Study On the Influence of CVT Capacitive Voltage Divider On the Harmonic Transmission Characteristics

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Abstract: In order to research the influence of the capacitive voltage divider of capacitor voltage transformers (CVT) on harmonic voltage transmission in voltage measurement, based on the analysis of the influence of different capacitive voltage divider combinations on the harmonic transmission characteristics, an off-line simulation combined with bilinear interpolation method is proposed to eliminate the influence of the voltage-dividing capacitor on the results of each harmonic measurements by using the method of equivalent circuit analysis in this paper. And the validity of the method is verified by the analysis and calculation of the actual field collected data. The method is of great practical application value for the development of the harmonic correction device based on CVT.

1. Introduction

CVT (*capacitor voltage transformer*) is the main voltage measuring devices in power grids above 110 kV. However, due to the measurement principle, the national standard clearly states that CVT cannot be used for harmonic measurement. In view of the increasing number of non-linear loads in power systems, the need to measure harmonic voltages by using CVT is becoming more and more urgent. Due to the measurement principle of CVT, the harmonic measurement is greatly affected by its structural parameters. Researchers at home and abroad have carried out a lot of research on the relationship between parameters and CVT harmonic transfer characteristics. Literature [1] analyzed the influence of CVT measurement voltage on electric energy metering and relay protection device when voltage contains harmonic components; literature [2] quantitatively analyzed CVT circuit parameters to its harmonics by simulation method; literature [3] used simulation and experimental verification methods to analyze the influence of stray capacitance parameters on harmonics measured by CVT; literature [4] uses the analysis method of network function to analyze the influence of parameters on harmonic transfer from different angles; literature [5]-[7] explored methods for implementing CVT harmonic correction measurements using different methods.

Although researchers at home and abroad have carried out a lot of fruitful research on the study of CVT harmonic correction technology, there is little research about the influence of voltage divider capacitance on harmonic transfer characteristics. Based on the analysis of the influence of voltage divider capacitance on harmonic transfer characteristics, this paper proposes a method to eliminate the influence of different combinations of voltage divider capacitors on harmonic transfer errors.

2. Analysis of The Influence of Capacitive Voltage Divider to CVT Harmonic Transfer

As we all know, CVT measurement of fundamental voltage is realized by means of capacitive voltage divider and compensating reactor full compensation, but when the signal under test is a harmonic signal, due to the change of frequency, the original circuit no longer has the characteristics of full compensation, and the influence of the voltage dividing capacitor is highlighted.

CVT equivalent circuit is shown in Figure 1. In this figure: C_1 and C_2 represent high voltage and medium voltage capacitors; R_s, L_s and C_c are the equivalent resistance, inductance and equivalent stray capacitance of compensating reactor respectively; R_m and L_m denote the excitation resistance and excitation inductance of the intermediate transformer; R_{T1}, L_{T1}, R_{T2} and L_{T2} represent the winding resistance and winding leakage inductance of the primary side and the secondary side of the intermediate transformer; C_{p1}, C_{p12} and C_{p2} indicate the stray capacitance of the primary winding to ground, the primary winding to the secondary winding and the secondary side winding to ground. L_Z, R_Z, L_b and R_b denote the equivalent inductance, the resistance of the damper and the load to the primary side respectively.

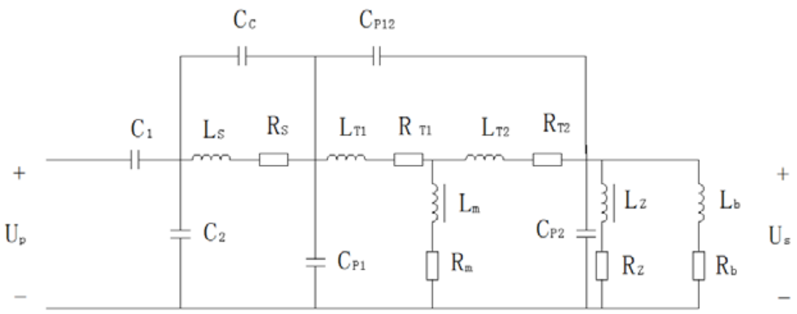

Figure 1 Equivalent circuit of CVT.

According to the standard of capacitive voltage transformer GB/T 4703-2001, the capacitor divider should correspond the requirements of the coupling capacitor and capacitor divider standard JB/T 8169-1999. In the selection of the capacitive voltage divider unit, the difference between the measured value and the nominal value (rated value) of any series capacitor unit should not exceed -5% to +10% of the nominal value. Therefore, the actual fluctuation range of the capacitance of the voltage dividing capacitors C_1 and C_2 are between -5% and +10%.

From the equivalent circuit of Figure 1, the relationship between the deviation of the capacitive voltage divider from the rated value and the signal transfer function of different frequencies can be derived:

$$\varepsilon = \frac{\Delta H(j\omega)}{H(j\omega)} = [\frac{1}{C_1} - \frac{j\omega(BZ_1 + A)}{j\omega(BZ_1 + A)C_1 + j\omega(BZ_1 + A)C_2 + B}] \cdot \Delta C_1 + \frac{j\omega(BZ_1 + A)}{j\omega(BZ_1 + A)C_1 + j\omega(BZ_1 + A)C_2 + B} \cdot \Delta C_2 \quad (1)$$

In formula(1): $H(j\omega)=U_S/U_P$, Z_1 represents the series-parallel impedance of R_s, L_s and C_c, A and B respectively represent the expressions of the numerator and denominator of the equivalent impedance composed of the intermediate transformer and its stray capacitance, damper and load. It can be seen from equation (1) that the changes in the capacitance values of C_1 and C_2 have different effects on the harmonics of different times. Figure 2 respectively shows the effect on the harmonic transfer when the value of C_1 is constant and C_2 is changed, and also shows the effect when the value of C_2 is unchanged and C_1 is changed.

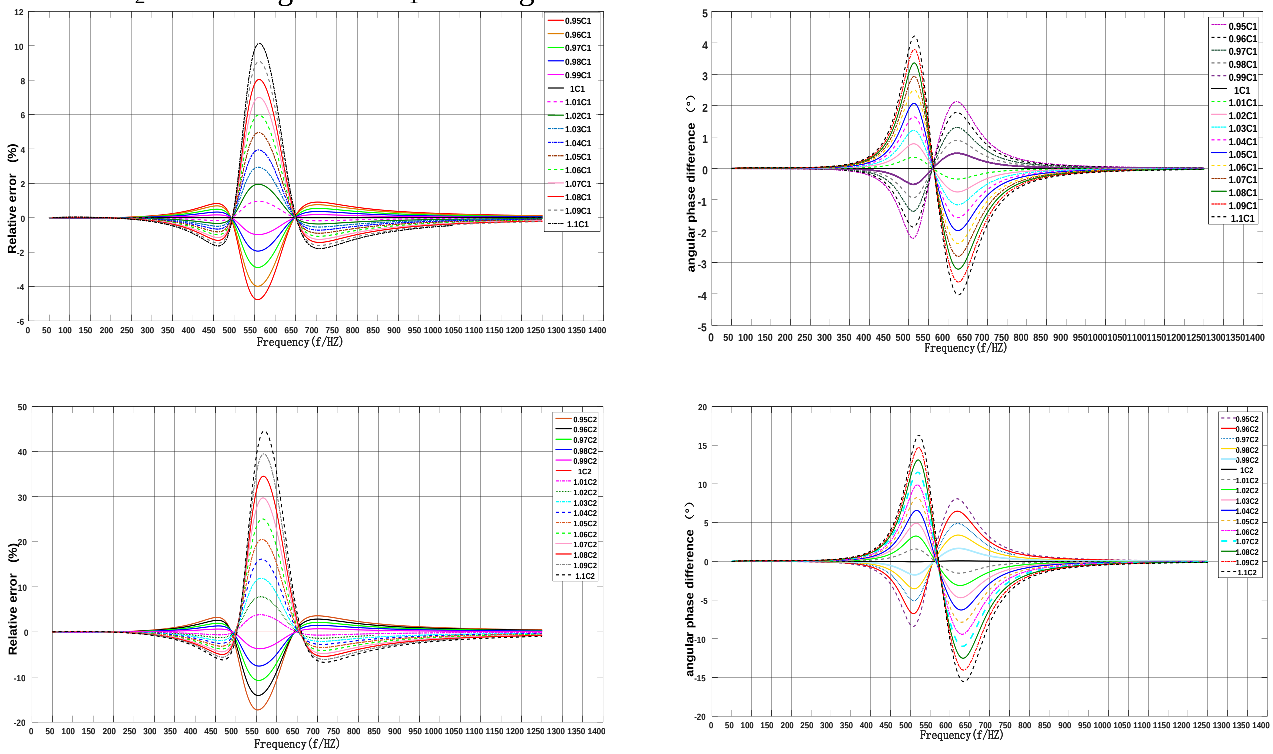

Figure 2 Influence of different C1 and C2 on harmonics transmission.

It can be seen from Fig. 2 that according to the quality control in the CVT production process, the changes in the values of C_1 and C_2 have no effect on the propagation of the fundamental wave (because the product is tested and calibrated). However, due to the difference in the combination of the parameters of C_1 and C_2, the transformation ratio and phase shift of each harmonic transmission relative to the value of the rated capacitance will change, which leads to the deviation of harmonic measurement results.

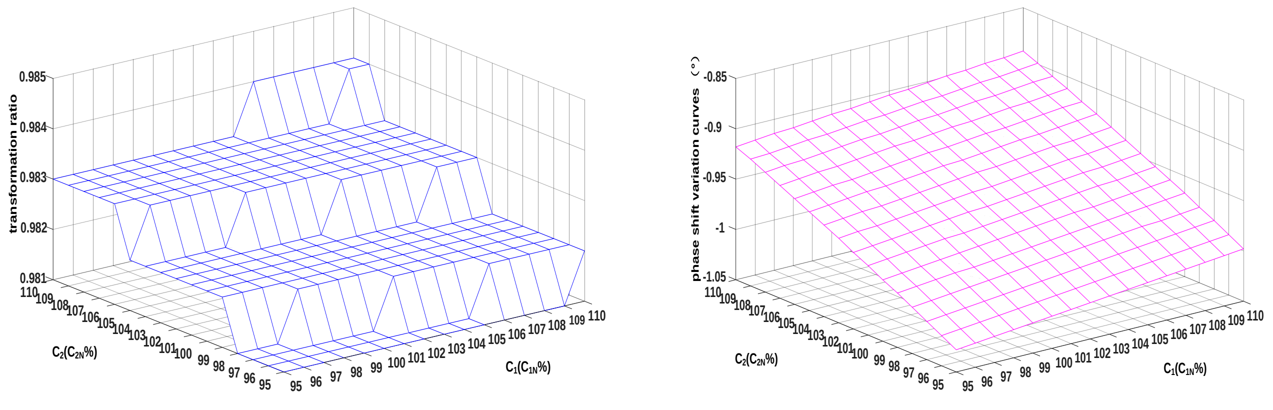

Figure 3 Relation curve between the 2th harmonic and the combination of C1 and C2。

Figure 3 shows the transformation ratio and phase shift of the second harmonic relative to the fundamental wave under the different combinations of C_1 and C_2 values.

According to the objective fact that the actual fluctuation ranges of the capacitance value of C1 and C2 is between -5%~+10%, through the actual value of the CVT divider capacitance C1 and C2, we can use the correction interpolation method to modify the harmonic measurement results in the harmonic measurement of CVT, so as to realize the accurate measurement of the harmonics.

3. CVT harmonic correction measurement principle

From the previous analysis, different capacitive voltage divider configurations have a great influence on harmonic transmission, in order to obtain the primary side harmonic voltage value by using the secondary side signal of the CVT transmission accurately, the influence of capacitive voltage divider must be corrected.

According to the equivalent circuit of Figure 1, the effects of the capacitance values of C_1 and C_2 are simulated offline in accordance with a set combination, for example, according to the combination of 1% step size, the three-dimensional curve of the transformation ratio and phase shift of each harmonic of CVT under the combination of different voltage-capacitor capacitance values can be obtained, as shown in Fig. 4.

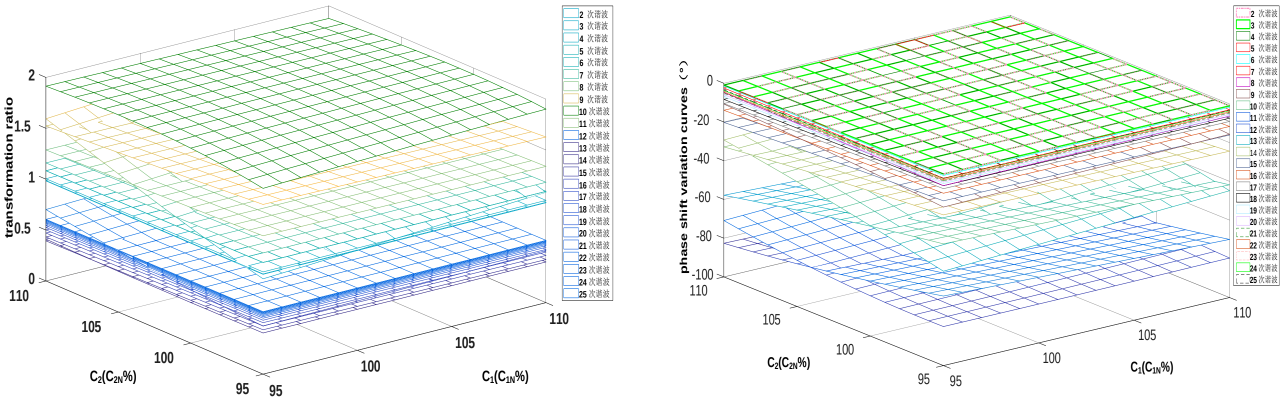

Figure 4 Relative transformation ratio and phase shift variation curves of each harmonic.

In the factory data of any CVT products contain the capacitive voltage divider parameters of the CVT, in other word, the capacitive voltage divider parameters are precise and known. Since the capacitive voltage divider cannot be exactly at the point calculated by the grid line in Figure 4, the bilinear difference algorithm can effectively reduce the measurement error caused by the difference of the capacitive voltage divider during the correction calculation. As shown in Figure 5, if the value of the actual capacitive voltage divider in the calculation space composed of （$C_{1(1)}$, $C_{2(1)}$, k_{h1}）,（$C_{1(2)}$, $C_{2(1)}$, k_{h2}）,（$C_{1(1)}$, $C_{2(2)}$, k_{h3}）,（$C_{1(2)}$, $C_{2(2)}$, k_{h4}）, where k_{hi} represents the ratio of the h^{th} harmonic at the four vertices of the range of values (or phase shift φ_h). Then the calculation formula of the ratio k_h (or phase shift φ_h) of any h^{th} harmonic is:

$$k_h=\frac{C_{2(2)}-C_2}{C_{2(2)}-C_{2(1)}}X_1+\frac{C_2-C_{2(1)}}{C_{2(2)}-C_{2(1)}}X_2 \text{ .where: } X_1=\frac{C_{1(2)}-C_1}{C_{1(2)}-C_{1(1)}}k_{h1}+\frac{C_1-C_{1(1)}}{C_{1(2)}-C_{1(1)}}k_{h2},\ X_2=\frac{C_{1(2)}-C_1}{C_{1(2)}-C_{1(1)}}k_{h3}+\frac{C_1-C_{1(1)}}{C_{1(2)}-C_{1(1)}}k_{h4} \quad (2)$$

$$\varphi_h=\frac{C_{2(2)}-C_2}{C_{2(2)}-C_{2(1)}}\Phi_1+\frac{C_2-C_{2(1)}}{C_{2(2)}-C_{2(1)}}\Phi_2 \text{ where: } \Phi_1=\frac{C_{1(2)}-C_1}{C_{1(2)}-C_{1(1)}}\varphi_{h1}+\frac{C_1-C_{1(1)}}{C_{1(2)}-C_{1(1)}}\varphi_{h2},\ \Phi_2=\frac{C_{1(2)}-C_1}{C_{1(2)}-C_{1(1)}}\varphi_{h3}+\frac{C_1-C_{1(1)}}{C_{1(2)}-C_{1(1)}}\varphi_{h4} \quad (3)$$

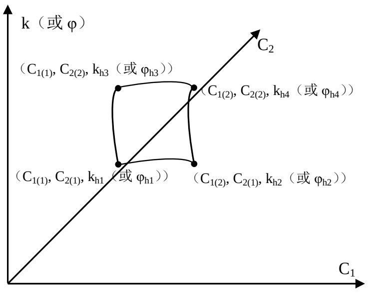

Figure 5 Schematic diagram of interpolation correction method.

From the calculation results of equations (2) and (3), use the formula:

$$\begin{cases} U_{hc} = k_h^{-1} n_1 U_{sh} \\ \Phi_{hc} = \varphi_{sh} + \varphi_h \end{cases} \quad . (4)$$

Where U_{hc} and Φ_{hc} represent the voltage value and phase value of the corrected h^{th} harmonic, respectively; U_{sh} and φ_{sh} respectively represent the voltage value and phase value of the h^{th} harmonic of the CVT secondary side output signal analyzed by FFT; n_1 represents the ratio of the CVT fundamental voltage.

4. Case analysis

December 4-12, 2017, Dongguan Power Supply Bureau conducted real-time data collection on the power quality of eleven lines between the eight substations in the area under its jurisdiction, the data acquisition system collects a set of power quality parameter data every 3 seconds, and then, only the amplitude of each harmonic voltage is output for the harmonic voltage. The method proposed in this paper is used to correct the harmonic monitoring data of a certain site as follows.

The substation adopts a CVT model of TYD 110/$\sqrt{3}$-0.01H from Guilin Power Capacitor Co., Ltd, its designed rated capacitance is C_{1N}=0.01257μF and C_{2N}=0.04885μF, the actual voltage dividing capacitance of the CVT participating in the test is C_1=0.01269μF and C_2=0.04953μF, and the result of the 3^{rd}, 5^{th}, and 7^{th} harmonic voltages obtained by the CVT with the one hour measurement result of the harmonic voltage of the electromagnetic voltage transformer is shown in Figure 6.

Since C1 and C2 deviate from the nominal values of +0.95% and +1.37% respectively, according to the scale division of Fig. 4, it can be seen that the correction calculation space falls within [1.0C_{1N}, 1.01C_{1N}], [1.01C_{2N}, 1.02C_{2N}], the corrected harmonic voltage values can be calculated by equations (2)-(4). Figure 7 shows the harmonic voltage values after the correction calculation. Figure 8 shows the relative errors of the harmonic measurements before and after the correction calculation. It can be seen from Fig. 8 that after the correction calculation, the measurement accuracy of each harmonic reaches the requirements specified in the national standard GB/T 14549-1993.

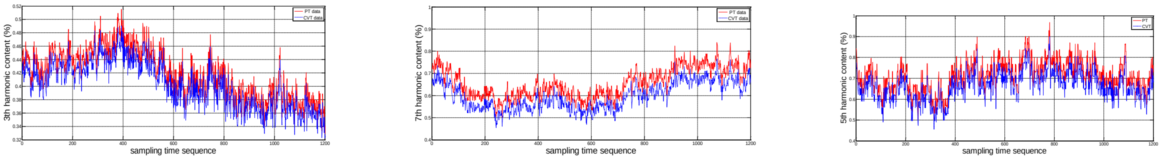

Figure 6 Raw data comparison chart of CVT and PT.

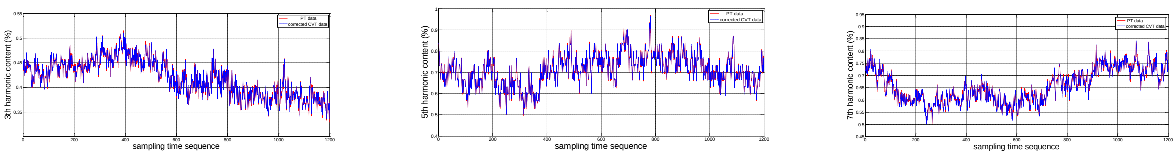

Figure 7 Corrected data comparison chart of CVT and PT.

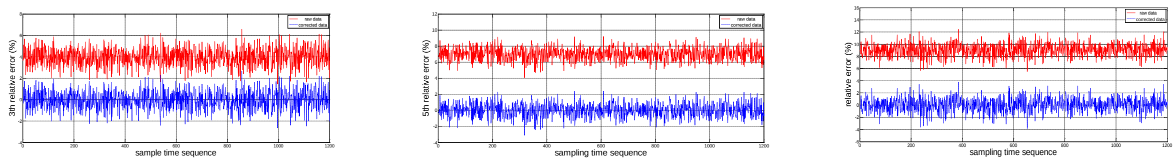

Figure 8 Relative error curve before and after correction.

5. Conclusion

Capacitor voltage transformer divider capacitor has a great influence on the harmonic voltage transmission. Through the modeling and simulation of CVT, this paper analyzes the relationship between the size of the voltage divider and the harmonic transformation ratio of each harmonic. An implementation method for correcting the influence of voltage divider capacitors is proposed. The calibration calculation results of the actual field test data show that the method can effectively reduce or even eliminate the influence of the discreteness of the voltage dividing capacitor on the harmonic voltage measurement results, as well as it has great guiding significance and reference value for CVT to realize the correction device for harmonic voltage measurement.

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