is connected to the inverse YNd11 transformer; In this situation, the simulation results are shown in Fig. 3(a).

2) Case 2: Phase B is connected to the inverse YNd11, and phase C is connected to the single-phase transformer, the simulation result is shown in Fig. 3(b).

![Figure 3. Single-phase line break fault occurs on phase A.](image1)

When single-phase line break fault occurs on phase A, it can be seen from Fig. 3 that only the case 2 can meet the requirement of positive-sequence three-phase voltage, but the case 1 obtains the negative-sequence three-phase voltage.

### 3.2. Single-phase line break fault occurs on phase B

This situation will be considered through the following two wiring cases:

1) Case 1: Phase A connected to the single-phase transformer, and the phase C is connected to the inverse YNd11 transformer; In this situation, the simulation results are shown in Fig. 4(a).

2) Case 2: Phase A is connected to the inverse YNd11 transformer, and phase C is connected to the single-phase transformer, the simulation result is shown in Fig. 4(b).

![Figure 4. Single-phase line break fault occurs on phase B.](image2)

When single-phase line break fault occurs on phase B, it can be seen from Fig. 4 that only the case 1 can meet the requirement of positive-sequence three-phase voltage, but the case 2 cannot meet the requirement.

### 3.3. Single-phase line break fault occurs on phase C

This situation will be considered through the following two wiring cases:

1) Case 1: Phase A connected to the single-phase transformer, and the phase B is connected to the inverse YNd11 transformer; In this situation, the simulation results are shown in Fig. 5(a).

2) Case 2: Phase A is connected to the inverse YNd11, and phase B is connected to the single-phase transformer, the simulation result is shown in Fig. 5(b).
When single-phase line break fault occurs on phase C, it can be seen from Fig. 5 that only the case 2 can obtain the positive-sequence three-phase voltage, but the case 1 can obtain the negative-sequence three-phase voltage.

3.4. Summary
When single-phase line break fault occurs on different phase of the low voltage three-phase distribution network, a positive-sequence three-phase voltage can be obtained according to the specific transformer wiring method shown in Table 1.

Table 1. The specific transformer wiring method.

| Single-phase line break fault | Transformer wiring |
|------------------------------|--------------------|
| On phase A                   | Phase B is connected to the inverse YNd11, and phase C is connected to the single-phase transformer |
| On phase B                   | Phase A connected to the single-phase transformer, and the phase C is connected to the inverse YNd11 transformer |
| On phase C                   | Phase A is connected to the inverse YNd11, and phase B is connected to the single-phase transformer |

4. Conclusion
This paper proposed a transformer that can transfer power from two-phase to three-phase, which can solve the single-phase line break fault. And this paper analyses the principle of the proposed transformer. Simulation results shows the correctness of the theoretical analysis.

Based on the principle analysis and simulation results, it can be seen that when the single-phase line break fault occurs, the three-phase positive sequence voltage can be obtained according to the specific transformer wiring method shown in Table 1, which can solve the problem that the three-phase loads cannot work due to the single-phase line break fault.

Acknowledgments
This work was financially supported by the Key Science and Technology Program of Yunnan Electric Power Grid (YNKJXM20180366).

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