A load switching intelligent sensing system based on medium voltage carrier communication device

Lishan Ma*, Tao Yu*, Xuerong Li, Shunhu Dong, Guorui Zhang, Jianying Xu

1State grid Qinghai electric power company, Guoluo, Qinghai, 814000, China;
2State grid Qinhuangdao electric power supply company, Qinhuangdao, Hebei, 066600, China;
3Qingdao Topscomm Communication Co., LTD, Qingdao, Shandon, 266000, China)
*Corresponding author’s e-mail: 13997231313@qh.sgcc.com.cn

Abstract: As the core line of distribution network load transmission, 10kV medium voltage power line can reduce line loss to a great extent. However, the current situation of the power grid is that the basic information of 10kV line is disordered and the relationship between line changes is fuzzy, which leads to unbalanced load and high line loss rate. At present, the solution is the traditional way such as manual line inspection and power drawing discrimination, which has poor timeliness, low accuracy and the risk of potential personnel injury. In this paper, a load switching intelligent sensing system based on medium voltage carrier communication device is discussed. By using the unique physical line of 10kV medium voltage line to transmit the characteristic sequence signal, the relationship between line changes can be accurately identified in real time, and the load switching intelligent sensing system can make the 10kV medium voltage power line in the optimal load distribution, reduce the line loss and effectively reduce the loss of electric energy.

1. Introduction

The 10kV medium voltage power line is the core line of load transmission in distribution network, the ideal state is that the load distribution on the line is uniform, the power loss is minimized, and the energy transmission efficiency is improved to the greatest extent. In fact, the load distribution on most lines is unreasonable, and the load on the line takes 10kV/380V transformer as the unit, only the reasonable distribution of transformers under the power supply line can reduce the line loss rate to the greatest extent. With the continuous development of power supply and distribution technology, new 10kV power frequency transformers are continuously connected, which greatly increases the complexity of medium voltage distribution network [1-2]. In addition, the terrain of medium voltage distribution lines is complex, the line modes are diverse, and the line transformation and load switching are often carried out in the process of construction and maintenance of medium voltage distribution network, which makes the original clear relationship between medium voltage lines change constantly and is difficult to clarify, and it greatly increases the difficulty of developing power distribution business [3].

Since 2016, many institutions in power system have begun to try to use big data method to identify the attribution, using electric energy meter current, power data, power frequency zero-crossing offset
and power frequency zero-crossing distortion to identify the attribution of stations. However, the big data method is greatly affected by factors such as equipment sampling accuracy and data synchronization, and the cost of discrimination is high, so the good results have not yet been achieved[4]. Medium-voltage power line carrier[5] is a kind of proprietary wired communication of power companies[6]. From the perspective of technical realization, this paper studies the method of intelligent sensing of load unit switching using medium-voltage carrier communication.

Qinghai Province has a wide area, and its distribution network extends along various terrains, spanning foothills, valleys, farmland, pastures and forests, which requires extremely high efficiency of electric energy transmission and 100% accuracy of power transmission stop. For these areas and such scenes, the medium voltage power line carrier is used as a communication means to accurately identify the attribution of transformer lines and locate the real-time physical operation state of each load unit.

2. Load switching intelligent sensing system
The line loss rate is an important index in the assessment of the power distribution department, and the accurate line-to-line relationship of load units is an effective means to reduce the line loss rate[7]. The terminal equipment in the intelligent sensing system for load switching (Figure 1) monitors the status of load units in real time, when the line-to-line relationship of load units changes, the terminal injects a low-frequency characteristic sequence carrier signal[8] into the low-voltage side, and the carrier signal passes through the transformer and is transmitted to the outlet end of the substation through the 10kV medium-voltage line, the analyzer at the outlet end extracts and identifies the characteristic sequence signal and reports it to the master station, which performs algorithm to judge the relationship between the outlet and the transformer and notifies the operating department by SMS.

2.1 Transmission characteristics of carrier signal through transformer
At present, the vast majority of power systems in the world use three-phase system for power production, transmission and power supply[9], and the industrial production of transformers has been standardized, the connection type of primary and secondary sides of 10kV/380kV transformers in field operation is Dyn11(Ydn11)[10]. When the connection type of primary and secondary sides of transformers is Dyn11, the primary side is triangular connection (D1) and the secondary side is star connection (D1), when the connection type of primary side and secondary side of transformer is Ynd11, the primary side is star connection (Yn) and the secondary side connection type is triangle (D11).

Taking the star triangle Dyn11 as an example (figure 2), it is transformed into a corner vector diagram (figure 3) through the connection group.

According to Kirchhoff’s current law (KCL), it can be known that,

\[ I_A = I_{AB} - I_{CA} = \frac{1}{n} I_a - \frac{1}{n} I_c = \sqrt{3} - \frac{1}{n} I_a \angle -30^\circ \]  
\[ (1) \]

\[ I_B = I_{BC} - I_{AB} = \frac{1}{n} I_b - \frac{1}{n} I_a = \sqrt{3} - \frac{1}{n} I_a \angle -30^\circ \]  
\[ (2) \]

\[ I_C = I_{CA} - I_{BC} = \frac{1}{n} I_c - \frac{1}{n} I_b = \sqrt{3} - \frac{1}{n} I_a \angle -30^\circ \]  
\[ (3) \]
Figure 1. Diagram of intelligent sensing system for load switching

Figure 2. Connection group of Dyn11 connection mode transformer

Figure 3. Dyn11 connection mode transformer star triangle Angle vector diagram
\[ I_a' = (I_a - I_c) / \sqrt{3} \]  
\[ I_b' = (I_b - I_a) / \sqrt{3} \]  
\[ I_c' = (I_c - I_b) / \sqrt{3} \]  

The current of phase A on the triangle side (primary side) is \( I_A \), which is in phase with the converted current \( I_a' \). Therefore, after measuring the phase A current \( I_A \) on the triangle side (primary side), inputting the star side (secondary side) \( I_a, I_c \) two-phase current value. Among them, the modulus of the two vectors \( I_a' \) and \( I_a \) is unchanged, but the phase is changed. The conversion method of the other two-phase currents is the same as the conversion method of phase A.

The conversion of two-phase carrier transmission is deduced as follows: 20 carrier waves are injected into A and B phases on the low voltage side, and the transformer ratio is 25:

\[ n = \frac{I_{\text{low voltage}}}{I_{\text{medium voltage}}} \approx 25 \]  

Assume a phase carrier on the low voltage side

\[ I_{\text{low}} = A \sin(\omega t), \quad I_{\text{low}} = A \sin(\omega t + \pi), \quad I_{\text{low}} = 0 \]  

Since the connection mode of the primary side and the secondary side of the transformer is Dyn11, according to the transformer current conversion in Dyn11 mode, the phase currents from the low voltage side to the medium voltage side are as follows:

\[ I_{A_{\text{medium}}} = \frac{I_{\text{low}} - I_{\text{low}}}{\sqrt{3}n} = \frac{A}{\sqrt{3}n} (\sin(\omega t) - 0) = \frac{A}{\sqrt{3}n} \sin(\omega t) \]  
\[ I_{B_{\text{medium}}} = \frac{I_{\text{low}} - I_{\text{low}}}{\sqrt{3}n} = \frac{A}{\sqrt{3}n} (\sin(\omega t + \pi) - \sin(\omega t)) = -\frac{2A}{\sqrt{3}n} \sin(\omega t) \]  
\[ I_{C_{\text{medium}}} = \frac{I_{\text{low}} - I_{\text{low}}}{\sqrt{3}n} = \frac{A}{\sqrt{3}n} (0 - \sin(\omega t + \pi)) = \frac{A}{\sqrt{3}n} \sin(\omega t) \]  

According to formulas (9), (10) and (11), when carrier current with the same amplitude is injected only into A and B phases on the low-voltage side, the B-phase current on the medium-voltage side is about \( \frac{2}{\sqrt{3}} \) of the B-phase current on the low-voltage side, the amplitude of carrier current of A and C phases on the medium voltage side is 1/2 of B current on the medium voltage side.

It is verified by simulation that when carrier signals of the same amplitude are injected into A and B phases on the low-voltage side, the B-phase current on the medium-voltage side is about \( \frac{2}{\sqrt{3}} \) of the B-phase current on the low-voltage side, and the amplitude of carrier current of three-phase A and C on the medium voltage side is 1/2 of B current on the medium voltage side. The simulation results are basically consistent with the theoretical calculation results.

2.2 Carrier signal extraction and identification

According to the transmission line theory, the carrier signal continuously oscillates and attenuates along the distribution line under the action of wave impedance, and the lower the carrier signal frequency, the farther the transmission distance is, this technology uses the low-frequency carrier signal for signal modulation transmission.
After passing through the transformer, the carrier signal is extracted on the 10kV medium voltage line at the substation side. According to the sliding DFT algorithm, the voltage and current harmonics in the carrier signal are extracted, wherein the calculation formula of the sliding DFT algorithm is:

\[ a_k = \frac{2}{N} \left[ \sum_{i=0}^{N-1} f(T_0 + i \frac{T}{N}) \cos(2\pi \frac{i}{N}) - f(T_0 + (i - N) \frac{T}{N}) \cos(2\pi k \frac{i}{N}) \right] \] (12)

\[ b_k = \frac{2}{N} \left[ \sum_{i=0}^{N-1} f(T_0 + i \frac{T}{N}) \sin(2\pi \frac{i}{N}) - f(T_0 + (i - N) \frac{T}{N}) \sin(2\pi k \frac{i}{N}) \right] \] (13)

Among them, \( a_k \) represents the real part of the k-th harmonic, \( b_k \) represents the imaginary part of the k-th harmonic, \( N \) represents the number of data points of the power frequency cycle, and \( k \) represents the harmonic order, \( T = 20ms \).

According to the cosine similarity calculation formula, the similarity between voltage and current harmonic waveforms is calculated, wherein the cosine similarity calculation formula is:

\[ r_k = \frac{\sum_{n=0}^{N-1} I_k(n) U_k(n)}{\sqrt{\sum_{n=0}^{N-1} I_k^2(n) \sum_{n=0}^{N-1} U_k^2(n)}} \] (14)

Among them, \( I_k \) is the extracted k-th current harmonic, \( U_k \) is the extracted k-th voltage harmonic, \( N \) is the number of data points used to calculate the similarity, and \( r_k \) is the similarity between the calculated kth voltage and current harmonic waveforms.

Using carrier coding, frequency discrimination, decoding and error correction techniques, the carrier signal identification equipment can still accurately extract the carrier characteristic signal when the amplitude ratio of the power grid background signal to the carrier characteristic signal at the outlet of the substation is 10000:1, ensuring the reliability of data transmission and completing the identification function of line-to-line relationship.

### 2.3 Coding scheme

Coding adopts BCH(45,63) scheme, which includes frame synchronization header (13 bits), transformer address number (16 bits), CRC(16 bits) and supervision bit (18 bits), with specific structure as shown in figure 4.

![Figure 4. Original BCD code](image_url)

![Figure 5. Adjusted BCD code](image_url)
In order to reduce the false alarm rate and distinguish the outgoing line by using relative threshold, when the coding scheme is actually sent, the sequence of frame synchronization and information is reversed, as shown in the following figure, this has two advantages: 1) The amplitude of carrier can be calculated by using frame synchronization, and the sequence of frame synchronization can be set to ensure the maximum amplitude of carrier; 2) After identifying the feature sequence, the background noise can be calculated, which can improve the accuracy of calculation. At the same time, the frame synchronization is closer to the background noise data, and the influence of background current fluctuation can be avoided as much as possible.

As for the calculation of bit error rate, because BCH can correct 3-bit data errors, there are five groups of carrier frequencies, and each group of carrier frequencies will be repeatedly identified four times, so the probability of false positives is:

$$P = \frac{(1+C^1_{33}+C^2_{33}+C^3_{33}) \times 2^{16}}{2^{63}} \times 5 \times 4 = \frac{(1+63 \times 31 \times 21 \times 31 \times 61) \times 2^{16}}{2^{63}} \times 5 \times 4 = 5.9299 \times 10^{-9}$$ (15)

The number of false positives in one day is:

$$N = 5.9299 \times 10^{-9} \times 5 \times 3600 \times 24 = 0.0026$$ (16)

That is, the false alarm occurs once every 390 days on average, so the false alarm rate is very small.

3. Application cases

In order to verify the recognition effect of intelligent sensing for high altitude and long distance medium voltage power line load cutting in Qinghai Province, a pilot project was carried out on the 10kV overhead line in Bama County of Guoluo Prefecture in Qinghai Province. Pilot 1: Substation (Lianhua Transformer)-Transformer (Baiyu Branch) and Pilot 2: Substation (Banma Central Transformer)-Transformer (Saiwu Road) are selected respectively, the test conditions are shown in table 1.

| Transformer substation | Transformer  | Altitude     | Recognition success rate |
|------------------------|--------------|--------------|--------------------------|
| Lianhua transformer    | Baiyu branch | 4670 meters  | 100%                     |
| Banma central transformer | Saiwu road   | 4520 meters  | 100%                     |

In the pilot, the accuracy rate of intelligent sensing is 100% by changing the load test. At the same time, it has been installed and applied in Xichang, Sichuan, Huludao, Liaoing, Yingtan, Jiangxi, Wuhan, Hubei Xiangyang, Hubei, Changsha, Hunan, Xieqiao, Anhui, etc., and the recognition success rate of intelligent sensing for load switching is 100%.

4. Conclusions

In view of the complexity of the medium-voltage power supply and distribution network in China and the confusion of the line transformation, an intelligent sensing system for load switching based on medium-voltage carrier communication device is proposed in this paper, the recognition accuracy rate is 100% through field installation test, and the load switching can be accurately judged in real time, which is of great significance to the operation control and fault diagnosis of 10kV distribution network. Qinghai Province has a low population density and a long distance in the network topology of distribution lines, which requires accurate attribution of load equipment. Intelligent load sensing is conducive to targeted control of load switching. Long-distance medium-voltage power line carrier is an effective wired special communication. Intelligent sensing of load switching provides an effective line loss control method for distribution automation and power consumption information acquisition system in Qinghai Province, which has great application value.
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