False Applications of Reliable Relaying Principles Revisited

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Introduction

In 1997 Walt Elmore presented a paper at several Conference titled “False Applications of Reliable Relaying Principles (Things We All Know To Be True – Which Are Not)”. The paper described a series of significant fundamental principles that are often misunderstood and used improperly. All these concepts are related to protective relaying either directly or indirectly. The paper was written in the interest of shedding light on basic fundamentals. 17 years have passed since the paper was written. What has changed? Do the basic principles illustrated hold up in today’s world? The purpose of this paper is to look back at the concepts discussed in Elmore’s paper and examines them for validity considering modern microprocessor relay technology.

Current Transformers

The following three “Truths” deal with excitation curves, error currents, and DC offset.

1. The excitation curve supplied with current transformers relates instantaneous secondary voltage and exciting current. **False**.

These curves, as in figure 1, are a plot of sinusoidal, clean, 60 Hz RMS voltage applied to the secondary terminals versus the reading of an RMS responsive ammeter, even though the secondary current which flows contains harmonics (Figure 2). It is incorrect to assume that this current represents instantaneous voltage to instantaneous current, or 60 Hz voltage to 60 Hz current relationship. Experience has shown though that reasonable results can be achieved by using RMS to RMS assumption. The ANSI standard C57.13-1993 allows this approach. Since the Instrument transformer standard C57.13-2008 contains same clauses on accuracy as C57.13 – 1993. This statement remains false.

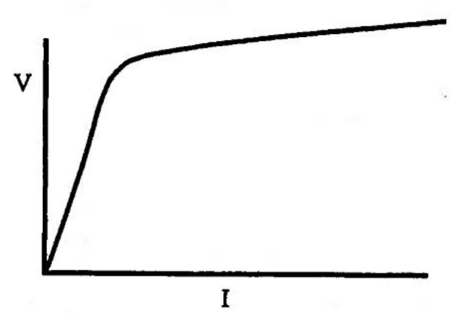

Figure 1: ct Saturation Curve

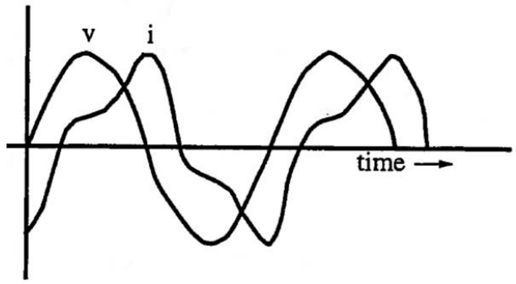

Figure 2: ct Exciting Current

2. For C Class current transformers, the maximum error with no more than rated secondary burden is 10%. **False**.

This applies for symmetrical currents, with no DC component, from 5 to 100 amperes secondary, but for only a ct having no residual flux. Figure 3 shows that the secondary voltage can be generated in a number of ways such as loop ab, cd, or ef, depending on the starting point. Previous history of the magnetic circuit, caused by faults or load and point of de-energization establish this starting point. Each of these loops has a different peak excitation current even though they are based on the same secondary current and burden.

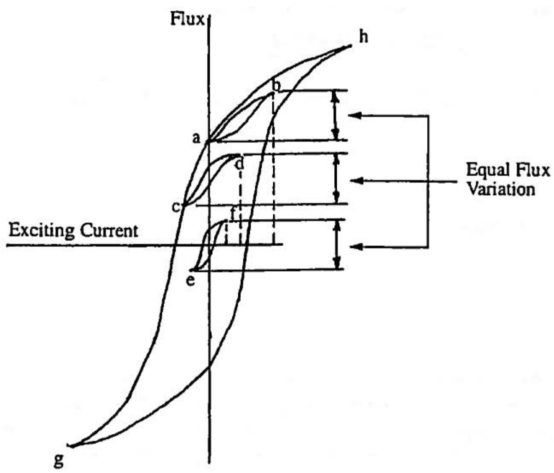

Figure 3: Effect of residual flux on ct exciting current

Loop ab cannot persist because of the dc component inherent in the non symmetry about the vertical axis. This dc current in the secondary current not matched by primary current will cause this location to move to loop cd. This loop can remain forever, along with the excessive error associated with the difference between the peak currents associated with d and f. Changing conditions change the location of the loop. Only ef relates to the specified behavior of the ct for relaying or metering because the standard tests reduce the residual flux to zero by applying a secondary voltage to the ct high enough to produce loop gh and reducing it gradually to zero. This restores the symmetry.

Since fault current interruption occurs at current zero, which is at zero ct secondary voltage with a resistive burden, which is near peak ct core flux, there is a good likelihood that severe faults will leave near peak flux entrapped. Since the physics of ct’s hasn’t changed this statement remains false.

3. Fault current having a dc offset is initially very high. **False**.

Following the occurrence of a fault, the current immediately after the fault is exactly the same as the current immediately preceeding the fault. Current cannot change instantaneously in an inductance. As figure 4 shows, the instantaneous magnitude of the current does not change at fault inception. The high current usually associated with faults having dc offset is that of the first peak which occurs a full half cycle after the occurrence of the fault. Physics hasn't changed since 1997, so this statement is still false.

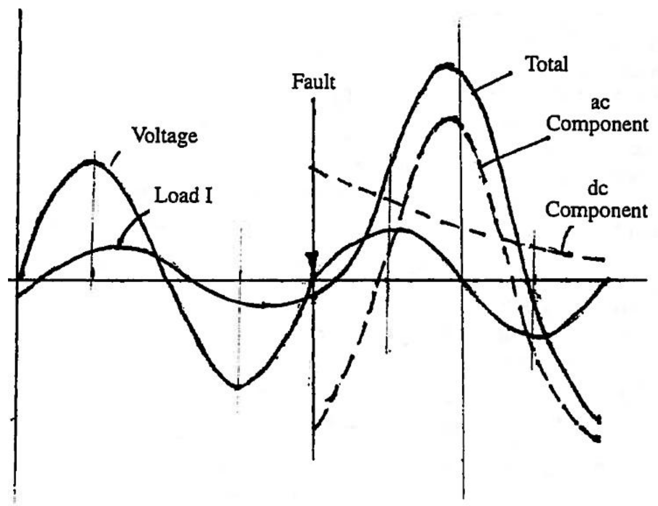

Figure 4: Shows no change in current at fault inception

Symmetrical Components

1. Third harmonic is always zero sequence in character. **False**

This statement is true only if the same level of third harmonic is generated in each of the three phases. A non linear load in a single phase circuit generates third harmonic voltage, but it contains positive, negative, and zero sequence characteristics in the same way that a phase to ground fault does.

2. Since operator "a" rotates a phasor 120° in the counter-clockwise direction, operator "-a" rotates a Phasor 120° in the clockwise direction. **False**

Figure 5 shows that "-a" rotates a phasor only 60° in the clockwise direction.

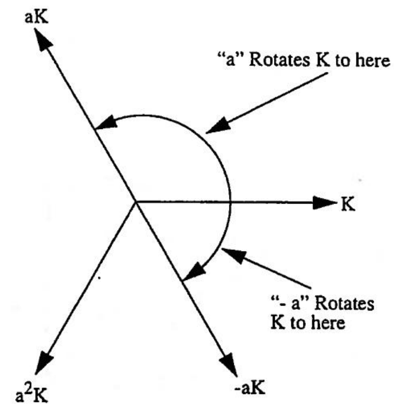

Figure 5: Showing "-a" does not rotate a phasor 120° in the clockwise direction.

3. Positive sequence phasors rotate in a counter clockwise direction and negative sequence phasors rotate in the clockwise direction. **False**

All phasors rotate in the counter clockwise direction. Negative sequence phasors peak in the opposite sequence to that of positive sequence phasors. (ACB for example as opposed to the normal ABC).

4. Seventh harmonic is positive sequence in character and therefore will have no effect on a negative sequence voltage relay. **False then now true with respect to microprocessor relays.**

Here's where microprocessor technology takes a different approach so the answer differs from what applies to electromechanical relays.

In 1997 virtually all negative sequence filters were designed for 60 hertz. They produce a single phase output voltage proportional to the negative sequence content of the input voltages or currents. For a typical negative sequence filter, at high frequency the filter output voltage is nearly the same whether the character of the high frequency voltage is positive, or negative sequence. Triple harmonics are automatically screened out through the use of phase to phase voltage instead of phase to ground voltage for the relay input. A filter designed for 60 hertz negative sequence sensing, will produce an output for a high frequency input even though the fundamental is purely positive sequence, which has essentially the same magnitude as if the fundamental were not present. Of course, some such filters are equipped with provisions to desensitize the relay to high frequency influence.

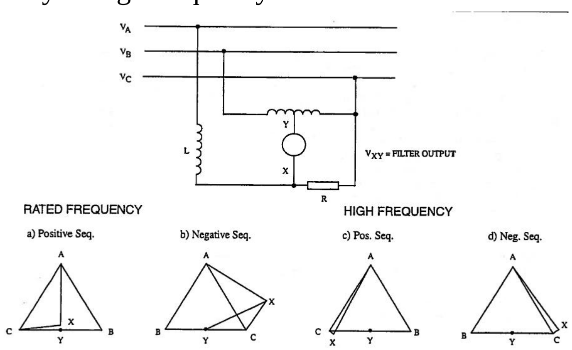

Figure 6: Typical negative sequence filter

In the numerical relay world, the method of calculating the negative sequence typically uses the following procedure. First the analog input goes through a low pass filter with a cutoff frequency of around 500 Hz. Then, the individual phasors for the three phases are calculated using a full cycle digital Fourier filter. This cancels the higher harmonics. Finally, the positive, negative, and zero sequence phasors are calculated using the classical matrix formulas. Based on the above, the 7^{th} harmonic (or any other exact multiple of the fundamental frequency) will have negligible influence on the sequence components calculated by digital relays.

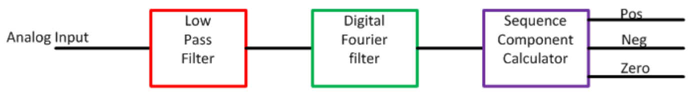

Figure 6a
Numerical Sequence Component Calculator

5. Faults which do not involve ground produce no zero sequence current. **False.**

Figure 7 shows the network interconnection for a simultaneous open phase and phase to phase fault. From this, it is apparent that zero sequence current will flow provided there is a zero sequence path, source on each side of the open. Care should be exercised with relays that have a weighted zero sequence response. This case could appear as an external fault, even though it's an internal phase to phase fault.

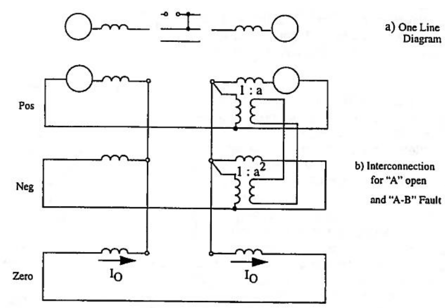

Figure 7: Simultaneous open and øø fault

Power Line Carrier

1. With center phase to ground coupling and center phase trapping, the carrier signal is confined to the coupled phase. **False**

With this type coupling mode 1 and mode 3 are coupled with magnitudes as shown in figure 8a and mode 2 is zero. Mode 3 attenuation is roughly 20 to 40 times(in db) that of mode 1, and so the received signal with any significant distance of transmission is purely mode 1. Since the nature of mode 1 is essentially one unit in two if the outer phases returning in the center phase, a substantial signal level can be expected at the receiving terminal on the two uncoupled phases in addition to the phase to which the carrier is coupled. Power line carrier systems have been operated for years unintentionally coupled to different phases at the two ends of the transmission line without ever experiencing difficulty.

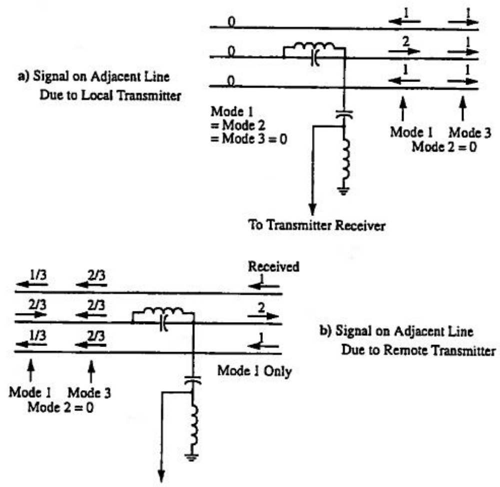

Figure 8: Carrier signal is not confined to coupled phase

2. Transmission line transpositions produce a concentrated 6 db carrier loss. **False**

At a transposition there is no carrier power loss. There is, however, a transformation of carrier mode. See figure 9a. A low loss mode 1 signal arriving at a transposition is attenuated and partially converted to mode 2. The mode 1 voltage content is half of that of the arriving signal (down 6db). Mode 2 voltage is generated by the transposition to a level of ¾ of the original mode 1.

Mode 2 attenuates at roughly 4 times (in db) the rate of mode 1, but any mode 2 that remains at the next transposition is attenuated (to half value) and partially converted back to mode 1 as figure 9b indicates.

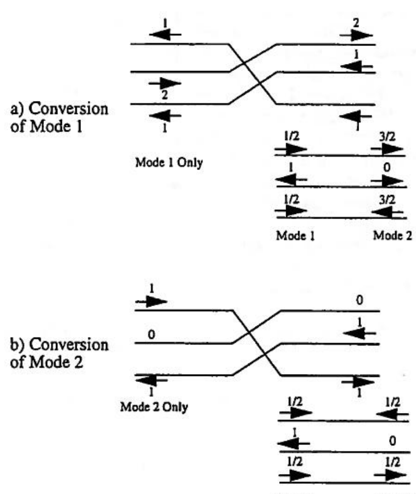

Figure 9: Mode conversion caused by transmission line transposition

Transformers

1. Phase sequence is important in connecting the differential relays for a power transformer. **False**

Take the example of a delta – wye transformer shown in figure 10. By connecting the current transformers in wye on the delta winding and delta on the wye winding, the phase sequence does not control the connection to the relay.

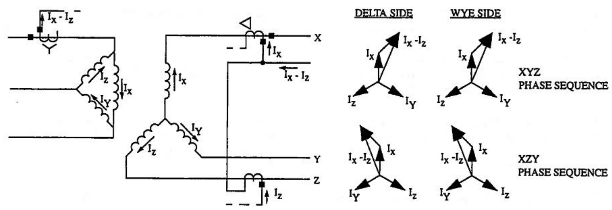

Figure 10: Partial circuit for transformer differential relay showing phase sequence does not matter

Commonly, in modern microprocessor relays current transformers are connected in wye regardless of the power transformer winding configuration. To compensate for the phase shift across the transformer, a phase compensation setting is used. The phase compensation, or clock number is the phase displacement between winding 1 and winding 2 with winding 1 being the HV side.

2. The instantaneous trip protecting a transformer must always be set above transformer inrush. **False**

Some transformer differential relays such as shown in figure 11 have the instantaneous trip located in such a position that it is not responsive to either dc current or second harmonic, both are significant components of inrush current.

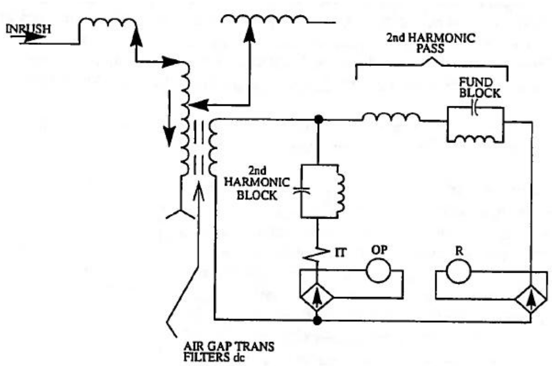

Figure 11: Example of IT location to allow more sensitive setting

In microprocessor relays the harmonics and dc can be stripped out via Fourier filters so the instantaneous element is only responsive to fundamental frequency currents.

As shown in figure 12, an instantaneous element responsive to just fundamental current can be set much lower than the inrush current.

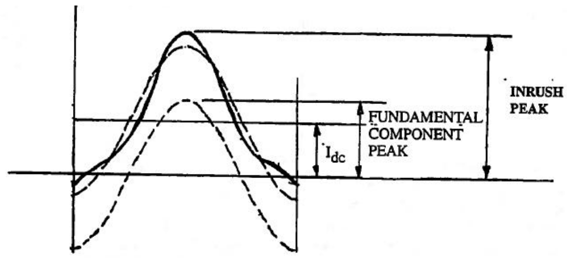

Figure 12: Influence of dc and second harmonic on peak of inrush

3. An autotransformer neutral is always a reliable source of zero sequence polarizing current for ground relays. **False**

Reliable means that the current is always up the neutral when zero sequence current is flowing to a ground fault, irrespective of fault location.

For two winding autotransformers, the neutral is not adequate because the current is always down the neutral for faults on the high voltage system and always up for faults on the low voltage system. It is an unsuitable polarizing source. As figure 13 shows, the relays on both the high voltage and low voltage systems would either trip for both fault locations or block for both fault locations.

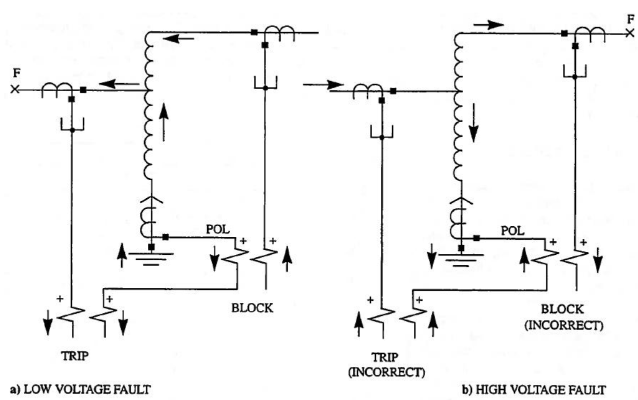

Figure 13: Neutral of autotransformer for polarizing

For autotransformers equipped with a tertiary, the neutral current may be a reliable polarizing source for relays on both sides of the transformer. In figure 14, it is apparent that the neutral current will be in the proper direction (up) when the current is flowing to a fault on the high voltage system provided $(1- KV_H/V_L)$ is positive where K is the per unit current that flows in the zero sequence network of figure 14a, and V_H/V_L is the ratio of the high and low voltages. The tertiary current is always in the same direction unless the $Z_L + Z_{OS}$ sum (figure 14a) is negative, which is possible but not probable. Z_L is usually a small negative value in the equivalent circuit. For that case K becomes greater than 1, and the tertiary is an unsuitable polarizing source.

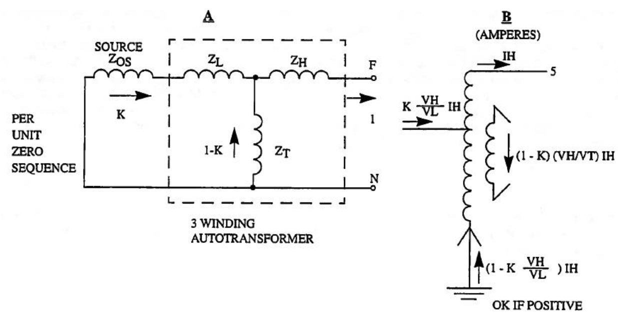

Figure 14: Neutral of autotransformer with delta tertiary for polarizing

4. Wye-ground – broken delta transformers always provide a reliable source of polarizing voltage. **False**

Figure 15 describes a connection that is sometimes proposed which will not work. The wye-ground – broken delta transformer properly reproduces across the break any zero sequence voltage that is present. However, the open delta – open delta connection used with it in this figure delivers no zero sequence voltage to it. There is no zero sequence content in phase to phase voltages. There will be no output from the wye-ground – broken-delta transformer even though considerable zero sequence voltage may be present on the power system,

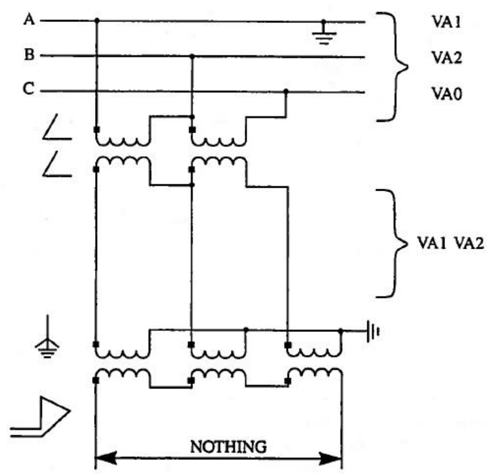

Figure 15: Incorrect use of wye-ground-broken-delta transformer connection

Transmission Line Relaying

Parallel line compensation is always good for ground distance relays. **False**

The introduction of the adjacent line zero sequence current into a relay is very appealing from the viewpoint of eliminating the error in a ground distance relay that is caused by zero sequence mutual inductance. However, the nature of the compensation is that the zero sequence current in the adjacent line increases the reach of the ground relay for faults on the protected line, and this increase also occurs for faults on the adjacent line. Since the adjacent line zero sequence current for a zero per cent fault on the adjacent line is limited almost exclusively by the source impedance (rather than the line impedance), the compensation may be overpowering, causing the relay to have a false sense of direction to the fault (see figure 16.) The addition of a zero sequence directional unit solves this problem, as would decreasing or eliminating the adjacent line zero sequence mutual compensation.

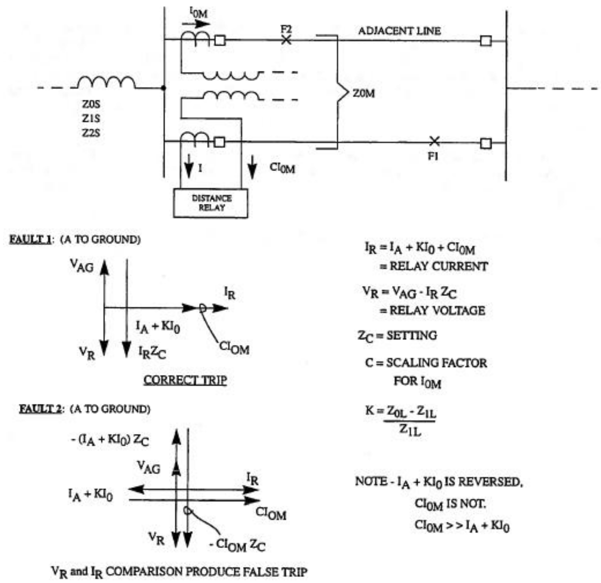

Figure 16: Effect of mutual compensation

Conclusion

This paper re-examined certain nuances of fundamental principles which are directly or indirectly related to protective relaying that were in the original paper. We've found that in most every case the previous conclusion reached was correct. In those instances filtering in microprocessor relaying was able to eliminate that harmonics that were applied to electromechanical relays. Current transformers still obey the laws of Physics. Fortescue's rules of Symmetrical Components still apply. Power line carrier modal analysis still applies, and Kirchoff's law still applies to transformer differential relays.

References

1. W. A. Elmore, False Applications of Reliable Relaying Principles, 1997 Western Protective Relay Conference.
2. IEEE Standard C57.13 -2008 Standard Requirements for Instrument Transformers
3. M.C. Perz "Natural Modes of Power Line Carrier on Horizontal Three Phase Lines", IEEE Transactions on Power Apparatus and Systems, July 1964, pp 679-686

Biography

Roger Hedding is a Senior Consultant for ABB Power Systems Automation and Communications (PSAC) Substation Automaton Group. In this capacity he guides the application of relays for the ANSI market. He's a graduate of Marquette University (BSEE) and the University of Pittsburgh (MSEE). He lives in New Berlin, WI. Roger's hobbies are travelling with his wife, Snorkeling, playing golf, and playing with his 4 grandchildren.