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Introduction on Current Application of Voltage Transformer

Jun Yang[1, 2], Ziming Fan[1, 2], Yue Yang[1, 2], Xiayao Zhao[1, 2]

[1] Inner Mongolia Power (Group) Co., Ltd., Inner Mongolia Power Research Institute Branch, Hohhot 010020, China
[2] Inner Mongolia Enterprise Key Laboratory of High Voltage and Insulation Technology, Hohhot 010020, China

Abstract: As an important equipment, voltage transformer is widely used in power grid to obtain voltage signal and protect the system. In this paper, the voltage transformers in power system are classified according to the working principle. The working principle and characteristics of potential transformer (PT), capacitor voltage transformer (CVT), electronic voltage transformer (EVT) and optical voltage transducer (OVT) are briefly analyzed. Besides, this paper also introduces the principle, category and characteristics of voltage transformer, as well as the application and development of voltage transformer in power system.

Keywords: Potential transformer; Capacitor voltage transformer; Electronic voltage transformer; Optical voltage transducer

1. Introduction

Voltage transformer is an important equipment for power system to obtain voltage signals for metering and protect the power system. As a kind of voltage transformer, potential transformer (PT) is commonly used in low voltage, which is actually a transformer with very small capacity. Capacitor voltage transformer (CVT) is usually used in the high-voltage part of the current power system, which is mainly composed of capacitor voltage divider and electromagnetic part[1-4]. In which, the electromagnetic part is also a transformer, while the primary voltage is the lower voltage after the capacitance voltage divider. In recent years, with the rapid economic development of various countries, the demand for electric power is increasing day by day. The rated voltage level and rated current of the power system have been greatly improved, and many new and stricter requirements have been put forward for current and voltage transformers.

However, shortcomings are still existed: ① The insulation structure is complex, bulky and expensive, especially for ultra-high voltage systems and to meet the requirements of dynamic stability and thermal stability of large short-circuit capacity. ② Low linearity. It is easy to saturate in case of short circuit, small static and dynamic accuracy range. ③ Oil impregnated paper insulation is flammable, explosive and unsafe.

According to the principle of signal change, the existing voltage transformers can be divided into three types of electromagnetic voltage transformers (EVT), CVT, and optical voltage transformers (OVT) respectively. The EVT is a voltage transformer that converts the primary voltage into the secondary voltage proportionally through electromagnetic induction without additional electrical components that change the primary voltage. The essence of CVT is that the capacitor is connected to the electromagnetic unit after series voltage division, which has the advantages of better insulation performance and lower cost. And the higher the voltage level, the advantages are more. According to the statistics of the State Grid Corporation of China, the number of CVTs used in high-level power grids, especially in 330 kV and above voltage levels, has a large of advantages. The most important and core part of the optical voltage sensor is the voltage sensing unit, which converts the voltage information into optical information through certain effects from photoelectric part. In addition, the structure and performance of the voltage sensing unit also have an important impact on the structure and performance of the optical voltage transformer.

Potential transformer

PT is made of electromagnetic induction principle, which has the characteristics of small capacity, long-term stable operation, and nearly no-load state under normal operation. The winding impedance of voltage transformer is very small. When a short circuit fault occurs on the secondary side, the short circuit current will increase instantaneously, which will burn out the winding. According to different internal insulation materials, it can be divided into resin wound insulation transformer, oil immersed transformer and gas insulated voltage transformer.

The characteristic of the EVT is that the primary side and secondary side are relatively independent, and the key point is to ensure that the secondary side load cannot affect the grid voltage when the measuring instrument is connected to the secondary side.

The classification of potential transformer is as followed. For the EVT closed with iron core, the box and iron core of the transformer are grounded. The primary coil and secondary coil are placed on the core column of the iron core. The windings are multi-layer, and the insulation between layers is made by oil impregnated paper. The structure can withstand impact and overvoltage with very high frequency. The heat dissipation performance can be improved by changing the structure, such as adding an oil gap. The electric field structure at the end of the winding must be considered during design and construction. Cascade EVT works with multiple transformers, which can not only ensure that the insulation performance of the transformer meets the requirements, but also achieve a very good heat dissipation effect. In high voltage power grid, the iron core of EVT with closed iron core is very easy to produce ferromagnetic resonance. Ferroresonance is formed by the resonant loop composed of winding inductance and circuit capacitance, which is very easy to form when switching or automatic is reclosing. Once ferromagnetic resonance is formed, over-voltage and over-current often make the instrument temperature too high, thus burning the instrument. For EVT with open iron core, the biggest feature of the transformer is that the iron core is open to withstand voltage value riseing to error, so that the shortcomings of the traditional electromagnetic voltage transformer are overcome.

2. Capacitor voltage transformer

Capacitor voltage transformer (CVT)[1-4] is widely used in 110 kV and above power system because of its good insulation performance and economy which is composed of capacitor unit and electromagnetic unit. High voltage capacitor and medium voltage capacitor are connected in series to form capacitor voltage dividing unit. Compensation reactor and intermediate transformer are composed of electromagnetic unit. The basic structure of CVT is shown in Figure.1. However, compared with PT[5], this type of voltage transformer is more complex in structure with low error stability, and is prone to out of tolerance in actual operation. The field operation experience[6-10] shows that the fault rate of CVT is about 5 times than that of PT and 10 times than that of electromagnetic current transformer (CT) in 110 kV and above voltage transformers.

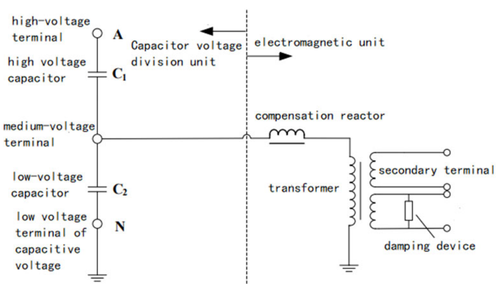

Figure 1 The basic structure of CVT

As a measuring equipment, the long-term stability of measurement error is one of the most important parameters to measure the operation performance of CVT. For the state evaluation of CVT measurement error, the general method is to use the standard to conduct error comparison detection with the verified CVT under power failure condition within a certain verification period[11-13]. However, due to the difficulty of power failure of high-voltage transmission lines, a large number of CVTs in the power grid are operating beyond the verification period, and there is a risk of measurement error exceeding the limit, which affects the fair trade settlement of electric energy. The existing measurement error state evaluation methods can not meet the operation requirements of intelligent substation for online monitoring of key equipment state. Therefore, it is necessary to carry out research on the evaluation and prediction methods of the measurement error status of CVT in operation under the condition of uninterrupted power supply, so as to grasp the measurement error status of CVT in real time, guide the operation and maintenance of CVT more pertinently, which is of great significance to ensure the safe, stable and economic operation of the power system. At the same time, the relevant technical routes and research methods for the evaluation and prediction of the measurement error status of CVT in operation can be extended to the research of other types of power transformers, which has important reference value for promoting the technical development of the industry.

3. Electronic Voltage Transformer

EVT is an important basic measuring equipment of smart grid, which can provide accurate and reliable secondary voltage information for smart grid measurement, metering control and relay protection, as shown in Figure.2. EVT is not an upgrade of traditional voltage transformer, but also a demand and reliable guarantee for the safe and stable operation of smart grid playing an important role in the construction of smart grid and smart substation. First of all, compared with traditional voltage transformers, EVT has the advantages of small size, light weight, no ferromagnetic resonance, good insulation performance, wide frequency response range, no requirement of short circuit at the secondary side, and digital output. Secondly, the digital signals output by EVT, electronic current transformer (ECT) and intelligent terminals form the layer network of intelligent substations, which enables intelligent substations to realize information digitization and information sharing, thus avoiding repeated sampling, simplifying secondary system wiring, and providing a solid foundation for safe operation of smart grids.Besides, acquisition of panoramic data of substation also provides conditions for new monitoring and protection methods of smart grid. Thirdly, the output of EVT reaches the process layer network through the merging unit, and the smart meter obtains the current and voltage data from the process layer for energy metering, which can eliminate the link of analog quantity transmission and secondary transformation of the meter and improve the accuracy of energy metering. Finally, EVT can meet the measurement requirements of PMU/WAMS, which is helpful to the realization of smart grid self-healing function, and will also play an important role in smart grid fast state estimation and grid transient stability monitoring. Therefore, the EVT has become a hot topic studied by scholars at home and abroad in recent years. So far, EVT developed by many companies has been put into grid test run or operation in the power system.

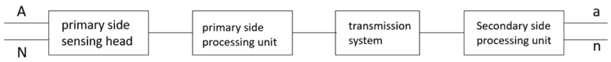

Figure 2 Basic structure block diagram of electronic voltage transformer

The existing EVT can be divided into passive type and active type according to the high-voltage side with or without power supply.. Passive EVT is usually an optical voltage transformer. Its primary sensing head uses the optical effect principle to convert the measured voltage into changes in optical quantities, and directly sends the optical measurement signal to the low voltage side through the optical fiber transmission system, then convers into corresponding electrical signals. There is no electronic circuit on the high voltage side, so there is no need for power supply on the high voltage side. The primary sensing head of the active EVT converts the measured voltage into an analog signal based on the electrical measurement principle, and further converts into a digital signal through an electronic circuit on the high voltage side. Then the electrical signal is converted into an optical signal through an electrical/optical conversion circuit, and transmitted to the low voltage side through optical fiber. Therefore, it is necessary to provide working power for the electronic circuit at the high voltage side. According to different installation methods, EVT can also be divided into two types of independent type and enclosed gas insulated combined electrical apparatus (GIS) matching type. The stand-alone EVT is used for outdoor independent installation, while the GIS equipped EVT is installed with GIS equipment, and the insulation is solved.

4. Optical Voltage Transducer

OVT uses optical materials to sense voltage and optical fiber to transmit signals with no iron core, inductance, ferromagnetic resonance and iron core saturation. It overcomes problems such as waveform distortion caused by magnetic saturation and measurement accuracy reduction caused by voltage drop of traditional voltage transformers[8-14]. Besides, the OVT also has the characteristics of compact structure, high security, wide measurement frequency band, large dynamic range, strong anti-interference ability, no secondary open circuit high voltage, easy to interface with computer, adapting to the requirements of power system automation and digitization, etc. The remote measurement and remote control of the system can be realized with the optical fiber transmission networking, which is easy to meet the requirements of miniaturization, intelligence and multi-function, and can not compare to traditional voltage transformers. OVT can also measure DC voltage, which is necessary in smelting and DC power system. As a result, OVT has attracted great attention in the industry since its inception. At present, Europe, America, Japan as well as other developed regions and countries have begun to use optical fiber sensors to develop new voltage transformers. The 161 kV voltage transformer of Tennessee Electricity Administration in 1989 was used to measure the voltage indirectly by current flowing through the capacitive voltage divider, as shown in Figure 3.

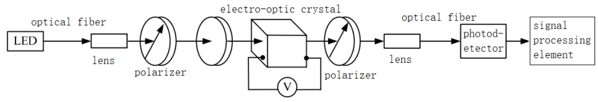

Figure 3 Principle diagram of optical voltage transformer

In terms of measurement principle, OVT can be roughly divided into three types based on Pockels effect (first order electro-optic effect)[15], Kerr effect (second order electro-optic effect) and inverse piezoelectric effect or electrostriction effect. In terms of type and structure, OVT can be divided into voltage division type and non voltage division type.

However, the OVT currently in the trial run stage is mostly based on the Pockels effect, which is required many optical components and difficult to calibrate and mass produce. In particular, the stability of the operation still needs to be improved. Therefore, countries around the world are constantly looking for and trying other more effective methods while improving the OVT based on the Pockels effect. In a word, OVT is still a long way from commercialization, and has great potential for performance improvement.

5. Conclusion

This paper classifies power system voltage transformers according to their working principles, and briefly analyzes the working principles and characteristics of PT, CVT, EVT and OVT. PT and CVT have a long history of application, and their implementation principles are simple and reliable, accounting for a large proportion in the power system. However, with the construction of ultra-high voltage, intelligent and digital power grids, ferromagnetic resonance, insulation difficulties, large floor space and other issues have become constraints to development. As new voltage transformers, EVT and OVT, can achieve real electrical isolation and eliminate the potential danger of ferromagnetic resonance by applying new measuring principles compared with traditional voltage transformers,. They have the advantages of small size, good insulation performance and strong anti-interference ability. The research of new voltage transformers is the need for the development of power system, but the research work and technology accumulation are obviously not enough at present, and the market share is still low. However, with the progress of science and technology, the improvement of production technology and the continuous efforts of researchers, EVT and OVT will be widely used in power system.

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