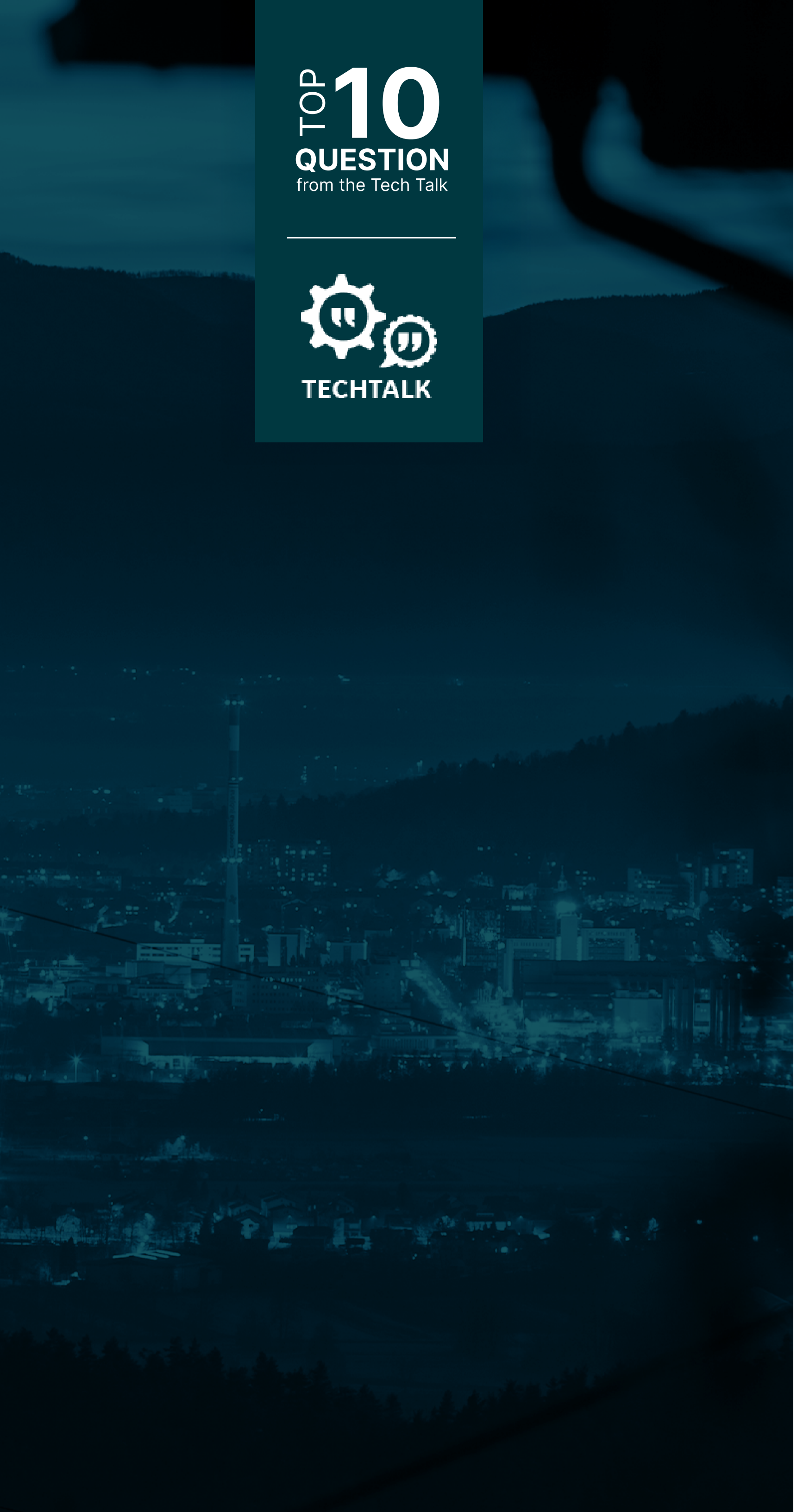

Beyond the Math: Understanding and Applying Symmetrical Components

In our Tech Talk, **Beyond the Math: Understanding and Applying Symmetrical Components**, get a refresher on the calculation of positive, negative, and zero sequence components. Learn how to determine fault currents with sequence networks during different types of faults and in varying system configurations. Plus see how symmetrical components can be applied in real-world fault conditions to aid in event analysis.

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

Please note: in the presentation slides, I3 is a typo, it should read I0.

LET'S GO!

GE VERNOVA

QUESTION

ANSWER

How does a protective relay use symmetrical components?

The relay calculates zero-sequency currents (I0), negative-sequence currents (I2), and in some cases positive-sequence currents (I1), from the equations for symmetrical components. Those quantities are available as metered quantities and are used as the operating quantities for protective elements. For example, the negative-sequence current, I2, is the operating quantity for negative-sequence overcurrent elements. The most often used sequence quantity is I0. The neutral overcurrent and neutral overvoltage elements in GE Vernova relays use 3I0, the vector sum of the three phases, because it is a large quantity. The equations for the sequence quantities are the following:

	Currents	Voltages
Positive-sequence component	$I_1 = \frac{1}{3}(I_a + aI_b + a^2I_c)$	$V_1 = \frac{1}{3}(V_a + aV_b + a^2V_c)$
Negative-sequence component	$I_2 = \frac{1}{3}(I_a + a^2I_b + aI_c)$	$V_2 = \frac{1}{3}(V_a + a^2V_b + aV_c)$
Zero-sequence component	$I_0 = \frac{1}{3}(I_a + I_b + I_c)$	$V_0 = \frac{1}{3}(V_a + V_b + V_c)$
Unbalanced, line-to-neutral phasors	$I_a = I_1 + I_2 + I_0$	$V_a = V_1 + V_2 + V_0$
	$I_b = a^2I_1 + aI_2 + I_0$	$V_b = a^2V_1 + aV_2 + V_0$
	$I_c = aI_1 + a^2I_2 + I_0$	$V_c = aV_1 + a^2V_2 + aV_0$

The operator ("a") is a 120-degree phase shift; a2 is a 240-degree phase shift.

QUESTION

ANSWER

How can a line-to-ground fault produce more fault current than a three-phase fault?

Refer to Fig. 1 , the calculation for the phase-to-ground fault and Fig. 2, the calculation for the three-phase fault. The phase-to-ground fault has 22.5 kA while the three-phase fault has only 18.1 kA. The key difference between the two is in the way the sequence networks are connected. The three-phase fault does not have zero-sequence and negative-sequence currents. When calculating A-Phase current, the zero- and negative-sequence quantities do not contribute to the three-phase fault. Additionally, the zero-sequence component of the source impedance isn't involved in the fault. The phenomenon is only present on the transformer secondary terminals. Once the fault location moves out into the distribution system, the larger values of zero sequence impedance make the available ground fault current drop below the available three phase fault current.

Build Sequence Network and Calculate for Phase-to-Ground Fault

$Zt1 = Zt2 = Zt0 = 5\%$ on 50-MVA base

$Zs1, Zs2 = 1$ pu on 215000-MVA base

$Zs1, Zs2 = 1 \cdot (230 / 13)^2 \cdot 50 / 215000 = 0.0728$ pu

$I = V / Z = 1 \text{ pu} / (0.05 \text{ pu} + 0.05 \text{ pu} + 0.05 \text{ pu} + 0.0728 + 0.0728)$

$I = 3.38$ pu

$Ibase = 50 \text{ MVA} / (\text{sqrt}(3) \cdot 13 \text{ kV}) = 2{,}221$ A

$I = Ipu \cdot Ibase = 3.38 \cdot 2{,}221 \text{ A} = 7.51$ kA

$Ia = I1 + I2 + I0 = 22.5$ kA

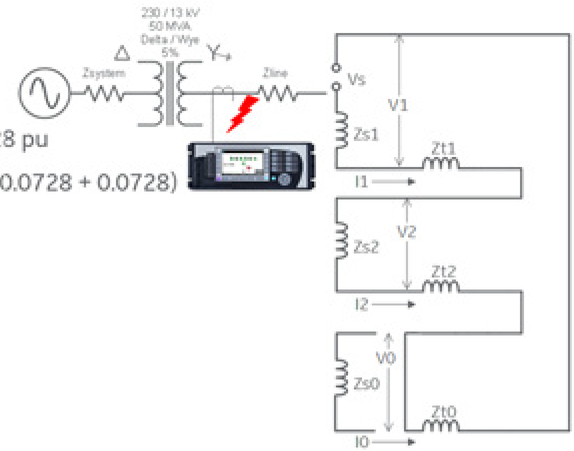

Fig. 1: Sequence network for line-to-ground fault

QUESTION

ANSWER

Build Sequence Network and Calculate for a Three Phase Fault

Zt1 = Zt2 = Zt0 = 5% on 50-MVA base

Zs1, Zs2 = 1 pu on 215000-MVA base

Zs1, Zs2 = 1 • $(230 / 13)^2$ • 50 / 215000 = 0.0728 pu

I = V / Z = 1 pu / (0.05 + 0.0728)pu

I = 8.14 pu

Ibase = 50 MVA / (sqrt(3) • 13 kV) = 2,221 A

I = Ipu • Ibase = 8.14 • 2,221 A = 18.079 kA

Ia = I1 + I2 + I0, but I2=I0, so IA=18.079kA

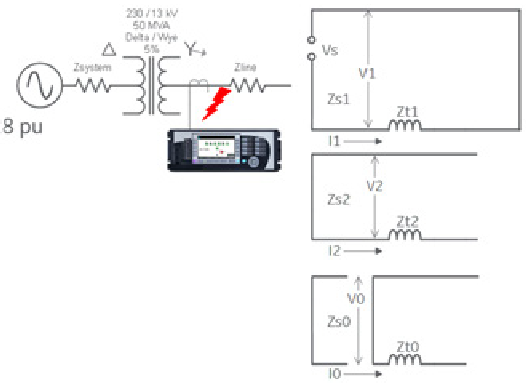

Fig. 2: Sequence network for three-phase fault

QUESTION

During the live Q&A, there was a question about using a broken-delta transformer connection to detect a grounded phase on an ungrounded system. Can you go into more detail on this?

ANSWER

A broken-delta VT circuit can detect a grounded phase on an ungrounded system by producing a voltage on the “broken” output of the delta connection. This VT connection is shown in Figure 3; it is a grounded-wye to broken-delta VT circuit. The VT secondary circuit is shown on the right with the connection of the VT output to a ballast resistor and to a UR relay auxiliary voltage input. The ballast resistor reduces the voltage shift from unbalanced excitation paths and from ferroresonance. With this wiring, an F60 auxiliary overvoltage element detects a ground condition on the ungrounded system.

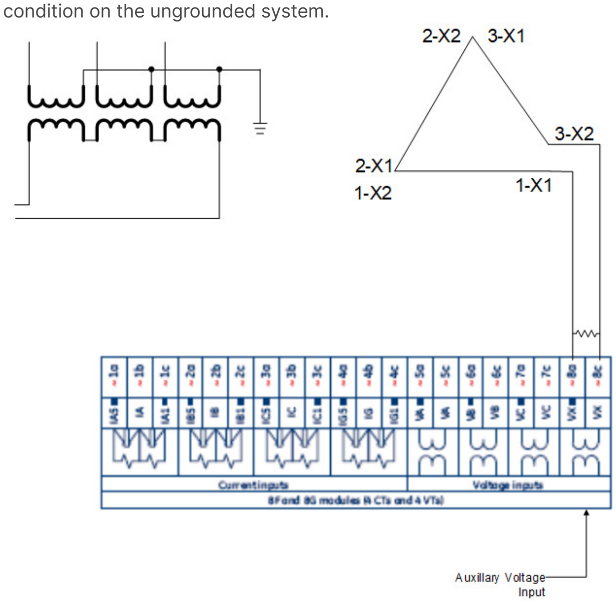

Fig. 3: Broken delta detects grounded phase in ungrounded system

QUESTION	ANSWER
For a phase-to-phase fault, why are the positive- and negative-sequence currents at 180 degrees from each other?	The answer lies in the way that the sequence networks interact for this ground fault. The equivalent circuit for a phase-to-phase fault can be referenced in Figure 4. Current flows through Zl1 from left to right, and through Zl2 from right to left. The I1 current and the I2 current are 180 degrees apart. When drawing the phasor diagram, the direction of I2 is opposite to the vector showing I1 flow.

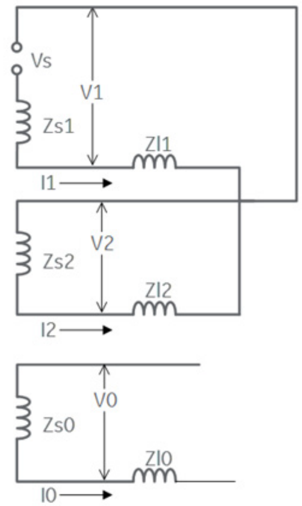

Fig. 4: Sequence network for phase-to-phase fault

For transmission line protection, why use line current differential?	Line current differential is a more secure and dependable protection scheme for transmission lines. Typically, the challenge for line current differential is implementing a communications channel between the two ends. Older lines, long lines, and radial lines in sub-transmission do not have that communications channel, so distance protection is necessary in these instances. GE Vernova has both distance protection and line current differential available in the L90 relay.

QUESTION	ANSWER
Why do some transformers use a buried delta tertiary winding?	Negative-sequence current "circulates" inside of the delta tertiary. You can see these in-phase currents circulating through the three tertiary windings. Figure 5 shows a T60 transformer where the U-module windings are connected "inside" of the delta connections of a tertiary winding, where the T60 measures these currents. Each of the three phases is in phase, which produces negative- and zero-sequence currents. Often, delta tertiary windings are used in older relay schemes to detect ground fault current.

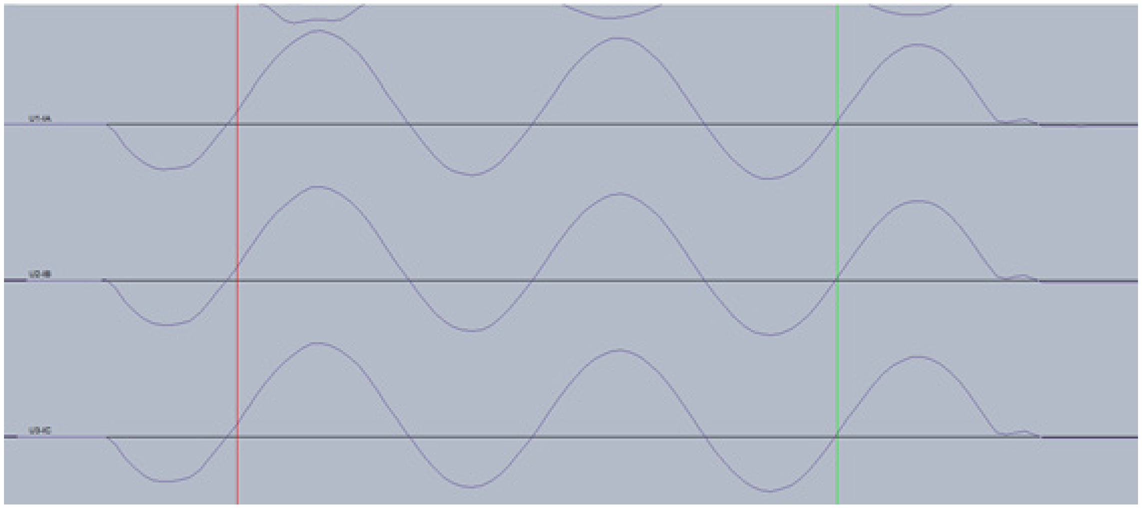

Fig. 5: Currents in the buried delta tertiary winding

Can we have zero- and negative-sequence components on an unfaulted system?	Yes, on some systems. If you have unbalanced loads on a grounded system, those unbalanced loads produce negative sequence and zero-sequence currents.

QUESTION

ANSWER

Can a delta-wye transformer be a ground source for a ground fault?

Yes, a delta-wye transformer is a ground source for a ground fault. Ground source means the transformer can provide ground current. The best example of this can be seen in the Figure 6 waveforms. These are the winding 1 currents on a 745 relay that are connected to the high-voltage terminals of a generator step-up transformer. In this case, the generator circuit breaker was open and the transformer was supplying current to the transmission line ground fault. These waveforms are in phase, which produces negative- and zero sequence currents.

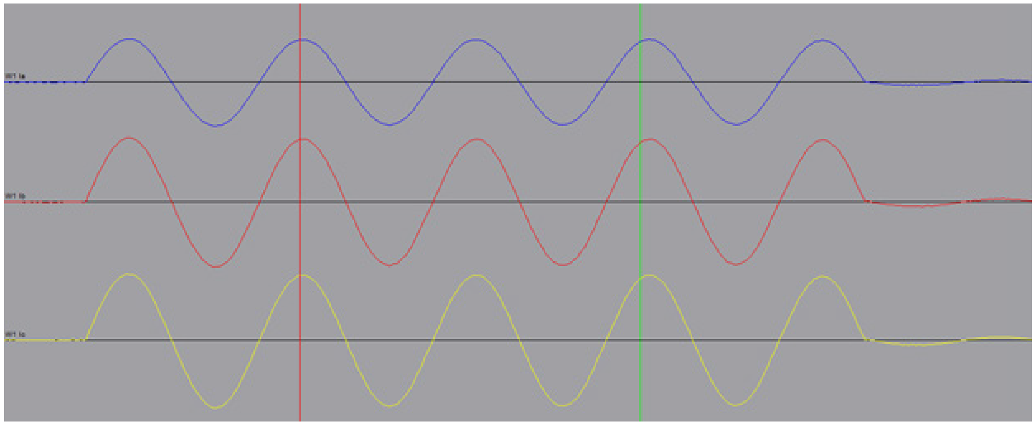

Fig. 6: Currents from a transformer providing ground fault current

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