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The protection of overhead lines and cables by current-differential schemes

Current-differential protective schemes, as stated earlier, have the great advantages that they can discriminate between faults within and external to their protected zones and can operate very rapidly when required to do so. Their basic principle, namely Kirchhoff's first law, that the algebraic sum of the currents flowing into a healthy circuit is zero, is very simple.

The behaviour of these schemes was considered in a general manner in Chapter 5 and their application to transformers, rotating machines and busbars was examined in Chapters 6, 7 and 8. They have been widely applied to relatively short cables and overhead transmission and distribution lines, which are often referred to as feeders, since the beginning of this century and are still being installed today.

Their behaviour and limitations are examined in detail in this chapter after the following section in which some historical information is provided.

9.1 HISTORICAL BACKGROUND

As stated in Chapter 5, C. H. Merz and B. Price submitted an application for a British patent on a current-differential protective scheme in February 1904. This was granted and numbered 3896. It included arrangements to cover both feeder circuits and transformers and the proposed scheme employed the balanced-voltage principle, the current transformers being so connected that their outputs opposed each other during healthy and external fault conditions. As a result, the secondary winding currents were zero under these conditions and the secondary winding e.m.f.s were of equal magnitudes and opposite polarities. One end of each secondary winding was earthed and hence only one interconnecting conductor was needed to protect a single-phase circuit. The inventors referred to the interconnecting conductors as pilot wires and this term, which has remained in use, will be used in this chapter. During internal faults a current flowed in the pilot wire and also in the relay windings, which were connected in series with the pilot wire, at each end of a protected line.
Merz and Price submitted two further patent applications in 1904 and were granted patents numbered 11364 and 15796. These covered improvements to the initial scheme. One proposal enabled the number of pilot wires needed in three-phase applications to be reduced. The use of auxiliary transformers which would allow several currents to be fed to separate windings mounted on a common magnetic core was also proposed. An output could be obtained from a further winding. These were forerunners of summation and core-balance transformers and indeed Merz and Price were granted a patent, numbered 28186 in 1908, on the latter devices.

Schemes based on the above patents were applied to lines and cables in the first decade of this century. In an article [1] published in the Electrical Review in 1908, it was stated that about 200 miles of high-tension network were protected in the North of England at that time by the Merz–Price system. It was further stated that the scheme had not just been perfected but had passed the perfected development stage for some 18 months or more. Most importantly, numerous faults of the most severe description had been isolated without visible shock on the system, and, better still, without opening healthy sections.

It was further stated that the relays were of the simplest design. They consisted of an ordinary electromagnet with a very light armature having, for the sake of rapidity in action, a small air-gap. They clearly did not possess any biasing windings.

It was presumably found, as the lengths of the lines and cables being protected increased, that incorrect operations of Merz–Price schemes were occurring because of the capacitance currents which were flowing between the pilot wires and earth during external faults. This situation is illustrated in Fig. 9.1(a), from which it can be seen that half the capacitance current to earth flows in each of the relays and clearly this current is proportional both to the length of the protected line and the current flowing in it.

To overcome this situation, special compensated pilot wires, covered by a British patent, were introduced. These cables incorporated metallic sheaths which surrounded the interconnecting conductors, there being a break in each sheath at the mid-point of a cable run. The protective arrangement with such cables was as shown in Fig. 9.1(b), from which it can be seen that the capacitance currents between a pilot wire and its sheath do not return through the relays.

As line operating voltages and fault current levels increased further, more complex current-differential schemes were produced. One of these, which was designated as ‘split-pilot’ protection, was described in a paper [2] presented at the International Conference on Large Electrical High-Tension Systems, which was held in Paris in 1931. This scheme, which incorporated summation transformers and had three pilot wires, was connected as shown in Fig. 9.2. The use of the parallel-connected pair of pilot wires ensured that imbalance currents did not flow in the relays during healthy conditions and the inclusion of the diverter reactors reduced the currents which flowed in the relays be-