Appendix C — Out-of-step Blocking Relaying

Out-of-step blocking, also known as power swing blocking (PSB), is sometimes applied on transmission lines and transformers to prevent tripping of the circuit element for predicted (by transient stability or other studies) or observed power system swings.

There are many methods of providing the out-of-step blocking function; one common approach, used with distance ~~tripping~~ relays, uses between one and three impedance~~a distance~~ characteristics~~ which is~~ approximately concentric with the tripping characteristic. These characteristics may be circular,~~ mho characteristics,~~ quadrilateral,~~ characteristics,~~ or other shapes~~may be modified circular characteristics~~.

During normal system conditions the accelerating power, Pa, will be essentially zero. During system disturbances, Pa > 0. Pa is the difference between the mechanical power input, Pm, and the electrical power output, Pe, of the system, ignoring any losses. The machines or group of machines will accelerate uniformly at the rate of Pa/2H radians per second squared, where H is the inertia constant of the system. During a fault condition Pa is much greater than~~>>~~ 1 resulting in a near instantaneous change from load to fault impedance. During a stable swing condition, Pa < 1, resulting in a slower rate of change of impedance.

For a system swing condition, the apparent impedance will form a loci of impedance points (relative to time) which changes relatively slowly at first; for a stable swing (where no generators "slip poles" or go unstable), the impedance loci will eventually damp out to a new steady-state operating point. For an unstable swing, the impedance loci will change quickly traversing the jx-axis of the impedance plane as the generator slips a pole as shown in Figure C-1 below.

For simplicity, this appendix discusses the concentric-distance-characteristic method of out-of-step blocking, considering circular mho characteristics, most commonly used with electromechanical relays. As mentioned above, this approach uses a mho characteristic for the out-of-step blocking relay, which is larger than and approximately concentric to the related ~~tripping~~ distance relay characteristic. The out-of-step blocking characteristic is also equipped with a timer, such that a fault will transit the out-of-step blocking characteristic too quickly to operate the out-of-step blocking relay, but a swing will reside between the out-of-step blocking characteristic and the tripping characteristic for a sufficient period of time for the out-of-step blocking relay to ~~trip~~operate. Operation of the out-of-step blocking relay (including the timer) will in turn inhibit the ~~tripping~~ distance relay from operating.~~ This timer may be fixed or settable, generally in the range of 2-4 cycles. More sophisticated schemes differentiate between a swing and a heavy load condition by using a second timer that identifies that the impedance did not cross the inner characteristic.~~ More sophisticated schemes differentiate between a swing and a heavy load condition by using a second timer that identifies that the impedance stays inside the outer load blinder, which is not characteristic of a swing, and unblocks the scheme. Often, this unblocking timer is built into the scheme logic and is not user settable.

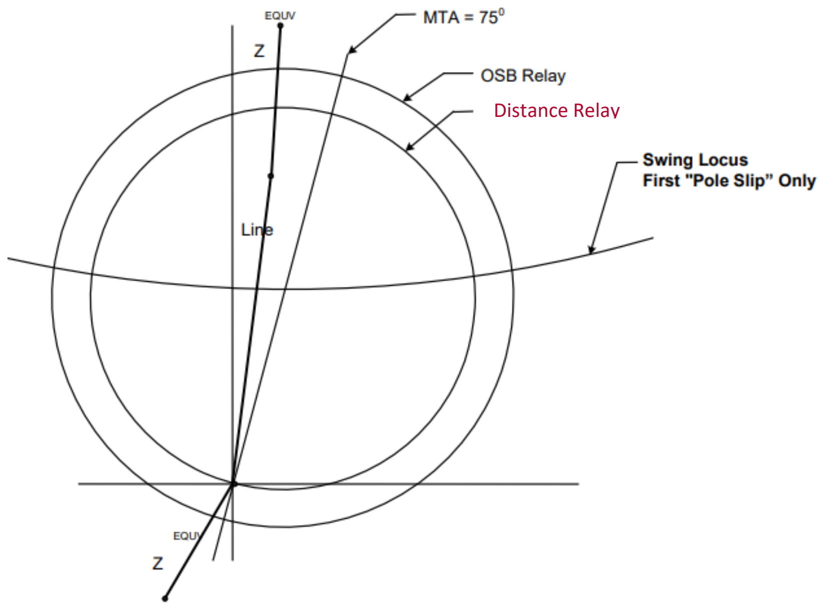

Figure C-1: Portion of an Unstable Swing

Figure C-1 illustrates the relationship between the out-of-step blocking relay and the ~~tripping~~ distance relay~~,~~ and shows a sample of a portion of an unstable swing.

Impact of System Loading of the Out-of-Step Relaying

Figure C-2 illustrates a ~~tripping~~ distance relay and out-of-step blocking relay~~,~~ and shows the relative effects of several apparent impedances.

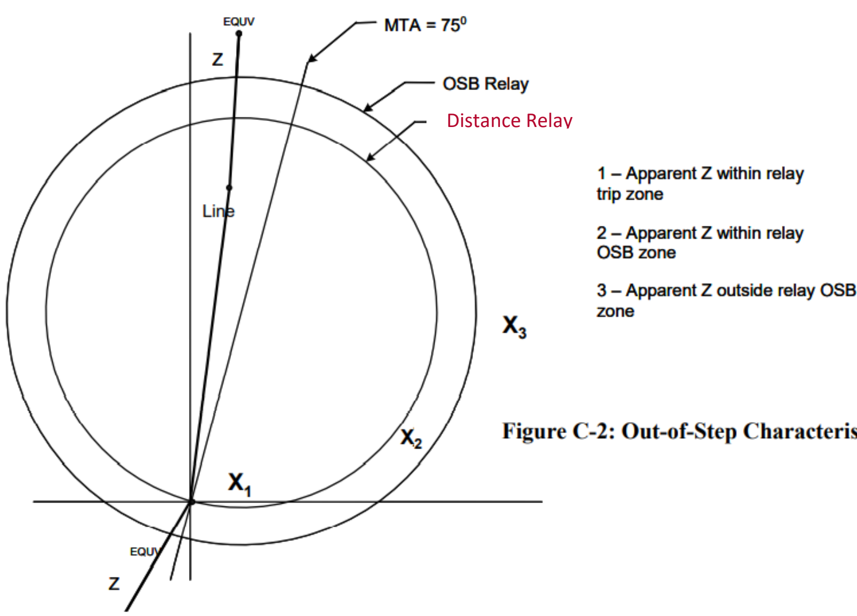

Figure C-2: Out-of-Step Characteristics with Load

Both the ~~tripping~~ distance relay and the out-of-step blocking relay have characteristics responsive to the impedance that is seen ~~by the distance relay~~at the line terminal. ~~In general, only~~ The ~~tripping~~ distance relays must be~~are~~ considered when evaluating the effect of system loads on relay characteristics (usually referred to as "relay loadability"). However, when the behavior of out-of-step blocking relays is also considered, it becomes clear that they must also be included in the evaluation of system loads, as their resistive reach must necessarily be longer than that of the ~~tripping~~ distance relays, making them even more responsive to load.

Three different load impedances are shown. Load impedance (1) shows an impedance (either load or fault) which would operate the ~~tripping~~ distance relay. Load impedance (3) shows a load impedance well outside both the tripping characteristic and the out-of-step blocking characteristic~~,~~ and illustrates the desired result. The primary concern relates to the fact that, if an apparent impedance, shown as load impedance (2), resides within the out-of-step blocking characteristic (but outside the tripping characteristic) for the duration of the out-of-step blocking timer, the out-of-step blocking relay inhibits the operation of the ~~tripping~~ distance relay. It becomes clear that such an apparent impedance can represent a system load condition as well as a system swing; if (and as long as) a system load condition operates the out-of-step blocking relay, the ~~tripping~~ distance relay will be prevented from operating for a subsequent fault condition.~~! A timer can be added such that the relay issues a trip if the out of step timer does not reset within a defined time.~~

Several techniques are commonly used by some solid state and many microprocessor relays, singly or in combination, to mitigate such "permanent" out of step blocking. Several, though not all, possible methods are briefly described here. These methods assure detection and clearing of all faults will occur during any of the loading conditions of PRC-023 R1.

- One mitigation method uses a timer to detect that the measured impedance remains between the blinders for a period that is longer than is characteristic of a swing, and unblocks the scheme. Often, this unblocking timer is built into the scheme logic and is not user settable. ~~—~~. This method can also be used with electromechanical relays and some solid state relays.
- The out of step algorithm may monitor the time that the impedance locus remains within an inner blinder region to reset the blocking using an adaptive timer based on the swing rate.
- The out of step algorithm may monitor negative and/or zero sequence currents and reset the out of step blocking for a significant unbalance.
- Distance protection may use quadrilateral or other non-mho shapes to allow smaller resistive reach settings for both protection and out of step characteristics that do not encroach on the relay loadability characteristic.
- Out of step characteristics that use quadrilateral or modified mho shapes may be set with shorter resistive reach that encroaches on the distance relay protection mho characteristics and use relay logic to only allow trips when the impedance locus is within both the protection and out of step characteristic.
- The out of step algorithm may continuously monitor parameters such as swing center voltage, currents, or impedance to determine whether out of step blocking should be asserted. Continuous monitoring prevents "permanent" out of step blocking by automatically resetting if the apparent impedance locus stops moving, as is characteristic of a fault.
- Other techniques may also be used.