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Application of Zone 3 Distance Relays on Transmission Lines

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Introduction:

The July 2, 1996 WSCC System Disturbance included several transmission lines which were tripped by Zone 3 distance relays. The purpose of this report is to provide some general guidelines for the application of Zone 3 distance relays to utility power lines. It is not intended to be a comprehensive tutorial on distance relay application and setting, but rather a discussion of some general concepts to keep in mind and typical problems encountered when applying Zone 3 distance relays.

For a typical transmission line in an electric utility's transmission system, there are up to three zones of distance relay protection for multiple phase fault protection. These relays may be the only phase fault protection on lower voltage transmission lines (e.g. 69 kV and 115 kV), but typically function as an independent backup system on higher voltage transmission lines employing a pilot relaying scheme as a primary system. The Zone 3 distance element is typically used to provide backup protection for phase faults associated with failure of equipment at remote substations (i.e. remote breaker or relay failure).

In some pilot relaying schemes, directional comparison blocking (DCB) in particular, a reverse-looking impedance relay used to detect faults external to the protected line (and send a blocking signal to the remote line terminal) may also function as a Zone 3 backup with a time delay. Some utilities do not use Zone 3 forward reaching functions.

Remote Backup:

The IEEE dictionary (ANSI/IEEE Std. 100) defines remote backup as: "A form of backup protection in which the protection is at a station or stations other than that which has the primary protection". Today, many transmission substations are being designed with either a ring bus or breaker-and-a-half scheme. Back-up in these applications should be looked a very carefully, because the remote end of an adjacent line frequently is required to trip during a breaker failure. Often breaker failure relays initiate transfer tripping of the remote breakers. Any number of problems could prevent the transfer trip signal from getting through. In this case, the remote backup relay will operate after the local breaker failure scheme has operated to remove infeed. In this application, which is typical on EHV systems, the Zone 3 relay can have a very important backup function.

Setting Considerations:

For a given transmission line with a positive sequence impedance Z, the zone distance relays are typically set as follows:

Zone 1:	80-90% Z
Zone 2:	100% Z plus additional reach
Zone 3:	100% of the Zone 2 setting plus additional reach

Typically, Zone 1 has no inherent time delay, Zone 2 is set for 20-30 cycles, and Zone 3 is set for 0.5-3.0 seconds. The setting philosophy will obviously vary between utilities and for specific applications.

Coordination Considerations:

Setting the reach of the Zone 3 relay on a particular transmission line in a looped transmission system may require the protection engineer to weigh the following parameters and make some compromises:

1. Length of the adjacent transmission lines connected to the remote bus (in the case of forward-reaching Zone 3 relays).

2. Infeed, i.e., a source of fault current within the operating zone of the relay.

3. The presence of local breaker failure protection at the remote bus, and the remote bus configuration.

4. Load encroachment.

5. Presence of tapped transformers within the operating zone of the relay. It is generally assumed that the time delay of the Zone 3 relay is set long enough to properly coordinate with all downstream protective devices that are within the reach setting of the Zone 3 relay. It is important to remember that if the Zone 3 relay overreaches the secondary side of delta-wye connected distribution transformers connected to the subject transmission line, then the impedance to the low-side bus as seen from the relay is shifted by 30 degrees on the R-X diagram. It may difficult to set the Zone 3 timer long enough to avoid miscoordination.

Voltage Considerations:

It is important to consider the difficulties encountered by any impedance based relay connected to a bus that is part of a power swing or experiencing a voltage collapse. Depending on the type of load connected to the bus, if the voltage drop is severe enough, there will be situations where the locus of the load in the impedance diagram undoubtedly will fall within the impedance characteristic, no matter what kind of blinders or load encroachment functions you apply.

Load encroachment has often been the culprit of undesired Zone 3 operations during system disturbances or abnormal operating conditions. This can be caused by not only increased loading, but also decreased system voltage. The protection engineer should therefore determine, preferably in coordination with the planning department, the maximum load current and coincident minimum voltage that the Zone 3 relay might be subject to during conditions for which the Zone 3 relay should not trip. (Clearly, there is a need for a WSCC recommended minimum voltage for which Zone 3 relays should not trip). The following procedure is suggested for checking a particular reach setting for a Zone 3 relay to avoid operation due to load encroachment within the previously agreed upon values of voltage and current:

1. Determine the maximum load, minimum voltage (and power factor, if available) on the subject transmission line in the direction of the Zone 3 relay under a multiple (second) contingency outage situation. Note that power swings can be relatively slow, and may cause momentary overcurrent and undervoltage conditions which might cause Zone 3 relays with short time delay settings to operate. Therefore, worst case stable swings should be reviewed for possible transient load encroachment. Also, if the Zone 3 element is part of the permissive initiate/receive circuit in a pilot scheme, preventive measures should be taken to avoid undesired operations.

2. Convert the MVA and voltage values to primary ohms using the following relationship:

   Z primary ohms = (kV)^2 / MVA

   Note: If actual power flow determined voltage is not available for the particular loading condition, it is recommended to use a voltage value less than 1 per-unit (e.g. 0.80 per-unit or less) when determining the MVA pickup of the relay.

3. Calculate the angle of the load impedance using $\cos^{-1}$ (Power Factor). If the power factor of the load is unknown, assume 0.85 which is typical of transmission systems. Then: $\cos^{-1}(0.85) \cong 30$ degrees.

4. Plot the load impedance point on an R-X diagram along with the mho circle representing the Zone 3 proposed setting. If the impedance point falls outside of the mho circle (with some reasonable margin), the relay will not operate for the particular load value. If the impedance point falls inside of the mho circle, the use of blinders or a load encroachment function in the relay is required. Note: If the relay characteristic is plotted on an R-X diagram scaled in secondary (relay) ohms, then the load impedance must be converted using the following relationship:

Z secondary ohms = Z primary ohms x CT ratio / PT ratio

Load Encroachment Relay Function:

Oftentimes, a cord is drawn in the R-X diagram at 30 degrees (representing a power factor of approximately 0.85) from the origin. The point where the Zone 3 mho circle intersects this cord is representative of the load at which the relay will operate.

Today's microprocessor based relays have a feature that allows Zone 3 to be set large but not trip in a defined area around the R axis. Modern solid state relays are capable of changing the shape of the typical mho circle characteristic to a lenticular or rectangular characteristic. With this capability, the Zone 3 relay can be set closer to the ideal setting and not be subject to load encroachment for the agreed upon values of voltage and current.. Some relays also employ a blinder on the R axis as part of the impedance characteristic.

Transmission Line Thermal Rating Considerations:

An impedance relay is not recommended for thermal protection of transmission lines. The impedance relay with its fixed reach and relatively short time delay is not the appropriate relay for thermal protection. The overloading of a transmission line conductor is primarily a function of load current, time, and ambient temperature. A relay which more closely replicates an integral time characteristic (I^2t) is far more appropriate for this application.

Stable Power Swings:

Response of impedance relays to dynamic power swings during a system disturbance is a major concern, since the swing appears to the impedance relay as a 3-phase fault. This is the case for the Zone 3 relay as well as the Zone 1 and Zone 2 relays. During system disturbances, the power passing through a transmission line termination can vary widely. If this power swing passes through the tripping characteristics of many types of impedance relays, a non-fault trip of the transmission termination will occur if the condition persists beyond the Zone 3 time delay. The result is often a spread of or worsening of the disturbance which could have been avoided if the termination had not operated.

One suggestion as an alternate screening tool is to consider a load swing margin factor (LSMF) when calculating the reach setting of the Zone 3 relay. These margins are multiples of the maximum expected line loading. The maximum loading is the lesser of line thermal rating and the highest flow found during power flow studies for heavy, stressed, contingency power flow studies.

The following margin is based upon the use of mho relays and is intended to serve only as a screening tool. A more in-depth, detailed analysis may be necessary. Also, when possible, the Zone 3 relay should be set with the highest torque angle that results in an R axis intercept of greater than 5 ohms (to accommodate 5 ohms or greater primary fault resistance). The same concepts would apply to Zone 3 relays using blinders or non-circular characteristics. The protection engineer will have to weigh the fact that the LSMF is more restrictive on medium and long transmission lines than shorter lines (short lines usually inherently have LSMF's greater than these minimums).

LSMF > 4 @ power factor = 1.0
LSMF > 2 @ power factor = 0.8

Out of Step:

If a power swing passes through the tripping characteristic of the Zone 2 & 3 elements at both ends of the line a pilot trip will occur. Out-of-step blocking relays can be applied to prevent the undesired trip and out-of-step tripping relays can be applied to force system separation at pre-planned locations. If it has been determined that tripping a line under out of step condition is not critical, some of the benefits of out-of-step blocking relays can be obtained without this added complexity. By selective use of mho circle torque angles, blinders, and non-circular characteristics, adequate margins usually can be achieved to avoid undesired tripping on load swings while achieving good protective margins for system faults.

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