Study on the Measuring Harmonics Based on Capacitor Voltage Transformer

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Abstract. In high voltage grade power networks, people usually use capacitive voltage transformers (CVT) to measure the harmonic voltage, but the results exist errors. This paper studied the basic structure of CVT, established the equivalent circuit model of CVT, and proposed a method to calculate the harmonic voltage of the grid side by sampling the grounding current signal of CVT. On the basis of that, the paper confirmed the correctness and feasibility of the method through model simulation.

Introduction

As the traditional impact load continues to develop, for example, power electronics technology has been widely and 110kV, 220kV grid-connected electric furnace steelmaking. The problems of power quality it caused, has obviously affected power system operation and the safety of the user's facilities [1,2]. Among all kinds of power quality problems, the harmonic, which has a wide range of effects, is a main indicator that needs to be monitored in power quality. The harmonic voltage, which is measured by the voltage transformer, is the basic parameter of measurement and analysis in the study of harmonic problems.

Among kinds of voltage transformer, “CVT” which is the common short form for “capacitor voltage transformer”, is mainly used in 110kV, 220kV and higher voltage grade grids [3]. Harmonic measurement results are basically derived from CVT in grids, which is applied CVT, with voltage levels of 110kV and above. But the transmission of harmonics by CVT has actually undergone a nonlinear change, in other words, the secondary side harmonic voltage measured by CVT can't reflect the true harmonic characteristics on the high voltage side. It is also clearly stated in GB/T14549-1993 that CVT can’t be used to measure harmonic voltage of power system [4].

If we can design a reasonable and effective measurement scheme, which is use the existing CVT to measure the percentage of harmonic voltage and obtain the true harmonic content in the high-voltage power grid. We will get more and more valuable references helping us solve the problem of monitoring power quality and governing harmonic in electric power system. This paper proposes a research method for harmonic measurement of CVT, based on an in-depth study of the basic structure of CVT. The research provides strong support for the management decision of power grid operation and maintenance department, improving the safety and economy of grid operation.

Basic Structure and Equivalent Circuit Model of CVT

Basic Structure of CVT

The basic structure of the CVT is shown in Figure 1. It consists of a capacitor divider unit and an electromagnetic unit [5]. The capacitor divider unit consists of a high voltage capacitor and a low voltage capacitor. And the electromagnetic unit is composed of a compensating reactor and an intermediate transformer. The grid-side voltage is firstly reduced to medium voltage by the capacitive voltage divider, and then to low voltage signal for measurement, control and relay protection [6].

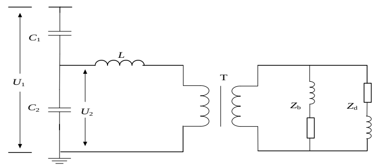

Figure 1. The working principle diagram of CVT

Z_b is equivalent to load resistance in the secondary side; Z_d is equivalent to equivalent impedance of damping device.

Equivalent Circuit Model of CVT

The references in [8] points out that stray capacitance effect which exists between conductor and conductor or between the conductor and the ground should be considered when we study the equivalent circuit model of CVT. We can build a complete equivalent circuit model of CVT based on taking full account of relevant factors, such as stray capacitance, dielectric loss of voltage divider capacitor, electrical load and so on [9]. The equivalent circuit model of CVT is shown in Figure 2.

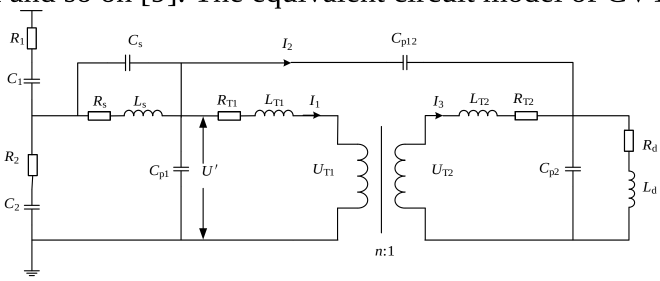

Figure 2. The equivalent circuit model of CVT

R_1,R_2 are equivalent to the dielectric loss of voltage divider capacitor; C_s is equivalent to stray capacitance which exists between the compensation reactor and the ground; C_{p1} is equivalent to stray capacitance which exists between the primary side of middle transformer and the ground; C_{p2} is equivalent to stray capacitance which exists between the second side of middle transformer and the ground; C_{p2} is equivalent to coupling stray capacitor between the primary side and the second side of middle transformer; R_d is equivalent to the equivalent resistance of the second of CVT; L_d is equivalent to the equivalent inductance of the second of CVT.

The Design of Measuring Harmonic Voltage of CVT

The design of measuring harmonic voltage of CVT is shown in Figure 1. We can easily calculate the voltage value on the high side by multiplying capacitive reactance by capacitance current which flows through the high-voltage and the low-voltage capacitor of CVT. In the same way, we can easily calculate the value of each harmonic voltage on the grid side by multiplying each harmonic current which can be calculated by Fourier decomposition of capacitive current by capacitive reactance which corresponds harmonic frequency mentioned above.

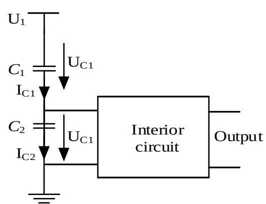

Figure 3. Typical structure of CVT

"internal circuitry" refers to CVT electro-magnetic unit which is composed of compensating reactor and middle transformer. The voltage on the internal circuitry is lower than the voltage on the low voltage capacitor (C_2).

The ground point of the low voltage capacitor (C_2) and that of internal circuitry are usually separate in the actual design of CVT. Just as shown in Figure 4, they are divided into two parts.

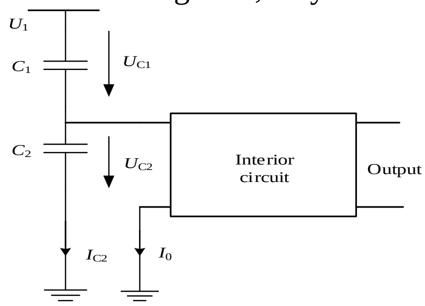

Figure 4. Actual structure of CVT

Divide I_{C1} into two measurable parts, one part is the current flowing through the low voltage capacitor, and the other is the current flowing through the internal loop.

$$I_{C1}(j\omega)=I_{C2}(j\omega)+I_0(j\omega). \tag{1}$$

The input voltage calculation formula of CVT can be written as:

$$U_{1cal}(j\omega)=(1/j\omega C_1)*[I_{C2}(j\omega)+I_0(j\omega)]+(1/j\omega C_2)*I_{C2}(j\omega). \tag{2}$$

I_0 is equivalent to the current flowing through the internal circuit; ω is equivalent to the angular frequency which corresponds harmonic voltage.

Simulation of Measurement Scheme

Simulation of Ground Current

The simulation model of CVT grounding current measurement is shown in Figure 5. The simulation model which is based on the equivalent circuit model of CVT is put up using MATLAB [10]. At the same time, we add two current measurement modules and an oscilloscope to the simulation model to get the ground current(I_{C2}) of the main circuit and the ground current(I_0) of the internal loop.

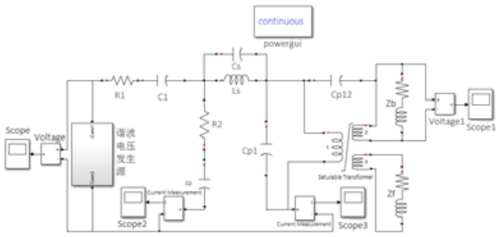

Figure 5. Simulation model of CVT grounding current measurement

In order to make a comparison with the frequency characteristic simulation of VA function, we use the same parameters which we set in the model we built in SIMULINK as that we set in the simulation of VA function. Besides, we use the same settings of harmonic source as before. We select fundamental voltage (63.51kV) overlying every odd harmonic voltage between 3 and 25 times, which is five percent of the fundamental voltage, and we can obtain the individual frequency components of the current, which include current I_{C2} and current I_0 by simulation.

Various harmonic components and phases of current I_{C2} and current I_0 can be read in FFT Analysis which belongs to the module called powergui. Simulink simulation results of current I_{C2} is shown in Figure 6. Simulink simulation results of current I_{C2} is shown in Figure 7.

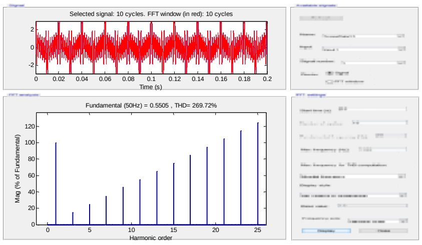

Figure 6. Simulink simulation results of current I_{C2}

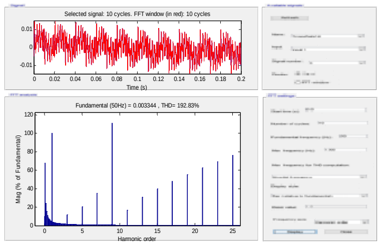

Figure 7 Simulink simulation results of current I_0

We can get the fundamental amplitude of two currents from the simulation results: I_{C2} =0.3893A, I_0=2.32mA. Simulation results of grounding current in Simulink is shown in Table 1.

Table 1. Simulation results of grounding current in Simulink

Harmonic Order	I_0 content [%]	I_0 phase [°]	I_{C2} content [%]	I_{C2} phase [°]
3	12.73	60.32	14.97	90.3
5	22.80	70.61	24.94	89.9
7	108.83	-21.29	34.90	89.8
9	19.87	85.79	44.85	89.6
11	30.67	86.28	54.93	89.6
13	38.70	86.05	64.96	89.2
15	46.99	86.23	74.89	89.1
17	52.81	86.32	84.85	89.0
19	55.89	86.43	94.82	88.9
21	66.61	86.51	104.79	88.8
23	73.36	87.16	114.76	88.7
25	80.0	87.62	124.73	88.5

Simulation of Harmonic Voltage Measurement Method

Just as shown in section 3.1, we obtain the individual frequency components of the current, which include current I_{C2} and current I_0 by simulation. We can find the virous harmonic voltage values of the primary side by using the formula, then we can analyze the correctness of the measurement method after comparing this result to the input voltage. Dielectric loss equivalent resistance of the high voltage capacitor and the low voltage capacitor are considered in the simulation of ground current, so the formula of calculating harmonic voltage which uses the harmonic current values is changed as below:

$$U_{1cal}(j\omega)=(R_1+1/j\omega C_1)*[I_{C2}(j\omega)+I_0(j\omega)]+(R_2+1/j\omega C_2)*I_{C2}(j\omega). \tag{3}$$

We can calculate U_{1cal} by substituting each harmonic current component into the calculation in MATLAB. The error between the calculation voltage and the applied voltage is shown in Table 2. The error between the calculated voltage and the actual voltage can be calculated using the following formula:

$$\varepsilon=[|U_1-U_{1cal}|/|U_1|]\times 100\%. \tag{4}$$

From the calculation results in table 2, we can learn that the calculated value of each harmonic voltage of CVT is in close proximity to the actual input of each harmonic voltage, proving that the method of calculating the harmonic voltage of power grid side through the measurement of ground current is completely correct.

Table 2. The error between the calculation voltage and the applied voltage

Harmonic Order	Standard value U_1 [V]	Calculated value U_{1cal} [V]	Error [%]
3	3175.5	3175.2	0.009
5	3175.5	3176.4	0.028
7	3175.5	3175.2	0.009
9	3175.5	3175.4	0.003
11	3175.5	3176.8	0.041
13	3175.5	3176.6	0.035
15	3175.5	3176.1	0.019
17	3175.5	3174.4	0.035
19	3175.5	3176.3	0.025
21	3175.5	3176.1	0.019
23	3175.5	3175.6	0.003
25	3175.5	3175.3	0.006

Conclusions

The paper proposes a research method for calculating harmonic measurement of primary side harmonic voltage using ground current of CVT, and analyzes the formula of the measurement based on the basic structure and equivalent circuit model of CVT, then we analyze the grounded current of CVT quantitatively by building a simulation model proving the measurement is completely correct. The method which provides ideas for measuring the level of the grid harmonic, is of great significance to practical application.

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