FAULT LOCATING USING VOLTAGE AND CURRENT MEASUREMENTS

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Prime reference:
Electrical Power Systems Quality
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Introduction

• Voltage and current measurements are taken while the fault is in circuit, and are used to compute the apparent impedance to the fault location seen from the relay or power quality monitor.

• Impedance-based methods have proven to be robust and effective in estimating fault locations particularly in overhead distribution circuits.

• Incipient faults can be located which helps in preventing actual short circuit from materializing.

• The fault locating methods are presented from the next slide:
Impedance-based fault location methods

• These methods are commonly used because of their simplicity and ease of implementation.

• Inputs:
  1. Voltage measurement
  2. Current measurement

• Positive and negative sequence line impedance values are also required.

• Output is in terms of distance to fault location.
Simple two bus distribution system

- Bus $B_1$
- Bus $B_2$
- $Z_1 = d \times z_1$
- $Z_0 = d \times z_0$
- PQM – Power Quality Monitor
- SLG Fault
- $I_{load}$
- $V, I_{tot}$
- $I_F$
Loop Reactance Method

- The method computes loop reactance to the fault location $X_t$, using the following expression:

$$X_t = \text{imag}(\frac{V}{3I_{\text{tot}}})$$

- The distance to fault location can be computed as $d = \frac{X_t}{x_{lt}}$ where $x_{lt}$ is the loop reactance in $\Omega$ per-unit length and is defined as

$$x_t = \text{imag}\left(\frac{2z_1 + z_0}{3}\right)$$

- This method performs well for light loads.
Positive-Sequence Reactance Method

• The positive sequence reactance method estimates the positive-sequence reactance to fault location $X_1$ as follows
  
  $$X_1 = \text{imag}(Z_1) = \text{imag}(\frac{V}{I_S})$$

• And the current $I_s$ is given as $I_s = I_{tot} + kI_{tot}$ where $k$ is computed as
  
  $$k = \frac{z_0 - z_1}{z_1}.$$

• The distance $d$ is obtained as $d = X_{\downarrow 1}/x_{\downarrow 1}$ where $x_{\downarrow 1}$ is positive-sequence reactance in ohms per unit length. This method works with reasonable accuracy on light and heavy loads.
Takagi Method

• It uses the following expression to compute the distance to fault location:

\[ d = \frac{\text{imag}(VI_{sup}^*)}{\text{imag}(z_1 I_S I_{sup}^*)} \]

where \( I_s \) is defined as \( I_s = I_{tot} + kI_{tot} \) while \( I_{sup} \) is the superposition current.

• Therefore to estimate the fault location, this method requires pre-fault load current data, \( z_1 \) and \( z_0 \) line impedance values as well as voltage and current measurements.
Error sources for Impedance-Based Methods

• Factors affecting the accuracy of these methods are:

1. Inadequacy in measuring voltage and current may result in errors.

2. $z_1$ and $z_0$ depend on parameters like size of conductors, distance between conductors etc. If any of these parameters is inaccurately measured, there will be significant error in values of impedances.
Assumptions

• The impedance-based methods are based on the assumption that the values of $z_1$ and $z_0$ are same for all the sections of distribution lines.
• The simplification is done by taking the values of $z_1$ and $z_0$ corresponding to the longest section of distribution lines.
• These methods either neglect load currents or use simplified load models while estimating fault location.

These assumptions might affect the accuracy of impedance-based methods adversely.
Sample application of Impedance-Based Methods
Fault voltage and current waveforms for Phase C to ground on utility
Inference

• An SLG fault occurred on the Phase C which resulted in increase in current from 200A to 1.9kA. The voltage sag occurred reducing the voltage to 10kV.

• The impedances were calculated and the methods discussed earlier were applied to estimate the fault location.

• The results can be seen in the table presented in the next slide:
• It can be seen that Loop reactance method proved to the most accurate while the other two methods yielded almost equal distance.
Locating Incipient Faults

• Incipient faults are self clearing faults which eventually result in permanent fault.

• The unique characteristics of self clearing faults are:
  1. Fault duration is less than half cycle.
  2. Fault generally starts near the peak of the voltage waveform.
  3. No overcurrent protective device operates because a relay generally needs more than half cycle to detect a fault.
  4. They are generally precursors to permanent faults on the same phase.
Example

- Self-clearing fault at 19:40
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b. Self-clearing fault at 21:11 on the same day.
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c. Permanent fault at 15:51 two days later
Fault Current Profile

• Impedance-based methods are widely used because of their simplicity but certain assumptions affect the accuracy of fault location estimates.
• To minimize the errors associated with impedance-based methods, the fault current profile approach is an alternative method for locating faults in a distribution system.
• It requires the availability of current waveforms measured during occurrence of fault.
• Utilities may have the circuit model of the distribution feeder in any of a number of distribution software packages and these are assumed to closely represent the actual feeder.
• The circuit model is used to build a reference current profile of short-circuited fault current versus reactance or distance to the fault.

• When a fault occurs in the distribution system, the fault current magnitude is extrapolated on the current profile to get a location estimate.

• The use of circuit model allows changes in line impedance hence improved accuracy.
Description of Method

• The fault current profile requires only fault current magnitude, pre-fault current and circuit model of the distribution feeder to determine location of a fault.

• Faults are placed at successive incremental distances from the relay in the circuit model.

• A typical short circuit fault current profile is exponentially decreasing curve, since the short-circuit fault current decreases with distance from the relay.
• When building a current profile for a complex distribution feeder, each branch or lateral is considered as an individual path and the current profile is built along every path from relay monitoring location.

• Let us consider a utility test case as shown in the figure presented in next slide:
Test Case
The circuit model shown can be implemented in the EPRI OpenDSS program.

The substation recorded a fault current magnitude of 1.9kA and pre-fault current is 208 A.

The load flow analysis indicated that the peak load current is 400A per phase. These means that the system is operating under half-load condition.

The distribution feeder has four branches and hence four paths were identified.
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• SLG faults are placed at every bus along the path and the developed fault current profile of short-circuit fault current versus the positive-sequence reactance to fault is shown below:
Result

• The fault current magnitude of 1.9kA intersects the paths 2 and 3 at positive-sequence reactance value of 2.58Ω and 2.79Ω. This corresponds to distances of 4.5 and 6.22 miles from the substation along the paths 2 and 3 respectively.

• The utility may now utilize customer outage reports or recloser operation status to determine which location has the maximum probability of a fault.

• In this case, the estimate of 4.54 miles on path 2 was determined and the actual location of fault was 5.33 miles along path 2. The error in estimates is 0.79 miles.
Thank you!