Analysis of Frequency Response Characteristics for CVT Over-voltage Monitoring Device under Different Load Conditions

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Abstract. The accurate measurement of over-voltage is very important to ensure the safety and stability of power grid. Therefore, the frequency response characteristics of the over-voltage monitoring device employing capacitive voltage transformer (CVT) under different load conditions are tested and analysed in this paper, and the effect of load change on the frequency response characteristics without and with interior low-voltage capacitor is studied. The results show that: for the case without interior low-voltage capacitor, when the secondary side of CVT is no-load or rated load, the frequency characteristics are roughly the same, but when the load is heavy, the frequency characteristics are greatly different from the situation under rated load. When there is an interior low-voltage capacitor, the presence of the interior low-voltage capacitor has almost no effect on the frequency characteristics of CVT under different load conditions, and there is also little effect on the frequency characteristics of the interior low-voltage capacitor high-voltage side under rated load and no-load conditions.

1. Introduction

Transient over-voltage is one of the effective means to evaluate the power grid operation state, and one of the important causes to cause equipment accident. Although a plenty of over-voltage protection devices have been invested into the power grid, various kinds of over-voltage phenomena are rather complicated in practice. Hence, over-voltage still occurs occasionally. Real-time monitoring and analysis are required for the over-voltage to diminish the over-voltage influence on the power grid [1,2].

There are mainly three mainstream over-voltage monitoring ways at present: 1) based on the voltage divider, such as capacitive voltage divider and resistance capacitance divider [3,4]; 2) based on the capacitive apparatus during operation, such as current transformer (CT) and bushing [5,6]; 3) based on capacitive voltage transformer (CVT) [7,8]. The voltage divider, as the off-line equipment, cannot be used during operation. This measurement method is still at the debugging stage due to complicated operation and certain safety hazards of the over-voltage monitoring device based on the capacitive apparatus. By comparison, CVT, belonging to the online equipment, has a better test result when the over-voltage is monitored. Thus, it has been applied to the actual online over-voltage monitoring system.

In the document [9], the online over-voltage monitoring system based on CVT, secondary cable and voltage divider are successfully set up for CVT-based over-voltage monitoring, and its frequency
response is actually measured and theoretically analyzed. In the document [7], online over-voltage monitoring implemented employing interior low-voltage capacitor is proposed in combination with the actual structure of 500 kV CVT. However, the above monitoring systems do not consider CVT’s frequency characteristics under different load conditions in practical operation, so as to affect the subsequent over-voltage waveform analysis. Accordingly, the frequency characteristics of the CVT-based online over-voltage monitoring device under different load conditions are studied, which has a practical guiding significance on later over-voltage monitoring and analysis.

2. CVT over-voltage monitoring device

Fig. 1 illustrates an electrical schematic diagram of conventional 500 kV CVT. It can be seen from Fig. 1 that conventional 500 kV CVT consists of capacitive divider (high-voltage capacitor C1 and medium-voltage capacitor C2), electromagnetic unit and secondary terminal. In which, T is intermediate transformer; K is medium-voltage earthing switch; L is compensation reactor; ZD is damper; BL is ZnO lightning arrestor; a-n is main and secondary winding terminals; da-dn is residual voltage winding terminals; 3az-3n is damper terminals.

![Figure 1. Electrical schematic diagram of CVT.](image)

CVT is employed for testing over-voltage by virtue of two methods generally. Two schematic diagrams of over-voltage test are shown in Figs. 2(a) and 2(b) respectively. The first measurement method is to externally connect the secondary voltage dividing device at the signal output end of CVT voltage divider directly (point O in Fig. 1), and to apply the secondary cable for connection (Fig. 2(a)). In addition to the method of directly using the externally connected secondary voltage dividing device, the low-voltage terminal N and earth point E of the capacitive divider can be disconnected, and over-voltage is measured from the C3 high-voltage terminal by virtue of introducing low-voltage capacitor C3 between points N and E (Fig. 2(b)).

With the exception of the above two testing methods, over-voltage can be tested at one side of secondary terminal, and over-voltage waveform can be recovered using the back calculation by combining output voltage uout(t) obtained by the measurement terminal with the transfer function of the measurement system. It's important to note that, when the signal cable is long, matching impedance is applied to the cable terminal for matching to reduce oscillation after over-voltage passes through the long cable.
3. CVT frequency characteristic under different load conditions

The frequency characteristics of WVL2 110-10H type CVT produced by Nissin electric (Wuxi) Co., Ltd. under different load conditions are studied for research on transferring characteristics of the CVT-based online over-voltage monitoring system under different load conditions. See Table 1 for detailed parameters of CVT.

Table 1. Detailed parameters of 110 kV CVT.

| Model                | WVL2 110-10H | Secondary winding | 1a-1n | 2a-2n | 3a-3n | da-dn |
|----------------------|--------------|-------------------|-------|-------|-------|-------|
| Highest voltage of equipment | 126 kV       | Rated voltage/V   | 100/√3 | 100/√3 | 100/√3 | 100   |
| Rated high-voltage capacitance | 11207 pF     | Rated output/VA  | 10    | 10    | 10    | 10    |
| Rated medium-voltage capacitance | 92857 pF     | Accuracy class   | 0.2   | 0.5   | 3P    | 5P    |

3.1. Load influence on CVT frequency characteristics without low-voltage capacitor

The measurement system shown in Fig. 3 is used for measurement to study load influence on CVT frequency characteristics (the measurement terminals are 1a-1n) without the low-voltage capacitor (C5 in Fig. 2(b)). For America Trek 2205 high-voltage amplifier, its highest output voltage is 500 V, and -3 dB bandwidth is 75 kHz. LeCroy 4054 oscillograph is used for data acquisition, with the maximum sampling rate as 2.5 GS/s and the vertical resolution as 12 bits. R||C, as an input impedance of the oscillograph, is set to be 1 MΩ||15 pF. It is necessary to note that the 10:1 probe is used for measuring the voltage of high-voltage side when the frequency characteristics are measured.
As can be seen from parameters in Table 1, the secondary winding load is in the rated state when 1000/3 Ω resistance is applied outside the secondary winding and 1000 Ω resistance is applied outside the residual winding. The test circuit shown in Fig. 3 is used for testing to keep the load in the rated and no-load states, so as to obtain the frequency response curves obtained under no-load at secondary sides, rated loads at secondary sides, only no-load at the measurement terminals (1a-1n no-load, and rated loads at other terminals) and only rated load at the measurement terminal (no-loads at other terminals) shown in Fig. 4.

As can be seen from Fig. 4, in case of rated load or no-load at the secondary side, the results obtained by the test under four conditions are similar, but also have certain differences: when the test frequency is 500 Hz, no-load at the secondary sides is essentially the same as the frequency characteristic when the measurement terminal is connected with the rated load, but has some differences from other two conditions; when the test frequency is 10 kHz, there are certain differences between the test results under the four conditions.

Furthermore, Fig. 5 gives the CVT frequency response test result when the load is heavy (10 Ω). As can be seen from the test results, when the test frequency is rated, the load is high and is similar to the frequency characteristic under the rated load because the reactance of the compensation reactor (L in Fig. 1) is equal to the equivalent capacitive reactance of the capacitive divider at the rated frequency (50 Hz). In contrast, there are great differences between the characteristic curves at other frequency points and the test results under the rated load at the secondary side, in addition to the rated frequency points. Therefore, when CVT is applied for over-voltage monitoring in practice and the secondary side load is heavy, there are great differences between the computed and real results if the frequency characteristics under no-load or rated load conditions are directly used for back calculation of real over-voltage waveform (the over-voltage waveform is recovered). Meanwhile, signals obtained from measurement will be attenuated greatly when the load at the secondary side is heavy, which is averse to over-voltage detection.

3.2. Load influence on frequency characteristics at outlet of interior low-voltage capacitor

Document [7] gives the 500 kV CVT based over-voltage monitoring system with interior low-voltage capacitor (Fig. 2(b)), but does not depict the frequency characteristics under different load conditions. Next, the frequency characteristics of the secondary side connecting different loads with low-voltage capacitor will be studied in the following paragraphs.
Fig. 6 illustrates frequency response curve at high-voltage side with interior low-voltage capacitor (C5=1100 nF) when the secondary side is connected with no-load or rated load. It can be seen from the test results in Fig. 6, the frequency characteristics obtained under no-load and rated load conditions at the secondary side are highly similar, that is, there is small influence on the frequency characteristics at the outlet of interior low-voltage capacitor when the secondary side is connected with the rated load.

Figure 6. Amplitude frequency characteristics of low voltage capacitor

3.3. Load influence on CVT frequency characteristics with low-voltage capacitor

Furthermore, Fig. 7 gives the CVT frequency characteristic curve with interior low-voltage capacitor. As can be seen from the results in Fig. 7, the CVT frequency characteristics under different load conditions with interior low-voltage capacitor are highly similar to those under different load conditions without interior low-voltage capacitor, that is, the interior low-voltage capacitor has small influence on the frequency characteristics under different load conditions.

Figure 7. Amplitude frequency characteristics of low voltage capacitor
4. Conclusions

The frequency characteristics of CVT-based online over-voltage monitoring device are studied under different load conditions, with the conclusions below:

1) When the rated load or no-load is connected to the secondary side of CVT, the frequency characteristics upon measurement are integrally similar, and only have small difference at partial frequency;

2) When the load at the secondary side of CVT is heavy, the frequency characteristics upon measurement obviously differ from the rated load, and are attenuated severely at high frequency;

3) There is also little effect on the frequency characteristics of the interior low-voltage capacitor high-voltage side under rated load and no-load conditions, and the presence of the interior low-voltage capacitor has almost no effect on the frequency characteristics of CVT under different load conditions.

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