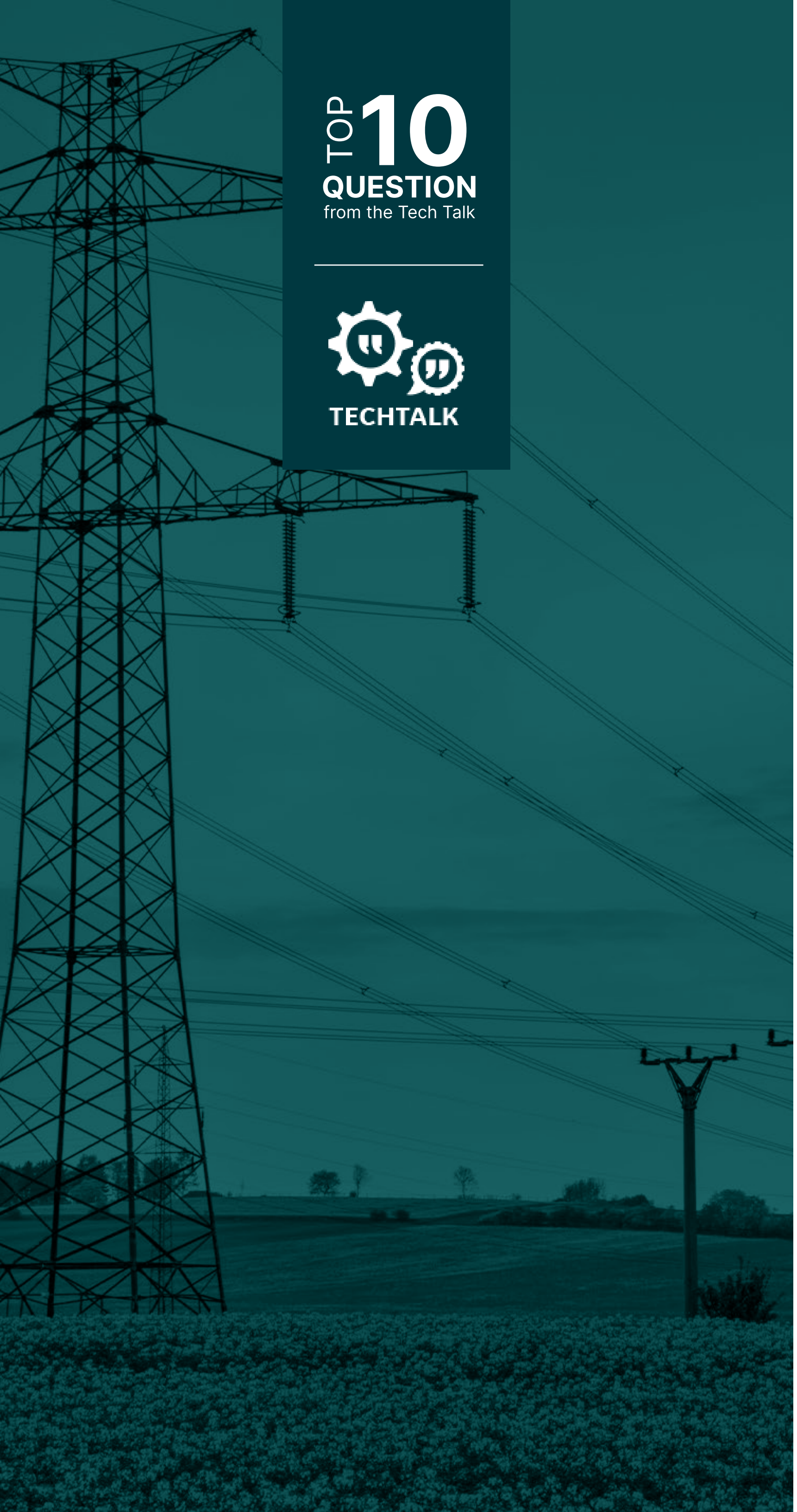


THE ART AND SCIENCE OF DISTANCE PROTECTION

In this Tech Talk, The **Art and Science of Distance Protection**, learn how to protect transmission lines to ensure system stability and reliability. Choosing and implementing the correct distance protection is key to achieving this goal. It is especially important to understand distance, pilot-aided schemes that use modern, digital, protection and control relays.

Need a recap of the webinar Q&A? Scan the top questions and answers from the session...

LET'S GO!

GE VERNOVA

QUESTION

ANSWER

What is a system impedance ratio (SIR) and why is it important?

The SIR takes the source impedance of the system behind the transmission line and divides that by the protected-line impedance; so, we have Zsource over Zline.

For example, a strong source has a small impedance of 1 ohm, meaning that this source can provide a lot of power. If the line impedance is 5 ohms, then the SIR is 0.2. For this strong source system, the fault current can be very large, and during a fault, the voltage remains stable.

If the system behind the transmission line is a weak source, then the system impedance ratio is larger. As an example, a weak source has a large impedance of 40 ohms, so the resulting SIR is 8. When a fault occurs on this transmission line, the fault current is small. The SIR affects the speed and reach of the distance relay. Fault-clearing speed is slower for large SIRs because the relay measures smaller voltages and currents. Therefore, it takes more time for the relay to ensure a secure trip decision.

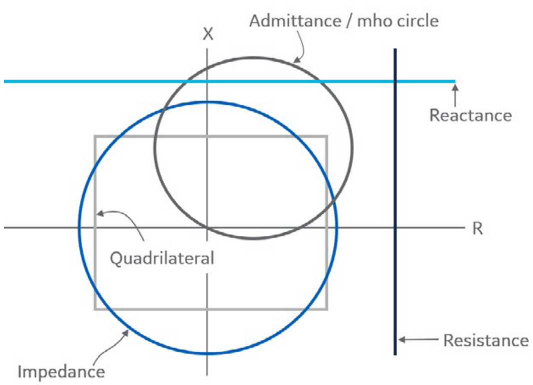
Underreach is problem with large SIRs because the relay does not detect faults well at the end of the distance zone. For short lines, with a SIR > 4, consider other types of line protection, particularly line differential, with distance backup.

The SIR is a very important factor in power-system stability at the time of a fault. We must consider the SIR when determining the type of protection needed and the fault-clearing speed required to keep the system stable.

What are the distance relay zones of operation?

The operation zones are the following:

- Impedance zone: centered on the origin of the R-X diagram
- Admittance or mho circle zone: traditional and widely used (mostly inductive reactance)
- Reactance zone: the area in the imaginary, jX plane
- Resistance zone: the area in the real, R plane
- Quadrilateral zone: adds greater coverage for resistive faults



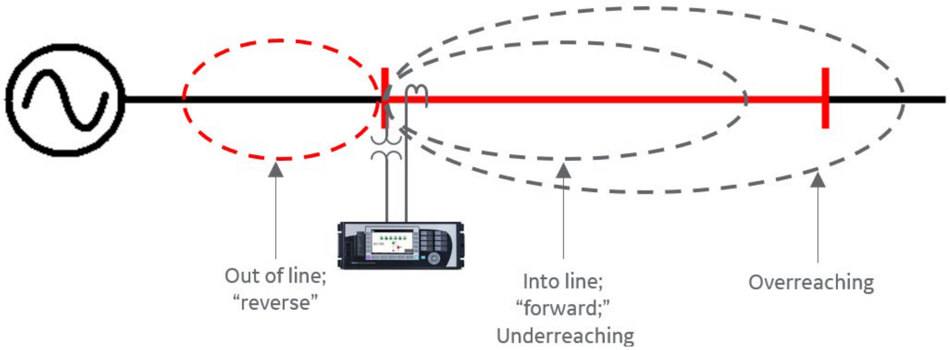
QUESTION

ANSWER

What is meant by the terms “forward,” “reverse,” “underreaching,” and “overreaching?”

Zones can be programmed to protect in either the forward direction or in the reverse direction. We say “into” the line when zones are set to protect in the forward direction and “out of” the line when zones protect in the reverse direction.

Shown here is an underreaching zone on the forward line. If the zone extends past the protected line, then it is an overreaching zone.



QUESTION

ANSWER

How does the relay compute the mho characteristic?

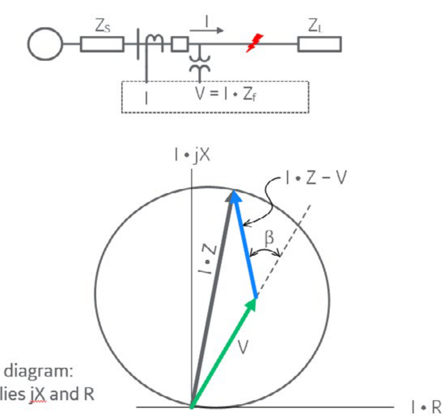
The relay uses a comparator to determine whether a fault is in/on the mho characteristic or outside the zone. It uses the measured current and voltage to determine where the apparent impedance plots in reference to the mho characteristic.

A simple mho distance function, with a reach of Z ohms, is shown below in a voltage diagram. This voltage diagram is exactly equal to an R-X diagram; the impedance vectors are multiplied by the current I.

The total line voltage is I times Z (the black phasor, representing the line segment).

The relay develops two voltages: the polarizing voltage, V, which is the measure fault voltage—the green phasor; and the operating voltage, which is the difference between the total line voltage and the polarizing voltage (I times Z, minus V)—the blue phasor.

Plotting these phasors creates the supplementary angle, β. The relay compares this β angle to 90°. If the result is less than or equal to 90°, then the fault impedance Zf plots within the mho characteristic, and the function produces an output. If the result is greater than 90°, then Zf falls outside of the characteristic and the fault is out of the zone.



Voltage diagram:
I multiplies jX and R

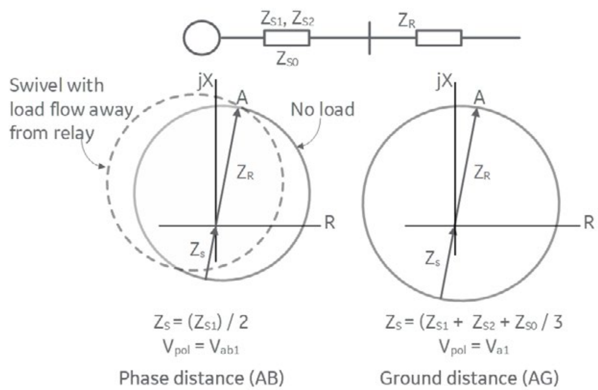
QUESTION

ANSWER

What is cross-polarization and how does it work?

One method of accommodating more fault-resistance coverage is through cross-polarization. This is when we set the relay to use other than the faulted voltage. Cross-polarization retains the circular characteristic, and the circle can swivel and vary in size, depending on system conditions.

For example, consider a distance function that uses positive-sequence voltage as the polarizing signal. The characteristics for a phase-distance function and a ground-distance function with positive sequence voltage polarization are shown below.



These characteristics are not fixed in size and vary proportionately with the source impedance directly behind the function. In the phase-distance (AB) diagram, load flow causes the characteristic to swivel to the left (as shown) or to the right relative to the forward reach (Point A). The amount and direction of the swivel depends on the magnitude and the direction of load flow.

In the ground-distance (AG) diagram, the characteristic expands proportionately to the source impedance.

Again, the effect of the swivel and size variation is to accommodate more resistance in the fault than would be obtained with a self-polarized mho function.

For more information, see Joe Andrichak's and George Alexander's paper, "Distance Relay Fundamentals" at https://www.gevernova.com/grid-solutions/sites/default/files/2025-09/article7.pdf

QUESTION

ANSWER

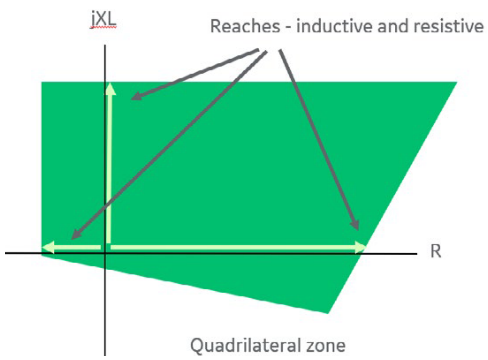
How does memory voltage work in a distance relay?

For a fault right at the relay location, the voltage will be very small (approaching zero for a bolted fault), and a self-polarized mho function might not operate. The cross-polarized mho is one solution, except for a three-phase fault. For a close-in, three-phase fault, all three voltages will be very small. Therefore, operation of any of the cross-polarized functions is jeopardized because there will be very little or no voltage available to develop the polarizing quantity.

To overcome this problem, the relay uses fault-voltage memory for polarization, which adds security and dependability for faults that occur very close to the relay measurement point. With memory, the relay changes the size of the mho circle when the calculated impedance is very close to the origin, detecting the close-in fault.

What is a quadrilateral zone? What is the advantage of using it?

The quadrilateral zone is a way to increase fault-resistance coverage. A modern relay has the calculation power to create a quad zone of protection from the measured voltages and currents. For the quad, there are essentially two reaches: one in the inductive direction and one in the resistive direction. You can set the reactance and resistive upper and lower boundaries to create a custom shape to match the needs of power systems.



QUESTION

ANSWER

Is voltage transformer fuse failure (VTFF) important in distance applications?

Voltage is essential to measuring impedance. Distance protection relies on valid voltage. Loss of voltage appears as a close-in fault for distance elements. If there is a VT fuse failure or other VT problem, then we must block the distance elements to prevent nuisance operation.

What is difference between permissive underreaching transfer trip (PUTT) and permissive overreaching transfer trip (POTT)?

Both PUTT and POTT schemes are permissive in that a key must pass between the two ends. What differs is sensing the fault.

In the PUTT scheme, the remote relay sends a PUTT key signal to the local relay when a fault is detected within the remote relay, underreaching, Zone 1 area of protection (usually 80%). This is origin of the expression “underreaching.” The relays clear faults quickly by the PUTT scheme only if these faults are detected by both Zone 1 elements (midline faults), or by the remote Zone 1 and local Zone 2 elements. If the fault is in the remote relay end zone (within 20% of the local relay), then we must wait for stepped-distance backup in the remote relay to clear the line.

In POTT, the relays clear faults quickly (in communications-aided time) if the faults are detected by both Zone 2 elements. POTT covers BOTH end zones, so it is preferred.

What are the directional comparison blocking (DCB) and the directional comparison unblocking (DCUB) schemes and the advantages and disadvantages of each?

The table below shows the advantages and disadvantages of the DCB and the DCUB schemes:

SCHEME	DCB	DCUB
Advantages	• Faster • Favors dependability more than security	• Fast • Favors security • Alerts for broken communications channel
Disadvantages	• Loss of communications channel (no blocking) means excess tripping • No alerting for broken communications channel	• Requires two communications functions (guard and trip) • More settings
Comments	One communications channel	Two communications channels

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