NEGATIVE K-FACTOR SETTING FOR POWER CABLES EXPLAINED VIA SEQUENCE IMPEDANCE MEASUREMENTS.

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ABSTRACT

Correct parameterizations of protection relay and fault locators are of utmost importance to obtain selective tripping and accurately identify fault locations. This paper explains an interesting phenomenon that occurs in power cable relay settings called "negative k-factors".

To be more accurate, the earth reactance of the line model can be negative. This phenomenon often occurs if the sequence impedance of a cable is measured because impedance calculation does neglect important impacts.

The paper shows that these negative earth reactances are possible and correct since they are caused by the model. The physical impacts reducing the measured loop reactance and causing the negative model reactance are explained.

A case study also shows measurement results of a cable installation with a negative earth reactance called "negative k-factors".

KEYWORDS

Cable impedance measurements; k-factors; Sequence impedance of power cables; Zero sequence impedance

INTRODUCTION

In order to accurately parameterize the individual distance protection relays, particularly with regard to single-phase faults, the exact line impedance values for both the positive phase-sequence system and the zero phase-sequence system are required [1]. The k-factor (determined by the positive sequence impedance and the ground impedance matching factor) resulting from these values is essential for accurate settings.

In the past, k-factors were calculated based on the parameters specified by cable manufacturers. This method never proved capable of providing settings which allowed the protection to reliably detect single-phase faults, resulting in an unacceptable amount of incorrect tripping [2]. Moreover, the inaccurately displayed fault locations resulting from the over-reach or under-reach of the protection also made it difficult for network control personnel to direct repair teams to the exact location where the fault occurred.

One of the most important settings of a distance protection relay is the sequence impedance. The impedance of a phase-to-ground fault is different from a phase-to-phase fault. Because the impedance of the ground path, or to be more precise, of the line-to-ground loop, is different, a factor within the relay gives the relation between the line-to-line and the line-to-ground impedances. This factor has many names [3], it is called ground impedance matching factor, residual compensation factor, earthing factor or simply k-factor, as it is often referred to.

The k-factor is often calculated using the earth impedance $\underline{Z}_E$ of the line. The associated earth reactance X_E can get negative or positive values. A negative value appears often if the reactance X_E is measured.

On the one hand, accurately measured earth impedances allow reliable and correct operation of distance protection and fault locators. On the other hand, the correctness of a negative reactance X_E has to be explained since negative reactances could appear wrong or could cause confusion.

LINE MODELS AND THEIR PARAMETERS

A cable or a balanced transmission line can be described by different models. These models are equivalent, although they have a different circuit diagram. In this section, the different models and their parameters for balanced lines are considered.

Physical Model Without Earth Impedance

Figure 1 shows the equivalent circuit diagram of the model without earth impedance. It is assumed for a balanced line that the entries of the impedance matrix meet the conditions

$$\underline{Z}_{L12} = \underline{Z}_{L13} = \underline{Z}_{L23} \tag{1}$$

and

$$\underline{Z}_{L11} = \underline{Z}_{L22} = \underline{Z}_{L33} \tag{2}$$

This model of a balanced line is determined by two parameters

- the diagonal element $\underline{Z}_{L11}$ and
- the non-diagonal element $\underline{Z}_{L12}$.

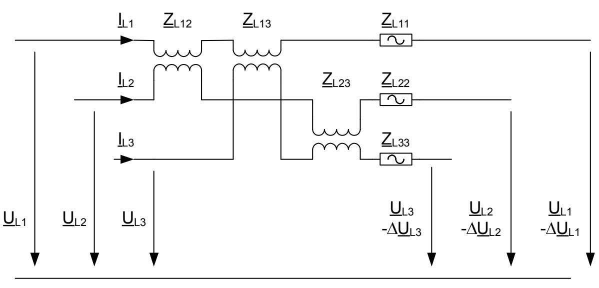

Figure 1: Equivalent diagram without earth impedance

Physical Model With Earth Impedance

Figure 2 shows the equivalent circuit diagram of the model with earth impedance. The balanced line model with earth return impedance is determined by two parameters

- the phase impedance $\underline{Z}_L$ and
- the earth impedance $\underline{Z}_E$.