CT & VT CONNECTIONS
A PRIMER

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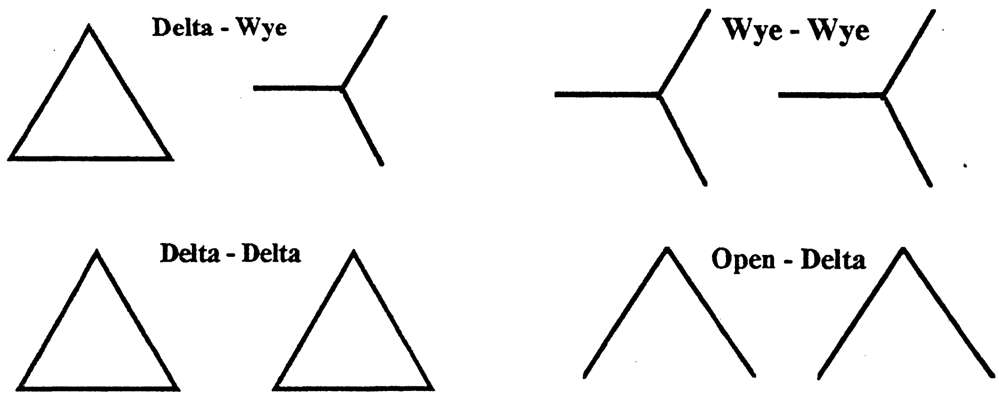
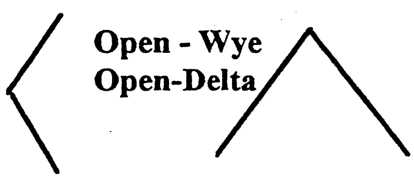
Introduction

Fundamental to the application of protective schemes is the proper connection of vt and ct inputs. Although most protective relay installations follow long practiced methods of connection, it is nevertheless important to understand why a method is employed. This paper will provide discussion of the options available and evaluate the strengths and weaknesses or limitations of each.

Connections of Voltage Sources - Basic Connections

Transformers used as voltage sources for relay applications can be connected in a number of methods. When three phase voltage is required, these methods are





For any of these connections, a ground or neutral can be connected. However, only a grounded wye primary connection is capable of providing zero sequence voltage, if it is required.

Figure 1

Note that many modern directional relays require three phase voltages from a connection that is capable of generating the zero sequence voltages. These relays cannot provide ground directional relaying from delta secondary connections or from any of the two-transformer connections.

Zero Sequence Connections

If the relaying application requires a zero sequence input, this input can be provided by a connection called a broken delta. Note that this connection is not the same as an open delta connection. A broken delta connection, as shown below, requires the primary to be grounded wye.

By leaving open a corner of the delta secondary, 3Vo can be measured across this opening. This quantity is commonly used as a polarizing reference for directional ground protection.

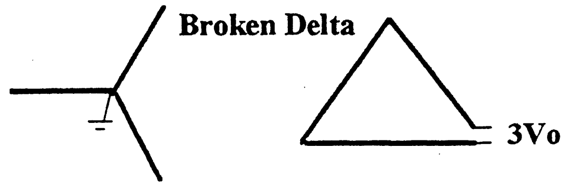


Figure 2

Location of Voltage Sources

The location of the voltage source can be important for a number of reasons. In particular, the location of this source has significant influence on the application of distance protection for transmission lines. First, the location of the voltage source is the origin of the R - X diagram, ie, the impedance as measured by the relay begins at this location. Therefore, if there is impedance between the voltage source location and the transmission line, such as an auto-transformer or a series capacitor, this impedance will need to be included in the setting determination for the impedance relay.

Another effect of the voltage source location involves the ability of the relay to respond when the protected line is energized. If the voltage source is located on the line and is energized at the same time as the line, the impedance relay may be unable to function properly for some fault types and locations [worst case being close-in 3-phase faults]. Most impedance relays will require the use of some type of switch-onto-fault capability to allow tripping based on current levels.

Voltage sources as applied to breaker-and-half schemes and some ring bus arrangements may also lead to some application problems. Some of the larger breaker-and-half applications have used bus potential transformers to supply relaying voltage instead of providing a set of potential sources for each line. When this approach is used, there would normally be capability to transfer the source of potential should one of the busses be out of service. For this arrangement, the relaying should be capable of properly working for two types of events.

The first event is the switching out of one of the busses. When this switching is done, the relaying supplied voltage from the transformers on that bus will, at least for a short while, lose their source.

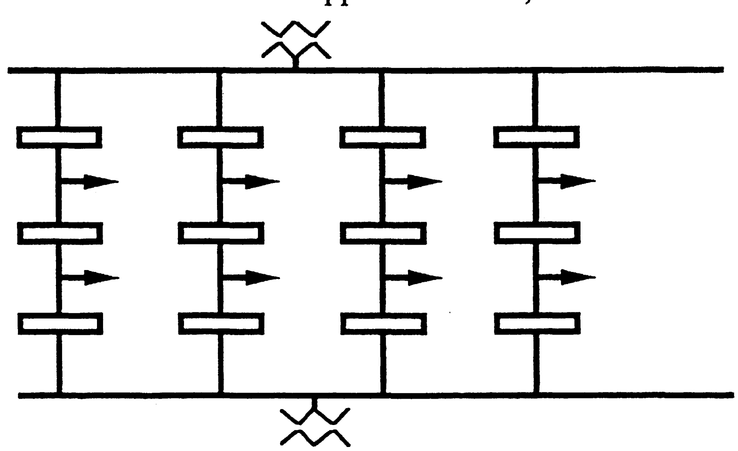


Figure 3

Since it is likely that load current will be flowing out onto these lines, the relaying should be able to restrain and remain secure for this loss of potential. This security is usually achieved by using some type current level detector or change of current detector.

The second event is a bus fault. During a bus fault, current will likely flow into the station from all external sources. As the bus fault is cleared by de-energizing the bus, the relays supplied by that bus will lose potential at the same time the current is changing from the inflow to the fault back to the outflow of supplying load. It is important the relaying be capable of remaining secure for this challenging sequence. Level detectors, current reversal detection, or other techniques may be used.

Connection of Current Sources - Basic Connections

Why Wye

Most ct connections for relaying applications are wye connected. The reasons are basic--to provide zero sequence when necessary and because it is a simpler connection to make and to understand.

Why Delta

Delta ct connections are made for two good reasons. One is common to transformer differential applications and is well understood. That reason is to provide a 30° phase angle shift to compensate for the phase angle difference from the primary to the secondary of a delta - wye connected power transformer. ***Note that proper connection of the delta cts will produce in-phase currents in the differential relay; improperly connected delta cts will result in currents that are 60° out of phase.***

The second reason to connect cts in delta is also common to tranformer differential applications, but is less well known. This reason is to block or filter the zero sequence components of the currents. If a ground fault occurs external to the differential zone and on the wye side of a delta - wye connected transformer, zero sequence current will be generated on the wye side of the transformer. However, the delta connection on the power transformer will not produce any zero sequence current. Without corrective measures, the differential relay would sense zero sequence current from the wye side cts and no zero sequence current from the delta side cts. This difference could cause a misoperation of the relay. By connecting the wye side cts in delta, the cts prevent zero sequence current from be supplied to the differential relays. ***Note that modern microprocessor differential relays allow all cts to be connected in wye. The relays provide internal filtering or blocking of the zero sequence currents.***

Parallel Connections of CTs

It is relatively common for cts to be connected in parallel for a number of different relaying applications. I will divide these applications into two categories. One I will call summed cts, the other I will call differential connected cts. Although the connections are the same, the protection associated with each varies and the resulting precautions are different.

Summed CTs

Summed cts refers to the applications that have two breakers associated with the part of the system that is being protected. This could be a ring bus, a breaker-and-a-half scheme, or a two bus arrangement. The cts are connected in parallel such that the net of the current flowing into or out of the protected system is provided to the relaying. This technique is an effective cost-saving alternative to requiring the relaying to accept the additional separate current inputs. However, this technique has a couple of disadvantages that should be understood.

Ideally, the summed [parallel] cts should only provide to the relay the net current that flows into or out of the protected system. However, If these cts are subjected to large currents external to the protected system, differences in ct performance can result in relatively large error current levels. If the protective relaying is designed or applied to operate at low levels, an incorrect operation may occur.

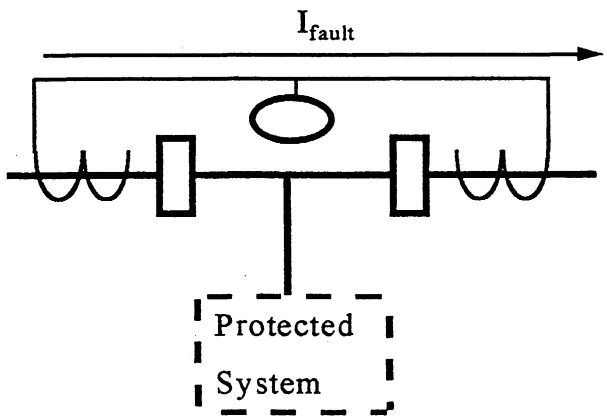


Figure 4

If the protected system in this figure is a transformer, ct error currents, which appear as differential currents, could likely cause a differential relay misoperation. The correct application would provide separate restraint inputs for each of the ct sets.

Another limitation of parallel cts is when separate currents are required, such as for breaker failure relaying, breaker condition monitoring, or some form of metering. If these additional functions are provided as an integral part of the protective relaying, they are typically not usable for these applications.

Differential Cts

The other application of parallel cts I am calling the differential connection. With the differential connection, the cts for each breaker around a zone of protection [typically a bus, but possibly a generator or transformer] are connected in parallel such that all currents in or out of the zone of protection are summed vectorially. The result is for faults external to the zone of protection, the net current is zero or as close to zero as relay accuracies can produce. For internal faults, the output of the parallel currents is the secondary value of the total fault current. The differential connection provides an excellent means of clearly defining a zone of protection and allows simple, inexpensive overcurrent relays to be used.

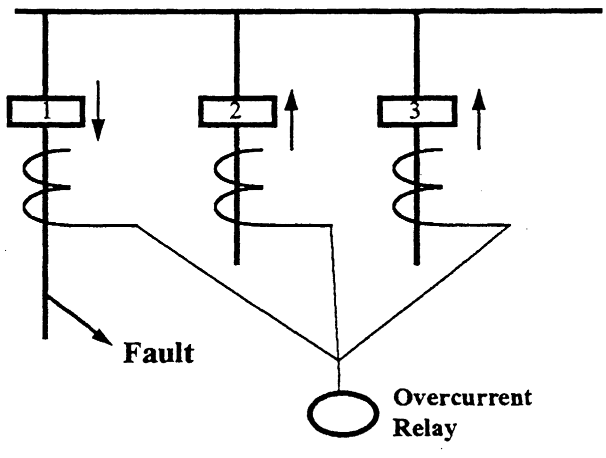


Figure 5

The problem of error currents that was discussed above is not as likely to cause a problem for these applications because the minimum fault levels are normally high enough to set the relays comfortably above any reasonable error currents.

The problems with these applications has to do with ct performance during faults just outside the zone of protection. For these faults, the ct associated with the breaker providing the full fault current must produce current to cancel the currents supplied by all the other breakers connecting sources. If this ct with the full fault current goes into saturation, the resulting current produced by the parallel cts will approach the same level as an internal fault.

To accommodate the problem caused by this ct saturation, a rather simple adjustment is made to the protection scheme. Impedance is added to the relay portion of the current circuit, as shown in the following figures. For external faults, correct ct performance will result in zero current and thus zero voltage across the impedance and relay path.
If the ct of breaker 1 go into saturation, the current from the cts of breakers 2 and 3 will have two possible paths, as shown in the following figure. One path is through the impedance and relay circuit; the other is through the saturated ct.

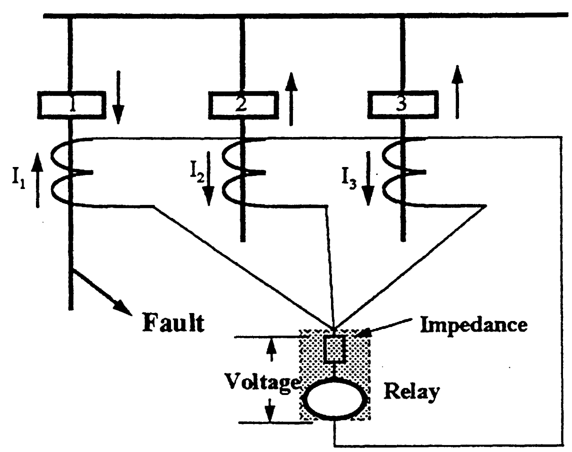


Figure 6

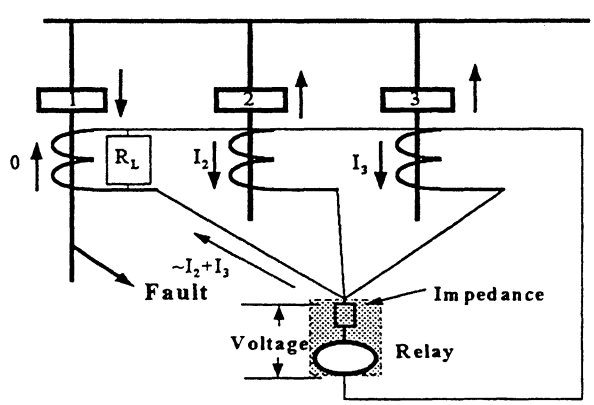


Figure 7

If the impedance in the relay path is high enough, most of the current will be forced through the path that consists of the lead resistance and the secondary ct winding resistance [R_L]. The relay can be set to operate either at a set voltage level or at the associated current level. For internal faults, the cts of all the breakers must produce a voltage to exceed the setting of the relay, whether that be a voltage level or a current level.

This protection is referred to as high impedance bus protection, but, as shown here, can be seen to be a rather simple application of either a voltage or current level detector.

Zero Sequence Differential Connections

Using similar connections and the same principles shown in the previous example, zero sequence differential protection can be applied to any transformer winding. The most common application is to provide sensitive ground fault protection for a wye winding.

This figure shows the 3 phase cts connected in parallel with the neutral bushing ct. [Not shown is any other relaying, such as the differential relays, that would be in series with each phase ct.] Under balanced conditions, the phase cts sum to zero and the neutral ct is zero. For external ground faults, the phase cts produce 3 I_o and the neutral ct produces 3 I_o. These connections provide that these equal values cancel one another. For internal faults, the phase cts and neutral ct would not cancel and the voltage or current level could be set to provide good sensitivity independent of the load current effects.

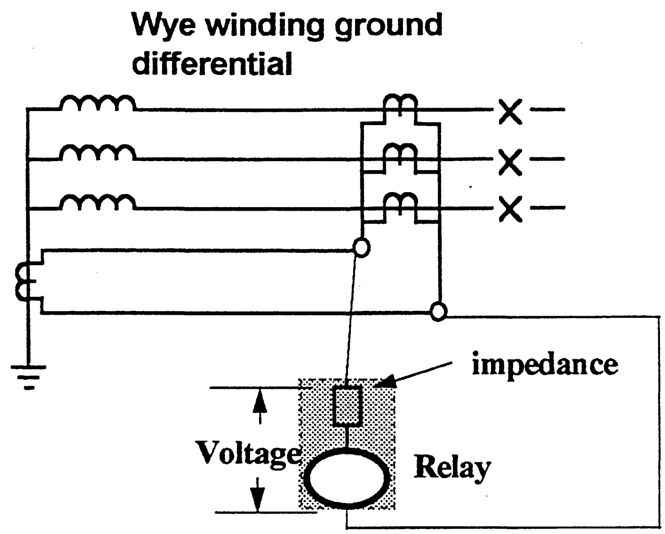


Figure 8

Once again, the impedance is added to the protection path to accommodate ct saturation by any of the involved cts. This protection, using the concept of parallel cts, provides secure winding ground fault protection with sensitivities well below load current levels.

Summary

This paper, I hope, has provided some basic and fundamental information about the connection of voltage and current sources to protective relaying. It is important to have a clear understanding of why certain connections are used and what precautions are necessary. Modern microprocessor relays, with many more integral features and capabilities, makes the knowledge of connections even more important.