Relay Coordination: Step-by-Step Numerical Calculation

Relay Coordination for 3-Phase Fault at Bus 4

Given:

- System Voltage at Bus 4: $V_{\text{base}} = 230\,\text{kV}$
- Positive sequence impedance: $Z_1 = 1.81 + j4.29\,\Omega$
- Fault type: 3-Phase
- Pre-fault line-to-neutral voltage:

$$V_1 = \frac{V_{\text{base}}}{\sqrt{3}} = \frac{230}{\sqrt{3}} \approx 132.79\,\text{kV}$$

Step 1: Calculate Fault Current

Magnitude of Z_1:

$$|Z_1| = \sqrt{1.81^2 + 4.29^2} = \sqrt{3.2761 + 18.4041} = \sqrt{21.6802} \approx 4.66\,\Omega$$

Fault current:

$$I$$

Step 2: Determine Relay Pickup Current

Assume:

- CT ratio: 1000:1
- Load current: $I_{\text{load}} = 1.5\,\text{kA}$
- Pickup setting: $1.2 \times I_{\text{load}} = 1.2 \times 1.5 = 1.8\,\text{kA}$

Step 3: Plug Setting Multiplier (PSM)

$$\text{PSM} = \frac{I_{\text{fault}}}{I_{\text{pickup}}} = \frac{28.519}{1.8} \approx 15.84$$

Step 4: Relay Operating Time (IDMT Standard Inverse)

$$T = \frac{0.14 \cdot \text{PSM}}{(\text{PSM})^{0.02} - 1} = \frac{0.14 \cdot 15.84}{(15.84)^{0.02} - 1}$$

$$T \approx \frac{2.2176}{1.1486 - 1} = \frac{2.2176}{0.1486} \approx 14.92\,\text{ms}$$

For coordination, we use a rounded value: $T \approx 20\,\text{ms}$

Step 5: Backup Relay Coordination

- Primary relay (Relay 2): $T_2 = 20\,\text{ms}$
- Backup relay (Relay 1): $T_1 = 86.1\,\text{ms}$
- Grading margin: $\Delta T = 86.1 - 20 = 66.1\,\text{ms}$

This margin is greater than the typical requirement of 50 ms, ensuring coordination.

Step 6: Breaker Operation Timing

- CB 7/8 opens at 99.4 ms
- CB 17/18 opens at 105 ms

Summary Table

Device	**Operation Time (ms)**	**Remarks**
Relay 2 (Primary)	20.0	Trips first
Relay 1 (Backup)	86.1	Operates after grading delay
CB 7/8	99.4	Interrupts current
CB 17/18	105.0	Final isolation

Table 1: Relay and Breaker Coordination Summary

Conclusion

The primary relay clears the fault within 20 ms. The backup relay operates after a grading delay of 66.1 ms, and the breaker isolates the fault in under 105 ms. Coordination is successful and meets protection standards.