Power Transformer Protection

An Online Continuing Education Course for Engineers

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Power Transformer Protection

Velimir Lackovic, Electrical Engineer

The advancement of electrical power systems has been reflected in the developments in power transformer manufacturing. This has led to a wide range of power transformers. Their ratings range from a few kVA to several hundred MVA and are used for a wide variety of applications. Power transformer protection varies with the application and transformer importance. In the case of a fault within the power transformer, it is important to minimize tripping time in order to decrease the impact of thermal stress and electrodynamic forces. Distribution power transformers can be protected by using fuses or overcurrent protection relays. This leads to time-delayed protection due to downstream co-ordination requirements. Nevertheless, time delayed short circuit clearance is unacceptable on larger power transformers due to system operation/stability and cost of repair.

Power transformer short circuits are typically grouped into five categories:

- Winding and terminal short circuits
- Core short circuits
- Tank and transformer accessory short circuits
- On–load tap changer short circuits
- Prolonged or uncleared external short circuits

Summary of short circuit causes initiated in the power transformer itself is shown in Figure 1.

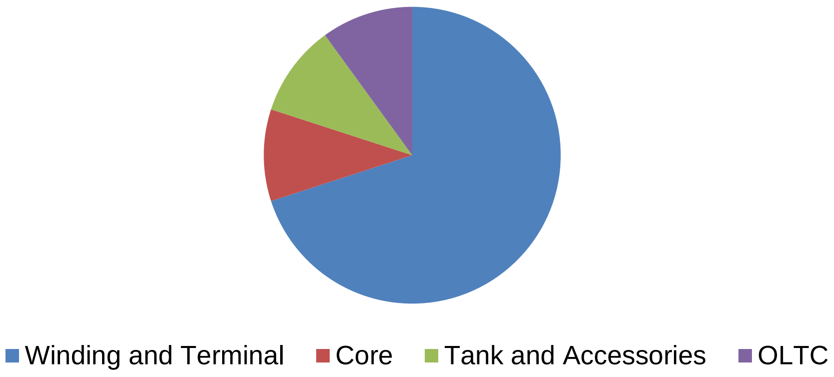

Figure 1. Power transformer short circuit statistics

Transformer Winding Faults

A transformer winding fault is limited in magnitude by the following factors:

- source impedance
- neutral grounding impedance
- winding connection arrangement
- fault voltage
- power transformer leakage reactance

Few distinct cases come up and are described below.

Star-Connected Transformer Winding With Neutral Point Grounded Through An Impedance

The winding ground fault current depends on the grounding impedance value and is also directly proportional to the distance of the fault from the transformer neutral point since the fault voltage will be directly proportional to this distance. For a fault on a transformer secondary winding, the matching primary current will depend on the transformation ratio between the primary winding and the short-circuited secondary turns. This also changes with fault position, so that the fault current in the transformer primary winding is directly proportional to the square of the fraction of the winding that is short-circuited. The case is presented in Figure 2. Faults in the lower third of the transformer winding generate very little current in the primary winding and that makes fault detection by primary current measurement challenging.

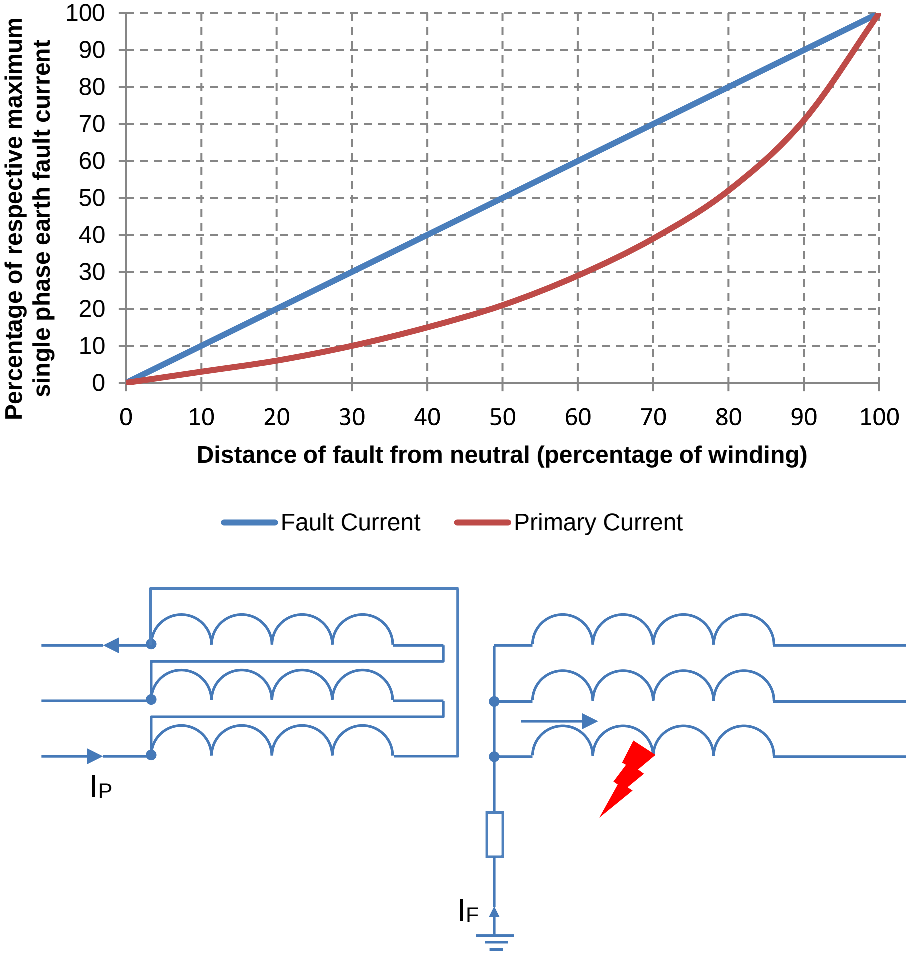

Figure 2. Ground fault current in resistance grounded star winding

Star-Connected Winding With Neutral Point Solidly Grounded

The fault current is limited by the leakage reactance of the transformer winding, which changes in a complex pattern with the fault position. The variable fault point voltage is also a critical factor, as in the case of impedance grounding. For faults close to the neutral end of the transformer winding, the reactance is very low and results in the greatest fault currents. The variation of current with fault location is presented in Figure 3.

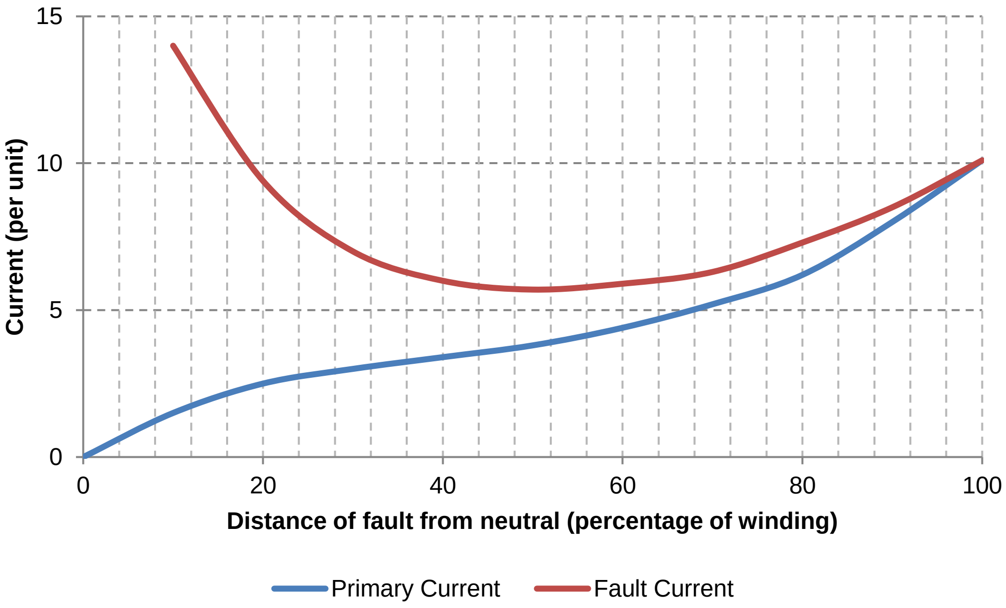

Figure 3. Ground fault current in solidly grounded star winding

For transformer secondary winding faults, the primary winding fault current is found by the variable transformation ratio. Since the secondary fault current magnitude remains high throughout the winding, the primary fault current is significant for most points along the transformer winding.

Delta-Connected Transformer Winding

Delta-connected winding elements do not operate with a voltage to earth of less than 50% of the phase voltage. Hence, the range of fault current magnitude is less than for a star winding. The real figure of fault current will still depend on the system grounding. It has to be noted that the impedance of a transformer delta winding is especially high to fault currents running to a centrally placed fault on one leg. It can be expected that the impedance is between 25% and 50%, depending on the power transformer rating, regardless of the normal balanced through-current impedance. Since the prefault voltage to ground at this point is half the normal phase voltage, the ground fault current may be no more than the rated current, or even less than this figure if the source or system grounding impedance is appreciable. The current will run to the fault location from each side through the two half-windings, and will be split between two phases of the system. Hence, the individual phase currents may be relatively low which can cause difficulties in providing protection.

Phase To Phase Transformer Faults

Faults between phases within a transformer are relatively uncommon. However, in the case such fault happens, it will give rise to a significant current comparable to the ground fault currents.

Interturn Transformer Faults

In low voltage transformers, interturn insulation breakdown is unlikely to happen unless the mechanical force on the winding due to external short circuits has caused insulation degradation, or insulating oil (if used) has become contaminated by moisture. A high voltage power transformer connected to an overhead transmission line will be exposed to steep-fronted impulse voltages, developing from lightning strikes, network faults and switching processes. A line surge, which may be of few times the nominal system voltage, will concentrate on the transformer winding end turns because of the high equivalent frequency of the surge front. Part-winding resonance, involving voltages up to 20 times nominal voltage may happen. The interturn insulation of the winding end turns is strengthened, but cannot be enhanced in proportion to the insulation to ground, which is relatively high. Therefore, partial winding flashover is more likely. The consequent progress of the fault, if not discovered in the earliest stage, may well destruct the evidence of the real cause.

A short circuit of a few turns of the transformer winding will give rise to a big fault current in the short-circuited loop. However, the terminal currents will be very small, because of the high ratio of transformation between the whole winding and the short-circuited turns.

The graph in Figure 4 presents the relevant information for a typical transformer of 3.25% impedance with the short-circuited turns symmetrically placed in the winding center.

Transformer Core Faults

A conducting bridge across the laminated structures of the transformer core can allow sufficient eddy-currents which can cause serious overheating. The bolts that clamp the core together are always insulated to prevent this problem. If any part of the core insulation becomes faulty, the resultant heating may attain a magnitude sufficient to damage the winding.

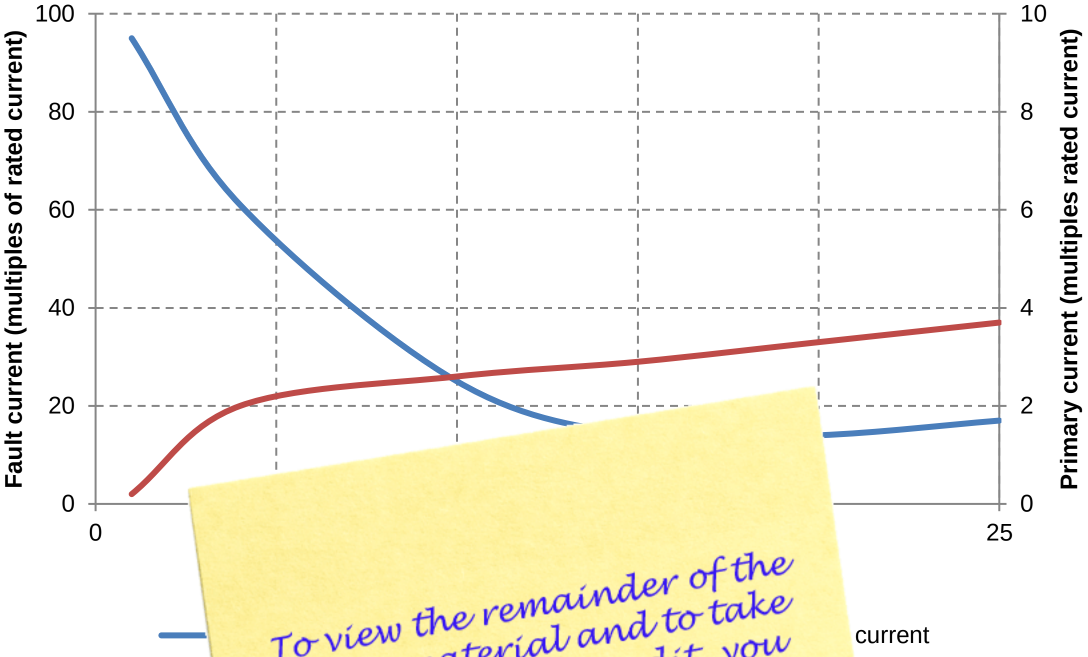

Figure … d turns

Even though additional … generate a detectable
change in input curren … electrical protection.
Nevertheless, it is cruci … ficant fault has been
created. In an oil-immer … h to cause winding
insulation damage also ca … on of gas. This gas
flows to the conservator a…