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Equal transfer processes-based distance protection of EHV transmission lines

Minghao Wen *, Deshu Chen, Xianggen Yin

State Key Laboratory of Advanced Electromagnetic Engineering and Technology, Huazhong University of Science and Technology, Hubei, China

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ABSTRACT

The overreach of the distance protection caused by CCVT is still a serious problem for high-speed line protections. Based on the theory of Equal Transfer Process of Transmission Lines (ETPTLs), a new high-speed distance relay scheme is proposed in order to overcome above problem. The solution is to make the three-phase voltages and currents at the relay location and the voltage at the fault point have the same transfer links by virtue of a new design. Three major steps of the new method are demonstrated: restructuring of the voltage at the fault point, the virtual digital transfer method and solving the R–L differential equation. A variety of ATP simulation tests show that the new method effectively reduces the transient error caused by CCVT and improves the operating speed by a series of technical countermeasures including three major steps, iterative calculations of the fault distance and an inverse time delay setting criterion. The distance measuring error is within 5% at approximately 15 ms after fault occurrence, which is superior to various adaptive protection algorithms based on CCVT transient error estimation or source impedance ratio (SIR).

1. Introduction

Distance protection is the foremost protection to protect the transmission line without needing the channel [1–6]. However, the overreach of the distance protection caused by CCVT is still a serious problem for high-speed line protections. Presently, CCVT is extensively applied to the power systems of 330 kV, 500 kV and above in China. Under normal conditions, the primary power system operates at steady-state. In this case, the transferring accuracy of CCVT is satisfactory. However, the system voltage drops suddenly when a fault occurs on any part of the transmission network. The output of the CCVT cannot trace the input simultaneously due to the very large capacitance and inductance of the CCVT, and the transient process may last for a long period of time.

The transient characteristics of CCVT distort the linear transfer relationship between the secondary voltage injected to the protection device and the primary voltage of the line, which may lead to the transient overreach of distance protections and endanger the security and stability of power systems [7–11]. In China, the zone-I setting of the distance protection is set as 0.8 time of the full line impedance. In order to avoid the transient overreach, the protection reach only can be up to 24% of the total length of the line if the protection is required to operate within between 5 ms and 10 ms. 56% of the total length can be protected if the operating time is required to be between 10 ms and 20 ms. It has been disclosed that the degree of transient overreach caused by CCVT is in relation to SIR [11].

At present, the usual approach preventing the protection from this type of overreach is to add additional time delay. However, in order to improve the operating speed and the reliability of distance protections, many studies are conducted on CCVT simulation and how to improve the transient response characteristics of CCVT. Some methods are proposed, e.g., transient error est based method. Different time delay strategies are adopted according to the quantity of error. In this case, the operation speed is enhanced compared with the regular distance protection [12].

The measurement error can be estimated by means of the quantity of SIR. This error is small when SIR is relatively small. In this case, time delay to issue the trip signal can be reduced [13]. What's more, the combination of various digital filter algorithms can be adopted to improve the accuracy of fault measurement by reducing the impact of the transient component of CCVT [14]. These methods, however, only partly improve the accuracy of fault measurement. Therefore, the effect of reducing the time delay of protection tripping is not satisfactory. The most ideal method is the recurrence of the input voltage of CCVT.

However, it is very difficult to reconstruct the input signal according to the output signal of a complex circuit. In [15], a simplified model of CCVT and corresponding parameters are used to

* Corresponding author. Tel./fax: +86 2787540945.
E-mail address: swenmh@mail.hust.edu.cn (M. Wen).

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correct the measuring error of the secondary voltage, which can reduce the error to some extent. However, the transient measuring error during the first cycle after fault inception is still quite big.

The voltage and current signals used by distance protection device do not match the corresponding actual signals of protected line due to the transfer of CCVT, which results in the transient overreach of distance relays. In order to prevent the distance relay from transient overreach, it is necessary to guarantee that the voltage difference between the relay location and the fault point with respect to the current measured by the distance relay can comply with the real transmission line model of taking the distribution parameters into account.

It is pointed out by ETPTL[16,17] that the relationship between the distributed voltage and the current of a transmission line does not change if they are transformed by the same linear circuit and still comply with the distribution parameter model of the original transmission line. Generally, CCVT can be regarded as a linear transfer circuit since the intermittent transformer of CCVT always will not saturate. Therefore, for the purpose of allowing the voltage difference between the relay location and the fault point with respect to the current measured by the distance relay to comply with the distributed parameter model of the original transmission line, both the transfer links for the voltage and the current signals at the relay location, as well as that for the voltage at fault point should be consistent.

To solve above problems, a fast distance protection scheme that can prevent from the transient overreach caused by CCVT is put forward. Three countermeasures are introduced. Firstly, the voltage at the fault point is restructured. The pre-fault voltage at the fault point is regarded to be close to the bus voltage at the relay location, and the post-fault voltage at this point is regarded as the voltage drop on a fault resistance. Secondly, a virtual digital transfer method is adopted, which can ensure that the current at the relay location and the voltage at the fault point pass the virtual digital transfer link whose transfer characteristic is the same as that of the actual CCVT equipped at the relay point. Thirdly, the R–L differential equation algorithm can be used to solve the fault distance by using the voltage at the relay position, which is transferred by the real CCVT, together with the current through the relay point, which is transferred by the virtual CCVT, and the voltage at the fault point, which is transferred by the virtual CCVT.

2. A fast distance protection method

2.1. Restructuring of the voltage at the fault point

When the CCVT is not applied to a transmission line, the bus voltage measured by the conventional distance relay is actually the voltage difference between the relay location and the fault point in the case of bolted faults. It is because that the voltage at the fault point is zero in this scenario. Therefore, this voltage and the line current comply with the model of the protected line. When the CCVT is used for a distance relay to measure the voltage, according to ETPTL, the relationship of the voltage difference between the relay location and the fault point with respect to the current measured by the relay cannot comply with the distributed parameter model of the protected line unless the measured current of the distance relay and the voltage at the fault point also pass the CCVT linear transfer circuits which are the same as that for the bus voltage measurement.

The voltage at the fault point can be regarded as zero when a bolted fault takes place. However, this voltage does not suddenly drop to zero at the moment of the fault inception if it passes the CCVT linear transfer circuit. Instead, a transient process should exist and last for dozens of milliseconds. If this transient process is neglected and the voltage at the fault point passing the CCVT linear circuit transfer is simply regarded as zero, the transient overreach of the distance relay will possibly occur to a great extent. It is necessary to estimate the voltage at the fault point according to the three-phase voltages and currents at the relay location that can be measured by the distance relays.

The process of restructuring the voltage at the fault point can be divided into two stages, namely, the pre-fault one and the post-fault one. In general, the pre-fault voltage at the fault point is a sinusoidal steady-state signal. The compensated voltage at a certain point of the protected line is used as the estimation of this voltage since the fault position is unpredictable.

Two scenarios should be taken into account during the stage of post-fault. Firstly, the voltage at the fault point can be regarded as zero in the case of bolted faults. Secondly, this voltage at the fault point can be regarded as the voltage drop on the fault resistance in the case of the grounding fault via a fault resistance. The voltage drop on the fault resistance can be expressed as the product of the current passing through the fault resistance multiplied by the fault resistance. According to the usual realization method of distance protection, the current through the fault resistance in the case of the grounding fault via a fault resistance is replaced with zero sequence current measured by the distance relay. The current through the fault resistance in the case of a phase-to-phase fault via fault resistance is replaced with the current of the faulty phase. In this case, the value of the fault resistance can be taken as a variable to solve. Therefore, the post-fault voltage at the fault point can be uniformly set as the voltage drop on the fault resistance, i.e., the product of the fault resistance and the current through the fault resistance. If the solution of this fault resistance is nearly equal to zero, this fault should be a bolted fault.

2.2. Virtual digital CCVT transfer method

A virtual digital CCVT transfer method is adopted, which can ensure that the currents at the relay point and the voltage at the fault point pass the virtual digital transfer link whose transfer characteristic is the same as that of the actual CCVT equipped at the relay point. So the problem about the difference between the transfer feature of the voltages at the relay point and that of the currents due to the transient characteristic of CCVT can be solved. The

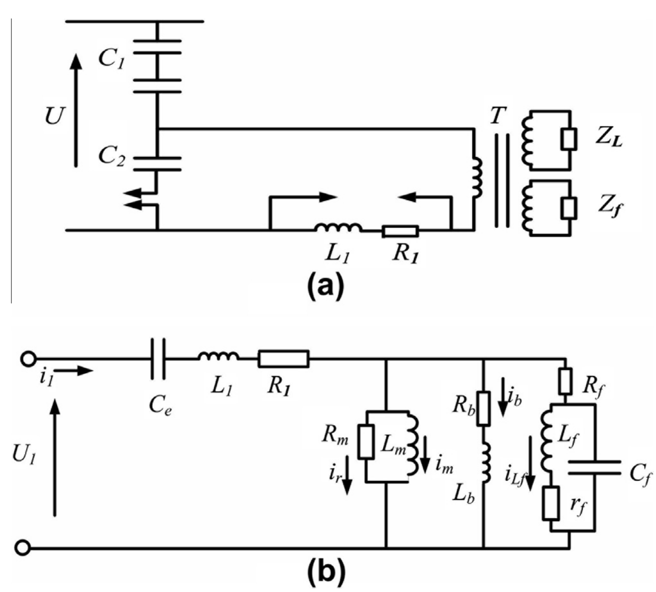

Fig. 1. CCVT circuit: (a) actual circuit; (b) equivalent circuit.