Study on 10kV Line Characteristics Based on Medium Voltage Carrier

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Abstract: Using medium voltage carrier communication to achieve full coverage of power information acquisition and distribution automation has become a hot spot in the domestic power industry. The characteristics of 10kV line will largely affect the reliability of medium voltage carrier communication, but due to the influence of voltage level and other factors, the research on 10kV line characteristics is not mature. In this paper, a research method of 10kV line characteristics based on medium voltage carrier is proposed. The improved medium voltage carrier communication machine and coupler can realize the collection of 10kV line impedance, attenuation and noise, accumulate useful data for the long-term study of 10kV line characteristics, help to improve the reliability of medium voltage carrier wave communication and assist 10kV line fault monitoring.

1 Introduction

Medium-voltage carrier communication¹ is a communication mode that uses the existing 10kV medium-voltage distribution line as the transmission channel, and using the existing and perfect distribution line as the transmission channel without extra investment in building special communication lines, and it has the advantages of less investment, simple equipment, easy construction, convenient maintenance and management, synchronization with power grid construction, quick opening with new construction, and consistent coverage with power system, etc. It is very important for realizing full coverage of power consumption information collection² and distribution.

10kV line characteristics³ are the main factor to affect medium voltage carrier communication, so it is particularly important to study the characteristics of 10kV line-impedance, attenuation and noise. However, due to the influence of voltage grade and other factors, the current research on the characteristics of 10kV line is more limited to simulation modeling, the real-time performance of high-precision test equipment is poor and cannot be applied in batch engineering. Aiming at the above-mentioned difficult problem of 10kV line characteristics research, this paper proposes a 10kV line characteristics research method based on the medium voltage carrier⁴, the impedance, attenuation and noise of 10kV line can be collected by improved medium voltage carrier communication equipment. Through practical application test verification, it is proved that this method can realize the acquisition of impedance at specific frequency point, attenuation of line interval at specific frequency point and noise within specific frequency band, which can accumulate useful data for long-term research of 10kV...
line characteristics. It is helpful to improve the reliability of medium voltage carrier communication, the auxiliary 10kV line fault monitoring is of great significance to promote the full coverage of electricity information collection and the construction of distribution automation.

2 Equipment introduction

2.1 improved medium voltage carrier communication machine
Traditional medium voltage carrier communication machine mainly realizes carrier signal sending and receiving, and carrier communication interface is connected with the coupler. Medium voltage carrier communication machine is divided into medium voltage carrier communication master machine and medium voltage carrier communication slave machine. The improved medium-voltage carrier communication machine mainly increases the voltage and current sampling part of carrier communication interface based on the traditional principle, as shown in figure 1.

2.2 Medium voltage carrier coupler
Medium voltage carrier coupler mainly realizes carrier signal transmission and power frequency isolation, with the top end connected to 10kV line, the bottom end grounded, and the signal interface connected to carrier communicator. Outline drawing of medium voltage carrier coupler is shown in figure 2:

![Figure 1. Principle block diagram of improved voltage carrier communication machine](image1)

![Figure 2. Outline drawing of coupler](image2)

3 Working principle

3.1 Impedance acquisition
The acquisition of 10kV line impedance\(^6\) is based on the improved medium voltage carrier communication machine to calculate the impedance of 10kV line at the carrier signal sending end and
the carrier signal receiving end at a specific frequency point. The principle framework is shown in figure 3.

![Block diagram of the improved medium voltage carrier communication host](image)

**Figure 3. Block diagram of 10kV line impedance acquisition principle**

Calculation of 10kV line impedance of carrier signal sending end: By collecting the amplitude and phase information of the voltage \( U_s(t) \) and current \( I_s(t) \) of the signal sent by the carrier communication interface, and analyzing the amplitude ratio and phase difference of voltage and current, the impedance and resistance-capacitance characteristic information of 10kV line at the sending end of carrier signal can be calculated. The calculation formula is as follows:

\[
Z_s(t) = \frac{U_s(t)}{I_s(t)}
\]  

(1)

If the voltage \( U_s(t) \) phase leads current \( I_s(t) \) phase, the line impedance is inductive; If the voltage \( U_s(t) \) phase lags current \( I_s(t) \) phase, the line impedance is capacitive; Otherwise, the voltage \( U_s(t) \) phase is the same as current \( I_s(t) \) phase, the line impedance is purely resistive.

Similarly, the 10kV line impedance at the receiving end of the carrier signal is calculated as follows: By collecting the amplitude and phase information of the signal voltage \( U_r(t) \) and current \( I_r(t) \) received by the carrier communication interface, and analyzing the amplitude ratio and phase difference of the voltage and current, the characteristic information of the 10kV line impedance and resistance-capacitance inductance at the receiving end of the carrier signal can be calculated. The calculation formula is as follows:

\[
Z_r(t) = \frac{U_r(t)}{I_r(t)}
\]  

(2)

If the voltage \( U_r(t) \) phase leads current \( I_r(t) \) phase, the line impedance is inductive; If the voltage \( U_r(t) \) phase lags current \( I_r(t) \) phase, the line impedance is capacitive; Otherwise, the voltage \( U_r(t) \) phase is the same as current \( I_r(t) \) phase, the line impedance is purely resistive.

### 3.2 Attenuation acquisition

The 10kV line attenuation acquisition is based on the improved medium voltage carrier communication machine to realize the attenuation calculation of 10kV line between the carrier signal sending end and the carrier signal receiving end at a specific frequency point. The principle block diagram is shown in figure 4.

The calculation of the 10kV line attenuation between the carrier signal sending end and the carrier
signal receiving end is as follows: By collecting the signal voltage $U_m(t)$ and $U_s(t)$ sent by the host and received by the slave of the carrier communication interface, and analyzing the amplitude ratio of the signal received by the host and the slave of the carrier communication interface at the same time period, the signal attenuation characteristics of the 10kV line can be obtained. The calculation formula is as follows:

$$A = 20 \log \left| \frac{U_s(t)}{U_m(t)} \right|$$

(3)

Figure 4. 10kV line attenuation acquisition principle block diagram

3.3 Noise collection

The 10kV line noise collection is based on an improved medium-voltage carrier communication machine to achieve 10kV line noise collection at the carrier signal transmitter and carrier signal receiver in a specific frequency band. The principle block diagram is shown in figure 5:

Figure 5. 10kV line noise acquisition principle block diagram

10kV line noise collection at carrier signal sending end: by collecting port voltage information $U_f(t)$ of carrier communication interface in idle state, the frequency component in the signal is analyzed by DFT algorithm, and the calculation formula is:

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

(4)
\[ b_k = \frac{2}{N} \left[ \sum_{i=0}^{N-1} f(T_0 + i \frac{T}{N}) \sin(2\pi \frac{i}{N}) - f(T_0 + (i - N) \frac{T}{N}) \sin(2\pi k \frac{i}{N}) \right] \] (5)

Among them, \( a_k \) represents the real part of the kth harmonic, \( b_k \) represents the imaginary part of the kth harmonic, \( N \) represents the data points of the power frequency cycle, and \( k \) represents the harmonic order.

The frequency spectrum characteristics of the signal in the frequency range of 100kHz-40MHz can be obtained through analysis, so as to confirm the noise variation characteristics of 10kV lines.

Similarly, 10kV line noise collection at carrier signal receiving end: by collecting port voltage information \( U_f(t) \) of carrier communication interface in idle state, the frequency spectrum characteristics of the signal in the frequency range of 100kHz-40MHz can be obtained by analyzing with formulas (4) and (5), so as to confirm the noise variation characteristics of 10kV lines.

4 Spot test
At Laoshan site in Qingdao, a 10kV medium voltage overhead and ground cable hybrid line is randomly selected to install medium voltage carrier communication equipment, with a distance of about 3km.

4.1 Impedance test
At Qingdao Laoshan site, the impedance values collected by medium voltage carrier communication machine are 70Ω (200KHz), 40Ω (300KHz), 20Ω (500KHz) and 120Ω (1MHz).

Impedance distribution acquired by professional impedance acquisition equipment\(^8\) is shown in figure 6:

![Impedance distribution collected by impedance acquisition equipment](image)

Figure 6. Impedance distribution collected by impedance acquisition equipment

According to the impedance distribution diagram acquired by professional impedance acquisition equipment, it can be seen that it is basically consistent with the impedance value acquired and calculated by medium voltage carrier communication machine.

To sum up, it can be seen that the impedance data collected by medium voltage carrier communication machine is not much different from the data collected by professional impedance acquisition equipment, which can be used as actual reference value.

The test data shows that the impedance characteristics of 10kV line change with the frequency, and its variation value ranges from several ohms to several hundred ohms. In low frequency band, the characteristics of 10kV line are mainly inductive; In high frequency band, the characteristics of 10kV lines are mainly capacitive. In the whole test frequency band, the line characteristics will have capacitive and inductive abrupt changes, especially in hybrid lines.

The improved medium voltage carrier communication machine realizes impedance acquisition function. First, it can accumulate data for the study of 10kV line characteristics; Secondly, the medium-voltage carrier communication machine can adjust the impedance of carrier communication interface
according to the impedance of 10kV line to realize impedance matching, improve carrier transmission efficiency, and then improve the reliability of medium-voltage carrier communication; Third, when the 10kV line fails, the impedance of the line will change dramatically. The improved medium voltage carrier communication machine collects impedance data in real time, which can be used as the basis for judging the 10kV line failure.

4.2 Attenuation test
At Qingdao Laoshan site, the attenuation values read by medium voltage carrier communication machine are 30dB(200KHz), 45dB(300KHz), 70dB(500KHz) and 90dB(1MHz).
        Grasp the transmission amplitude of carrier signal at the transmitting end with high-precision oscilloscope as 32.53dBV (200KHz, 300KHz, 500KHz, 1MHz);
Grasp the receiving amplitude of the carrier signal at the receiving end with a high-precision oscilloscope as 1.5dBV (200KHz), -12.46dBV(300KHz), -38.69dBV(500 KHz) and -56.23 dBV, (1 MHz);
According to the data captured by the high-precision oscilloscope, the attenuation values of this section are calculated as 31.03dB (200 KHz), 44.99dB (300 KHz), 71.22 dB (500 KHz) and 88.76 dB (1 MHz).
To sum up, it can be seen that the attenuation data collected by medium voltage carrier is not much different from the data collected by professional equipment, which can be used as actual reference value.
The test data shows that the attenuation characteristics of 10kV lines change with frequency, and the attenuation in low frequency band is less than that in high frequency band, and the attenuation will increase when the overhead line is transferred to the ground cable or the ground cable is transferred to the overhead line.
The improved medium voltage carrier communication machine realizes attenuation acquisition function. First, it can accumulate data for 10kV line characteristic research; Second, the medium voltage carrier communication machine can adjust the carrier transmission frequency or increase the transmission power according to the attenuation of 10kV line, and improve the reliability of medium voltage carrier communication; Third, when the 10kV line fails, the attenuation of the line will change dramatically. The improved medium voltage carrier communication machine collects attenuation data in real time, which can be used as the basis for judging the 10kV line failure.

4.3 Noise test
At Qingdao Laoshan site, the noise frequency read by medium voltage carrier communication machine is 481KHz;
The noise spectrum distribution collected by professional noise collection equipment is shown in figure 7:

![Figure 7. Noise spectrum diagram collected by professional noise acquisition equipment](image)

According to the noise spectrum distribution diagram collected by professional noise collection equipment, it can be seen that the noise frequency with the largest amplitude is concentrated around 480KHz.
To sum up, it can be seen that the attenuation data collected by medium voltage carrier is not much different from the data collected by professional noise equipment, which can be used as actual reference value.

The test data show that there is no obvious regularity in the noise characteristics of 10kV lines.

However, the improved medium-voltage carrier communication machine realizes the function of noise collection. First, it can accumulate data for the study of 10kV line characteristics; Secondly, the medium voltage carrier communication machine can adjust the carrier transmission frequency according to the noise of 10kV line to avoid the same frequency interference of noise and improve the reliability of medium voltage carrier communication; Third, when the 10kV line fails, high-frequency characteristic noise will appear on the line. The improved medium-voltage carrier communication machine collects noise data in real time, which can be used as the basis for judging the 10kV line failure.

5 Concluding remarks

Compared with the field test data, based on medium voltage carrier, impedance acquisition at specific frequency point, attenuation acquisition of line interval at specific frequency point and noise acquisition within a certain frequency band can be realized. These data can be used as reference values of actual values. Long-term data accumulation can guide the research and modeling of 10kV line characteristics\[9\], which is helpful to improve the communication reliability of medium voltage carrier and assist the fault monitoring of 10kV line. It is of great significance to promote the full coverage of power consumption information acquisition and the construction of distribution automation.

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