C.4 Calculating slope for use in a transformer differential relay

Figure C.1 shows the characteristic of a typical percentage-bias differential restraint relay. The x-axis and y-axis show restraint and differential currents used by the relay. In almost all relays, differential current is the vector difference of all input currents. However, there are variations as to how the restraint current is calculated; some of the options used are as follows:

— Half of the sum of the magnitude of all restraint or input currents

— Sum of magnitudes instead of half of the sum of all input currents

— Average of the magnitudes of all input currents

— Half of the vector sum of all input currents

The characteristic shown in Figure C.1 has restraint current calculated as half of the sum of the magnitudes of all input currents. Also, differential and restraint currents are calculated using p.u. or normalized values of all input currents. Typically, tap values, which are CT secondary currents when the transformer is operating at maximum rating at nominal voltage, are used as a basis for per-unitizing.

A proper application of percentage-bias characteristic decreases protection sensitivity as the differential currents increase with increased load currents or fault currents due to external faults so that the relay does not misoperate. Sources of these erroneous differential currents include transformer magnetizing current, operation at off-nominal taps, mismatch in ratio or characteristics of CTs, unmetered loads on tertiary windings, and relay measurement errors.

The characteristic, as shown, has three distinct restraint regions: minimum pickup, first slope, and second slope. The minimum restraint setting prevents misoperation when the transformer is lightly loaded and the through-currents are of low values. Considering that the transformer is operating at maximum offset tap, the differential current due to CT ratio mismatch would be 0.1 p.u.. If the magnetizing current is assumed to be 0.03 p.u., the total expected differential current would be 0.13 p.u. However, the CT and relay measurement errors at light loads can be higher than the nominal errors. Higher settings for the minimum pickup are often used; these can be as high as 0.3 p.u. on forced rating, which is approximately 0.5 p.u. on natural rating.

The second slope prevents misoperation when heavy external faults and mismatch increases significantly due to CT saturation. Based on experience, 60% to 70% for the second slope is used as a rule of thumb and breakpoint between the first and second slopes is set at 3.0 p.u.

Instead of using this rule of thumb, it is possible to simulate the performance of a differential characteristic when a CT saturates. The procedure starts with simulating an external fault and preparing a data file of the fault currents at the high-voltage level. Models of unsaturated and saturated CTs can then be used to calculate the data that would be provided to the differential relay algorithm that calculates the phasors of the operate currents and restraint currents. Plots of the restraint-operate currents can then be prepared. One such plot from a simulation is shown in Figure C.6. This plot shows that the margin between the calculated restraint-operate currents combination during CT saturation and the second slope is small. The gradient of the second slope needs to be increased to ensure adequate security margin.