Protective Relay Traveling Wave Fault Location

N. Fischer, V. Skendzic, R. Moxley, and J. Needs
Schweitzer Engineering Laboratories, Inc.

PROTECTIVE RELAY TRAVELING WAVE FAULT LOCATION

N. Fischer*, V. Skendzic*, R. Moxley*, J. Needs*

*Schweitzer Engineering Laboratories, Inc., 2350 NE Hopkins Court, Pullman, WA 99163 USA,
papers@selinc.com

Keywords: Traveling wave, fault location, filter, differential.

Abstract

For decades, various versions of the Takagi algorithm have been used by microprocessor-based relays for fault location. This system provides accurate fault location, limited by nonhomogeneous infeed, load flow, fault resistance, and series-compensated or parallel lines. With the emphasis placed on reliability in today's power system, the need for improved accuracy in fault location has increased. Cases involving transmission lines spanning rivers or large valleys mean that a small error in fault location can force maintenance crews to spend added hours, or days, to find broken insulators or other faulted line components.

Traveling wave fault location overcomes the issue of measuring distance using high-frequency fault transients measured from a single line end or both line ends. The complications that have to be overcome include connections to protection current transformers and voltage transformers, filters on incoming circuits to avoid surges and spikes, and processing both power system frequencies (1 Hz to 3 kHz) and traveling wave transient frequencies (10 kHz to 600 kHz) in the same device.

This paper discusses the implementation and application aspects of traveling wave fault location in a protective relay. Performance limitations are discussed, as well as system requirements and practical installation considerations.

1 Introduction

A complete traveling wave fault location system includes more than just the detection of the traveling wave itself. The practical aspect of adding this capability without multiplying entire measuring systems means it needs to be combined with existing devices.

The basic process of a traveling wave fault location system involves detecting the wave peak, tagging the time of arrival, and comparing it with the time of arrival at the remote end of the line. Of course, each of these steps has its own complications and issues that must be addressed in order to achieve the accuracy promised by today's high-accuracy timing available at any location in the world.

2 Input signal selection

A fault on a transmission circuit produces both voltage and current traveling waves. Either one can be used for accurate fault location, so the question is which one produces a more detectable signal to the relay. How the primary sensor reproduces the traveling wave is the most significant factor in the selection of a current transformer (CT) versus a capacitance voltage transformer (CVT) [2].

Fig. 1 shows the CVT response based on the frequency of the input.
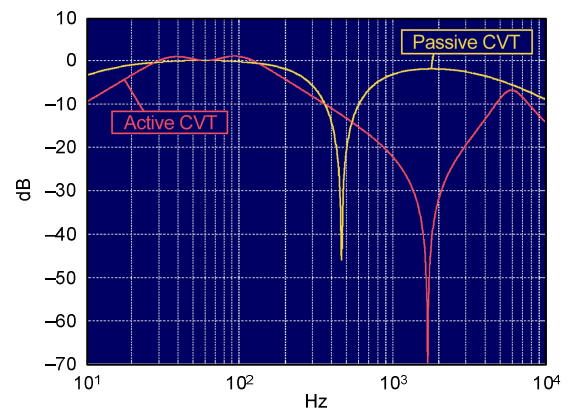

Fig. 1. CVT frequency response.

Note the sharp drop-offs in the kilohertz range and the fading response in the 10 kHz range. This has the impact of requiring a much larger traveling wave in order to be reliably detected. Contrast the CT response of Fig. 2 with the CVT response of Fig. 1.
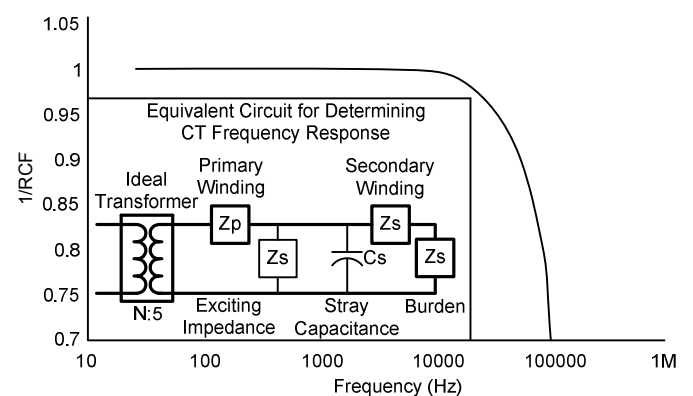

Fig. 2. CT frequency response.

The wider and flatter response of a CT makes it more suitable to detect traveling waves in a reliable and consistent manner. In Fig. 2, we see that out to 100 kHz, the response is only down to 70 percent.

3 Filtering

Once the input signal is selected, it needs to be processed to extract it from the overall power frequency signal, even though it might be of a significantly lower magnitude. Consider the fault shown in Fig. 3.
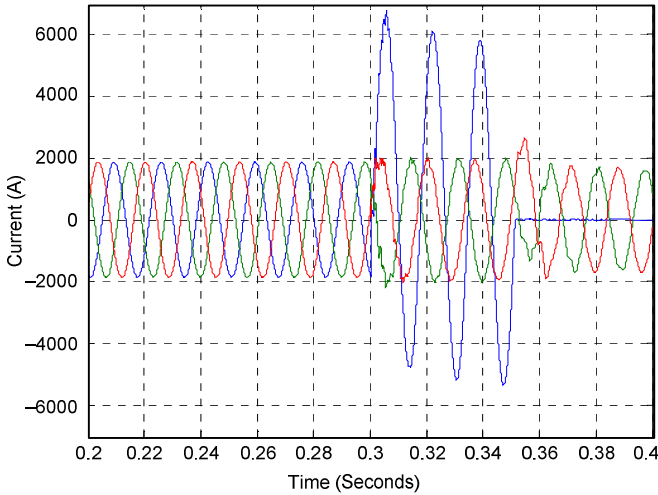

Fig. 3. Primary current at power system frequency filtering.

The sudden change in current occurring at time 0.3 signals the initiation of the traveling wave. The problem is that while we can see the current changes between time 0.3 and approximately time 0.305, this is not sufficient accuracy to establish fault location.

Now we compare the primary current in Fig. 3 with the same currents going through a 10 kHz and 600 kHz filter in Fig. 4.
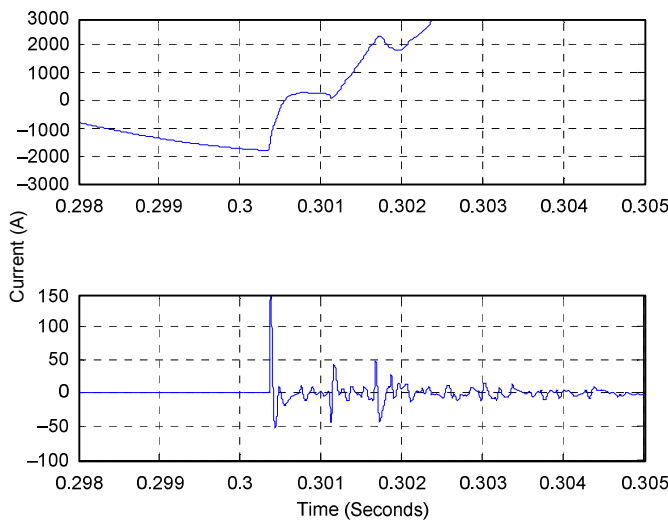

Fig. 4. Same wave as Fig. 3 with filter from 10 kHz to 600 kHz.

The resolution of the time of arrival of the wave front improves with each step of higher-frequency filtering. At 600 kHz, we can reasonably see the sharp edge of the arriving wave front to a resolution of 0.0001 seconds or better. In an actual implementation of the traveling wave system in a relay, a sampling frequency of just over 1.5 MHz was selected. Detecting and recording the traveling wave in this unit from two ends of a simulated transmission line produces the plot shown in Fig. 5.
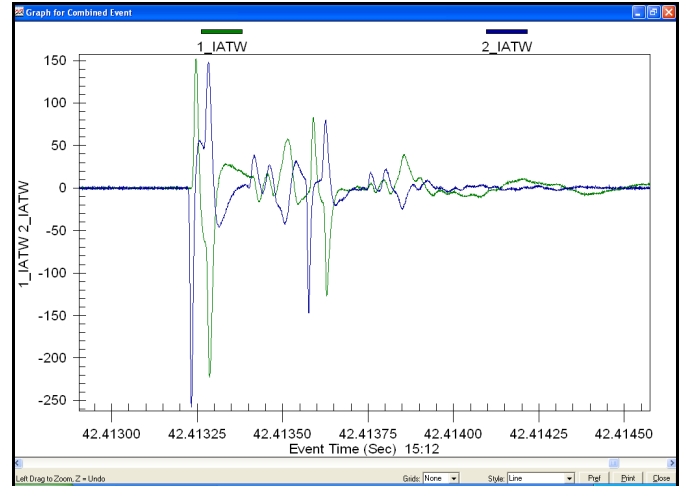

Fig. 5. Double-ended traveling wave detection.

In Fig. 5, we see the arrival at the two ends of the traveling wave. The two superimposed wave forms give the information we need to determine fault location. The first wave front is the arrival of the wave at the nearest terminal, and the second wave front is the arrival of the wave at the farther line end. Additional spikes are due to reflections.

4 Fault location

Reviewing elementary school physics, we know that distance = velocity • time.

In the case of a traveling wave that begins at an unknown fault location, we can write a similar equation to determine this beginning location:

$$\tau_{Line} = \frac{Line\ Length}{\nu_p} \tag{1}$$

where:

τ is the travel time of the wave on the transmission line.
ν_p is the phase velocity of the traveling wave.

While we know that the phase velocity of the wave approaches the speed of light, this is not precisely c (300 km/millisecond or 186,000 miles/second).

We know:

$$\nu_p = \frac{1}{\sqrt{\mu_0 \varepsilon_0 \varepsilon_r}} \tag{2}$$

However, for the line constants of a transmission line, this can be simply determined by (3) [1].

$$v_p = \frac{1}{\sqrt{LC}} \qquad (3)$$

where:

    L is the line inductance.
    C is the line shunt capacitance.

These values can be simply determined by the line construction conditions.

For a typical 500 kV line:

$$L_1 = 8.852 \cdot 10^{-7}\,\text{H/m}$$
$$C_1 = 1.302 \cdot 10^{-11}\,\text{F/m} \qquad (4)$$

which gives a phase velocity of:

$$v_{p1} = 2.946 \cdot 10^8\ \text{m/s}$$
$$= 0.982\ c \qquad (5)$$

Using these characterizations, we can express the fault location as:

$$F_{\text{Location}} = \frac{L_{\text{LENGTH}}}{2} + \frac{\left(t_{S\_TERM} - t_{R\_TERM}\right)}{\tau_{\text{LINE}}} \cdot \frac{L_{\text{LENGTH}}}{2} \qquad (6)$$

where:

    S and R refer to the sending and receiving terminals, respectively.

With Global Positioning System-based (GPS-based) clocks providing a typical accuracy of ±100 nanoseconds and a guaranteed accuracy of ±500 nanoseconds, this timing gives an accuracy of about ±300 meters.

For the practical matter of setting the relay with the required values to perform the calculation, the user is required to input the line length in miles or kilometers, the secondary cable length (which, in effect, is part of the line as far as the receipt of the traveling wave is concerned), and the line propagation velocity calculated as described in (3).

An additional practical consideration is to avoid a nuisance operation of the traveling wave fault location system when there is no actual fault on the line. Any event on the line or neighboring line—line switching, surge arrester conduction, or large birds landing on the line—will produce a traveling wave. Using a sensitive tripping element, such as a line current differential element, to qualify line events can eliminate these problems.

5 Conclusion

Workforce productivity and necessary customer service improvements require faster repair of problems in the transmission system. Highly accurate fault location can help meet this goal without adding significant additional cost to the overall protection and control system with the following:

- Modern relays have the processing capability and communications required for highly accurate fault location.
- Sufficient information about the transmission line is readily available to calculate fault location from traveling waves received at the two ends of a transmission line.
- Line current differential relays with GPS clocks provide sufficient communications and timing accuracy for traveling wave fault location.

New technologies and combined functions provide improved operational efficiency without increasing costs incurred by utilities and paid by customers.

References

[1] *Electrical Transmission and Distribution Reference Book*, Westinghouse Electric Corporation, 1964, p. 525.

[2] D. Hou and J. Roberts, "Capacitive Voltage Transformers: Transient Overreach Concerns and Solutions for Distance Relaying," proceedings of the 22nd Annual Western Protective Relay Conference, Spokane, WA, October 1995.