A New Method to Analyze the Error-wiring of Electric Energy Metering Device

Jia Li*, Wanyu Xue, Li Gao, Bing Zhang and Min Zhou
State Grid Sichuan Technical Training Center, Chengdu 610072, China
E-mail: itouvi@qq.com.

Abstract. The error-wiring of the three-phase three-wire electric energy metering device will cause large measurement error which results in the economic dissension. The previous research focuses on the circuits between the transformers and the electric energy meter, but neglects the polarity of the transformers caused by oversight. So a more perfect method is presented, which considers the reverse polarity of the voltage transformers. The steps are given to solve the problems which can’t be solved by the original methods. The correctness and validity of the technique are proved by a calculation example.

1. Introduction
In the connection of all kinds of electric energy metering devices, the type of wrong wiring of the three-phase three-wire electric energy metering device is the most difficult to be judged [1]. The causes for error-wiring of three-phase three-wire electric energy metering device may include: the connection error between transformer and electric energy meter, the error of current transformer polarity and the error of voltage transformer polarity.

In the case of wrong connection between the transformer and the electric energy meter, the main analysis methods [2] include: phase breaking method, phase voltage cross method, six-angle-graph method, phase meter method, etc. The phase breaking method [3] and the phase voltage cross method have higher requirements for the metering points, which affect the metering during the inspection period, and distinguish right from wrong, but not judge the types of the wrong wiring. The method of six-angle-graph needs to be tested in the 48 wrong connection modes by adjusting the phase quantity according to the phase sequence in the phasor diagram. The phase meter method [4-6] is a widely used method at present. If the phase of the first element voltage leads the second element 300 degrees, the voltage connection way of electric energy meter is positive sequence. And if the phase of the first element voltage leads the second element 60°, the voltage connection way of electric energy meter is reverse sequence. The above two cases are not applicable to the condition of mutual inductor with polarity reversal. The polarity reversal of the current transformer can be regarded as the correction of the reverse connection of the secondary circuit, for the single-phase connection of the current transformer. Due to the V-v connection of the voltage transformers [7] in the metering secondary circuit, it can be divided into two cases: one is both polarities of secondary windings reverse, which can be deal with the reverse connection of voltage circuit; the other is the single polarity reverse, which has no exact method now.

With more and more electric selling entities entering into the Chinese power market, the difficulty in the supervision of measuring instruments is increasing. It maybe lead to the measurement errors, that the transformers with reverse polarity are applied in power grid. This paper has studied the physical phenomena caused by the wrong wiring under the circumstance of the voltage transformer with one polarity of secondary winding reverse, and puts forward the steps of wiring inspection
process, supplements the phase meter method.

2. The types of error connection considering polarity reversal of voltage transformer

In the case of voltage transformers with one polarity reverse, the voltage connected into the electric energy meter may rise, and the phase sequence cannot be carried out by the original phase meter method. The error connection situations are shown in Figure 1.

![Diagram of error connection](image)

**Figure 1.** The types of error connection considering polarity reversal of voltage transformer

3. The phasor relationship of error connection considering polarity reversal of voltage transformer

In the case of (1) in Figure 1, the voltage of the electric energy meter is

\[
\begin{align*}
\dot{U}_{12} &= \dot{U}_{ab} = k \dot{U}_{BA} \\
\dot{U}_{32} &= \dot{U}_{cb} = k \dot{U}_{CB}
\end{align*}
\]  

(1)

In the form, \( k \) is the transformer ratio. It is known that the voltage connected into the electric energy meter is in the reverse phase sequence (BAC). The phasor relationship is shown as the (a) of Figure 2, which indicates that \( \dot{U}_{12} \) leads \( \dot{U}_{32} \) 120°.

In the case of (2) in Figure 1, the voltage of the electric energy meter is

\[
\begin{align*}
\dot{U}_{12} &= \dot{U}_{ba} = k \dot{U}_{AB} \\
\dot{U}_{32} &= \dot{U}_{ca} = k \left( \dot{U}_{CB} + \dot{U}_{AB} \right)
\end{align*}
\]  

(2)

It is known that the voltage connected into the electric energy meter is in the positive phase sequence (ABC). The phasor relationship is shown as the (b) of Figure 2, which indicates that \( \dot{U}_{12} \) leads \( \dot{U}_{32} \) 330°, and the voltage of the second element is higher than the line voltage \( \sqrt{3} \), that is 3 times as much as the phase voltage.
Figure 2. The phasor relationship of error connection considering polarity reversal of voltage transformer

In the case of (3) in Figure 1, the voltage of the electric energy meter is

\[
\begin{align*}
\dot{U}_{12} &= \dot{U}_{bc} = k \dot{U}_{BC} \\
\dot{U}_{32} &= \dot{U}_{ac} = k \left( \dot{U}_{AB} + \dot{U}_{BC} \right)
\end{align*}
\] (3)

The phasor relationship is shown as the (c) of Figure 2, which indicates that \( \dot{U}_{12} \) leads \( \dot{U}_{32} \) 30°, and the voltage of the second element is higher than the line voltage \( \sqrt{3} \), that is 3 times as much as the phase voltage.

In the case of (4) in Figure 1, the voltage of the electric energy meter is

\[
\begin{align*}
\dot{U}_{12} &= \dot{U}_{ac} = k \left( \dot{U}_{AB} + \dot{U}_{BC} \right) \\
\dot{U}_{32} &= \dot{U}_{bc} = k \dot{U}_{BC}
\end{align*}
\] (4)

The phasor relationships shown as the (d) of Figure 2, which indicates that \( \dot{U}_{12} \) leads \( \dot{U}_{32} \) 330°, and the voltage of the second element is higher than the line voltage \( \sqrt{3} \), that is 3 times as much as the phase voltage.

In the case of (5) in Figure 1, the voltage of the electric energy meter is
The phasor relationship is shown as the (e) of Figure.2, which indicates that $\dot{U}_{12}$ leads $\dot{U}_{32}$ $240^\circ$.

In the case of (6) in Figure.1, the voltage of the electric energy meter is
\[
\begin{align*}
\dot{U}_{12} &= \dot{U}_{ca} = k (\dot{U}_{CB} + \dot{U}_{AB}) \\
\dot{U}_{32} &= \dot{U}_{ba} = k \dot{U}_{AB}
\end{align*}
\]  
(6)

The phasor relationship is shown as the (f) of Figure.2, which indicates that $\dot{U}_{12}$ leads $\dot{U}_{32}$ $30^\circ$, and the voltage of the second element is higher than the line voltage, that is 3 times as much as the phase voltage.

In the case of (7) in Figure.1, the voltage of the electric energy meter is
\[
\begin{align*}
\dot{U}_{12} &= \dot{U}_{ab} = k \dot{U}_{AB} \\
\dot{U}_{32} &= \dot{U}_{cb} = k \dot{U}_{BC}
\end{align*}
\]  
(7)

The phasor relationship is shown as the (g) of Figure.2, which indicates that $\dot{U}_{12}$ leads $\dot{U}_{32}$ $120^\circ$.

In the case of (8) in Figure.1, the voltage of the electric energy meter is
\[
\begin{align*}
\dot{U}_{12} &= \dot{U}_{ba} = k \dot{U}_{BA} \\
\dot{U}_{32} &= \dot{U}_{ca} = k (\dot{U}_{BC} + \dot{U}_{BA})
\end{align*}
\]  
(8)

The phasor relationship is shown as the (h) of Figure.2, which indicates that $\dot{U}_{12}$ leads $\dot{U}_{32}$ $330^\circ$, and the voltage of the second element is higher than the line voltage, that is 3 times as much as the phase voltage.

In the case of (9) in Figure.1, the voltage of the electric energy meter is
\[
\begin{align*}
\dot{U}_{12} &= \dot{U}_{bc} = k \dot{U}_{CB} \\
\dot{U}_{32} &= \dot{U}_{ac} = k (\dot{U}_{AB} + \dot{U}_{CB})
\end{align*}
\]  
(9)

The phasor relationship is shown as the (i) of Figure.2, which indicates that $\dot{U}_{12}$ leads $\dot{U}_{32}$ $30^\circ$, and the voltage of the second element is higher than the line voltage, that is 3 times as much as the phase voltage.

In the case of (10) in Figure.1, the voltage of the electric energy meter is
The phasor relationship is shown as the (j) of Figure.2, which indicates that \( U_{12} \) leads \( U_{32} \) 330°, and the voltage of the second element is higher than the line voltage, that is 3 times as much as the phase voltage.

In the case of (11) in Figure.1, the voltage of the electric energy meter is

\[
\begin{align*}
\dot{U}_{12} &= \dot{U}_{ac} = k(\dot{U}_{AB} + \dot{U}_{CB}) \\
\dot{U}_{32} &= \dot{U}_{bc} = k \dot{U}_{CB}
\end{align*}
\]  

The phasor relationship is shown as the (k) of Figure.2, which indicates that \( U_{12} \) leads \( U_{32} \) 240°.

In the case of (12) in Figure.1, the voltage of the electric energy meter is

\[
\begin{align*}
\dot{U}_{12} &= \dot{U}_{ca} = k(\dot{U}_{BC} + \dot{U}_{RA}) \\
\dot{U}_{32} &= \dot{U}_{ba} = k \dot{U}_{RA}
\end{align*}
\]  

The phasor relationship is shown as the (l) of Figure.2, which indicates that \( U_{12} \) leads \( U_{32} \) 30°, and the voltage of the second element is higher than the line voltage, that is 3 times as much as the phase voltage.

4. **The technical roadmap of wiring inspection**

Based on the above conclusion, the original phase table method is amended to get the following steps:

1. Measure the terminal voltage of the electric energy meter, and the terminal whose voltage value is 0 is connected with the B phase.
2. Measure the phase difference between the first element and second element. If the phase difference equals to 30°, 120° or 300°, the rest connected voltages of the electric energy meter can be determined by the positive sequence. If the phase difference equals to 60°, 240° or 330°, the rest connected voltages of the electric energy meter can be determined by the reverse sequence.
3. If the phase difference is 60°, 120°, 240° or 300°, the current phase can be judged according to the principles of the phase table method, and then calculate the compensating electricity.
4. If the phase difference is 30° or 330°, judge the reverse polarity according to the principle of "B phase without current" firstly, and then identify the voltage and current phase of meter’s terminal. At the time of calculating the compensating electricity, the element with higher voltage connected, and the power expression in the wrong state is multiplied by \( \sqrt{3} \).

5. **Example analysis**

In the site survey of a three-phase three-wire electric energy metering device, the voltage transformer ratio is 10000V/100V; the current transformer ratio is 100A/20A. The first element of the electric energy meter is 100V, and the second element of the electric energy meter is 173V. The first voltage terminal of the electric energy meter has the voltage of 0. The phase difference between the first element and the second is 330°. For the first element, its voltage leads the current 50°. And for the second element, its voltage leads the current 290°.

According to the method in this paper, the first voltage terminal of the electric energy meter is
connected with the B phase, for it has the voltage of 0; the second voltage terminal is connected with the A phase, and the third voltage terminal is connected with the C phase, for the reverse sequence deduced by the phase difference is 330°. On the basis that the current of B phase isn’t collected, the secondary winding between A phase and B phase reverses. Its phasor relationship is shown in the Figure.3.

![Figure 3. Phasor relationship of the voltage and current](image)

It is known that the power factor angle for the first element is $30^\circ + \varphi$, and the power factor angle for the second element is $60^\circ - \varphi$, and the voltage connected into the second element rises $\sqrt{3}$. So the power measured in the case of error-wiring is

$$P = UI \left[ \cos(30^\circ + \varphi) + \sqrt{3} \cos(60^\circ - \varphi) \right] = UI \left[ \sqrt{3} \cos \varphi + \sin \varphi \right]$$

And the correction coefficient is $K = \sqrt{3} / (\sqrt{3} + \tan \varphi)$.

6. Conclusion
When one winding of the voltage transformers in the three-phase three-wire electric energy metering device is reversed, the phase difference between elements will appear in special angles, such as 30°, 120°, 240° or 330°. So the original phase metering method no longer applies. 12 kinds of error-wiring cases are analyzed resulted by the polarity of the voltages transformers and wrong connection, and deduce a new method to solve the complex error-wiring problems. It is proved by an example that the error type can be judged effectively and accurately, and the correction coefficient is calculated.

7. References
[1] Zhou N, Wang J, Wang Q. A novel estimation method of metering errors of electric energy based on membership cloud and dynamic time warping [J]. IEEE Transactions on Smart Grid, 2017, 8 (3): 1318-1329.

[2] Gu F B. Analysis On Phase Shift Method Of Stealing Electricity Meter Wiring[C]//International Conference on Education, Management, Commerce and Society (EMCS-15). Atlantis Press, 2015.

[3] Leite C C, de Jesus A, Kolling L, et al. Extraction method based on emulsion breaking for the determination of Cu, Fe and Pb in Brazilian automotive gasoline samples by high-resolution continuum source flame atomic absorption spectrometry[J]. Spectrochimica Acta Part B: Atomic Spectroscopy, 2018.

[4] Ren X, Summers A M, Vajdi A, et al. Single-shot carrier-envelope-phase tagging using an f–2f interferometer and a phase meter: a comparison [J]. Journal of Optics, 2017, 19 (12): 124017.

[5] Pamulaparthy B, Gerdan G P. Method, system and device of phase enable or disable functionality in a meter: U.S. Patent 9,197,066 [P]. 2015-11-24.

[6] Kawagoe J, Kawasaki T. A new precision digital phase meter and its simple calibration method [J]. IEEE Transactions on Instrumentation and Measurement, 2010, 59 (2): 396-403.

[7] Liu L, Li H, Xue Y, et al. Decoupled active and reactive power control for large-scale grid-connected photovoltaic systems using cascaded modular multilevel converters [J]. IEEE
Transactions on Power Electronics, 2015, 30 (1): 176-187.