Challenges with Sequence Impedance Measurement for Underground Power Cables

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ABSTRACT

Sequence impedance of the transmission line is a critical parameter in power transmission and distribution (T&D) system design, which is widely utilized in protection coordination. The calculated sequence impedance may contain large errors up to 50% due to the uncertainties in the earth impedance, cable layout, etc. Therefore, the measurement of sequence impedance of underground power cables is commonly required by end users. The measurement methods and the practical challenges are discussed in this paper. The testing lead effect, which is the main uncertainty in measuring short lengths of power cables, is discussed with a case study. A method to determine the testing lead effect through measurement is proposed.

KEYWORDS

Sequence impedance; line impedance; transmission and distribution; power cables; protection

INTRODUCTION

Sequence impedances for transmission lines, also referred to as line impedance, are one set of symmetrical components widely utilized in power system analysis, particularly under unbalanced fault conditions. The asymmetric fault (unbalanced condition) can be expressed with the superposition of three sets of symmetrical components, i.e., positive (direct), negative (inverse), and zero (homopolar) sequence components. Those sequence components are heavily utilized in power system protections, in which sequence impedance is one of the most important parameters adopted in the fault location estimate and protection coordination.

Sequence impedances for transmission line systems (both overhead and underground) include positive, negative, and zero sequence impedances. The positive sequence impedance is the ratio of the normal fundamental frequency sinusoidal voltages to the positive-sequence currents flowing through the power system components, which measures the balanced load condition in the power system. The negative sequence impedance is the same as the positive sequence impedance, except the phase sequence of the current is reversed. In a transmission line system, the positive sequence impedance equals the negative sequence impedance. The zero sequence impedance is the ratio of the in-phase voltages in all three phases to the in-phase currents, which is critical in calculating the unbalanced load or fault condition in a power system.

The sequence impedance values can be calculated from the basic electrical characteristics of the cable system such as the AC resistance of the conductor, self and mutual inductance, shunt capacitance, etc. The inductance values depend on the installation layout, i.e., the distances and the configuration among the phase conductors. The zero sequence impedance measures the in-phase current flowing from the phase conductor through the earth, which is strongly determined by soil resistivity and cable sheath bonding methods, etc. Although there is published literature that guides the calculation of sequence impedance for underground cable systems [1], such calculation may introduce large error mainly due to the uncertainties in soil condition and the complexities in construction. The calculation error could be up to 50% or more. Therefore, measuring the sequence impedance is commonly required from the protection engineers for newly installed underground power cable systems during the cable after-installation (commissioning) test.

The measurement of sequence impedance for underground power cables can be performed with a symmetrical, three-phase AC power supply as per [2]. The positive sequence impedance is measured by injecting balanced three-phase current into the cable system with the far end of the cables open and short-circuited, respectively. The zero sequence impedance is measured by injecting single-phase current into all three phases together (the near end is short-circuited) with the far end of the cables open and short-circuited, respectively. The sequence impedance, together with the other electrical characteristics of the measured transmission line system can be derived from those measured values. The challenge of this approach is that the required balanced three-phase AC power supply is sizable and expensive, which limit its mobility and leads to high costs for such measurement.

The sequence impedances can also be measured with a single-phase AC power supply [2]. Considering the portable size of the equipment, simplicity of the operation, and the low cost of testing, this single-phase measurement method has been widely adopted for field testing sequence impedances for underground power cables.

This paper focuses on the sequence impedance measurement with a single-phase measuring method. The measuring principle is briefly summarized, and the practical challenges are illustrated with a case study. The testing lead effect is the main uncertainty in the measurement, which is particularly important for short circuits where the impedance of the testing leads is often comparable with the measured cables. The extra resistance and reactance introduced by the test leads can be calculated or estimated and then subtracted from the measured data. Alternatively, such impedance for the test leads could also be determined through thorough analysis of the measured values and the testing system setup. Both approaches are demonstrated in a case study below.

SEQUENCE IMPEDANCE MEASUREMENT

Measurement Method

Sequence impedance measurement with a single-phase AC power supply is performed with seven measuring loops. The simplified connection diagram for the measurement circuit is shown in Fig. 1. All the cable conductors at the far end are short-circuited with jumpers (daisy chained), and then grounded at one phase conductor to the substation ground. The cable conductors at the near end are