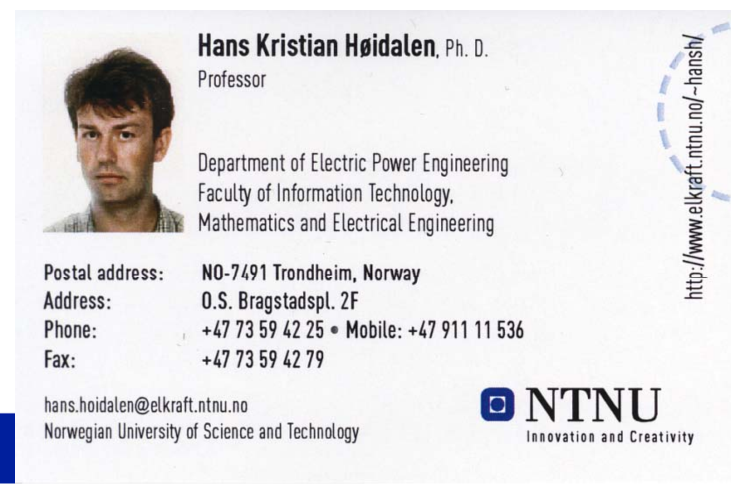
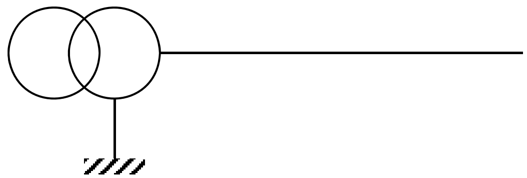
Power System Protection Ground faults in resonance grounded systems

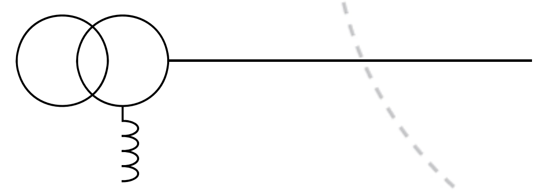
Briefly about the speaker

- Professor at Norwegian Univ. Science and Technology – Dept. Electrical Engineering
  - Power system transients and protection
  - High voltage engineering, stress calculations
  - Recent focus on Power Transformers
- Developer of ATPDraw
- Sabbatical at MTU
  - Room 628, phone 487-2910
  - hhoidale@mtu.edu



Solid vs. resonance neutral



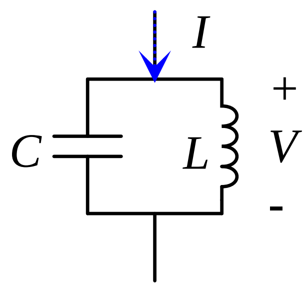


- \+ No over-voltages in fault situations
- \- High fault current
- \+ Easy fault detection
- \+ Ground faults persist
- • Fast trip and reclosing
- \- Poor power quality
- \- Extra stress

- \- Undefined voltages to ground. High at resonance.
- \+ Ideally zero fault current. Arc self-extinguish.
- \- Difficult fault detection/location. Requires special competence and maintenance.
- \- In dynamic systems the coil must adapt. Expensive equipment.
- \+ Can continue to operate during ground fault. Increased power quality.
- • Safety issues: down/broken conductors

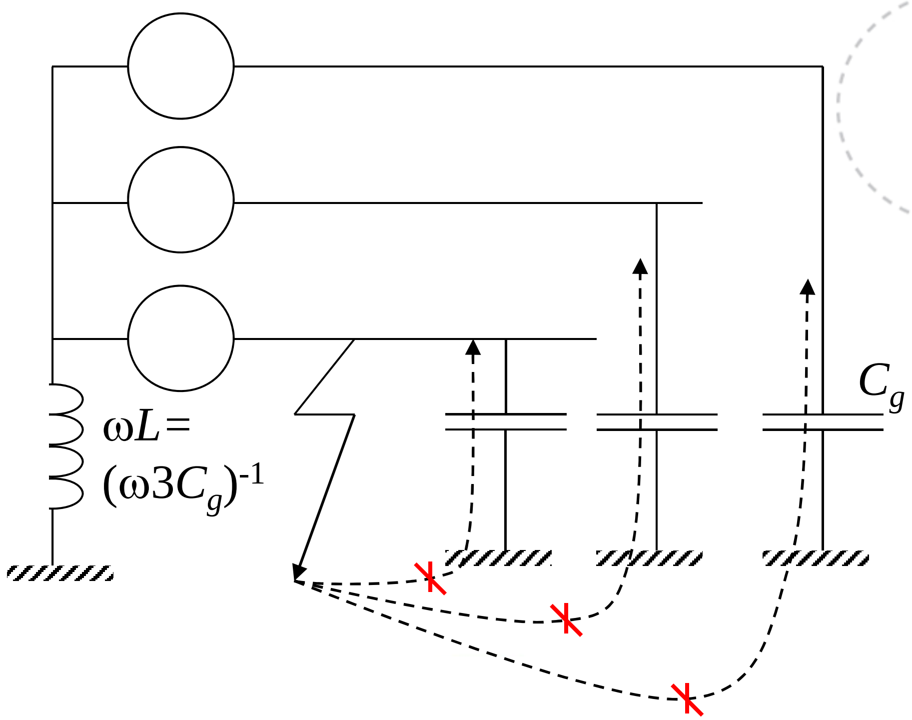
How can be reduce fault current further from isolated neutral systems?

- Compensate capacitive current with inductive.
- Resonance principles:

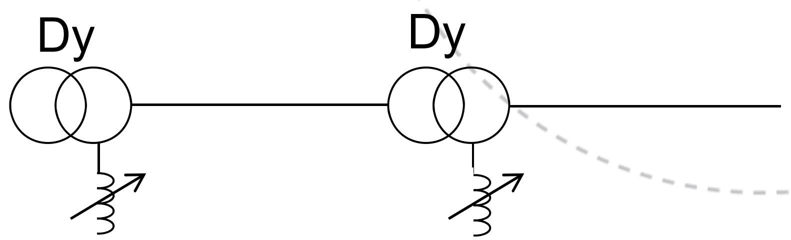


$$I = V \cdot \left(\frac{1}{j\omega L} + j\omega C \right) = \frac{V}{j\omega L} \cdot \left(1 - \omega^2 LC \right)$$

At resonance ($\omega^2 LC$=1) the current is zero



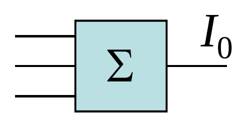
Usage of resonance grounding



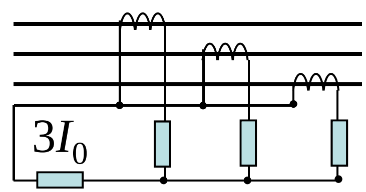
- In Norway
  - MV system 12-24 kV
  - Distribution level 66-132 kV
- Self-tuning Peterson coils used
- Weather conditions result in a lot of temporary ground fault
- Power quality is very important to the industry
  - Fast trip & reclosing not acceptable
- Increasingly a preferred solution in Europe

Zero sequence measurements

- Current I_0: Sum I_a, I_b, I_c
  - Summing the current numerically

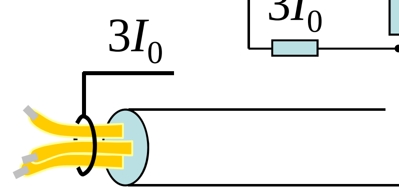


  - Residual connection

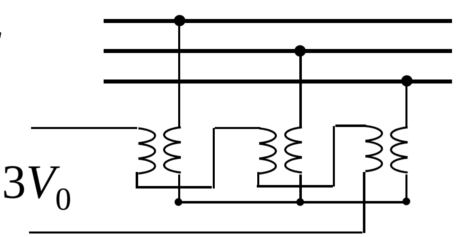


Lower accuracy due to CT differences

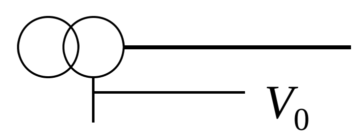
  - Summation transformer (Toroidal/Rogowski coil)



- Voltage V_0: Sum V_a, V_b, V_c
  - Open delta



  - Neutral point (isolated or resonance earth)

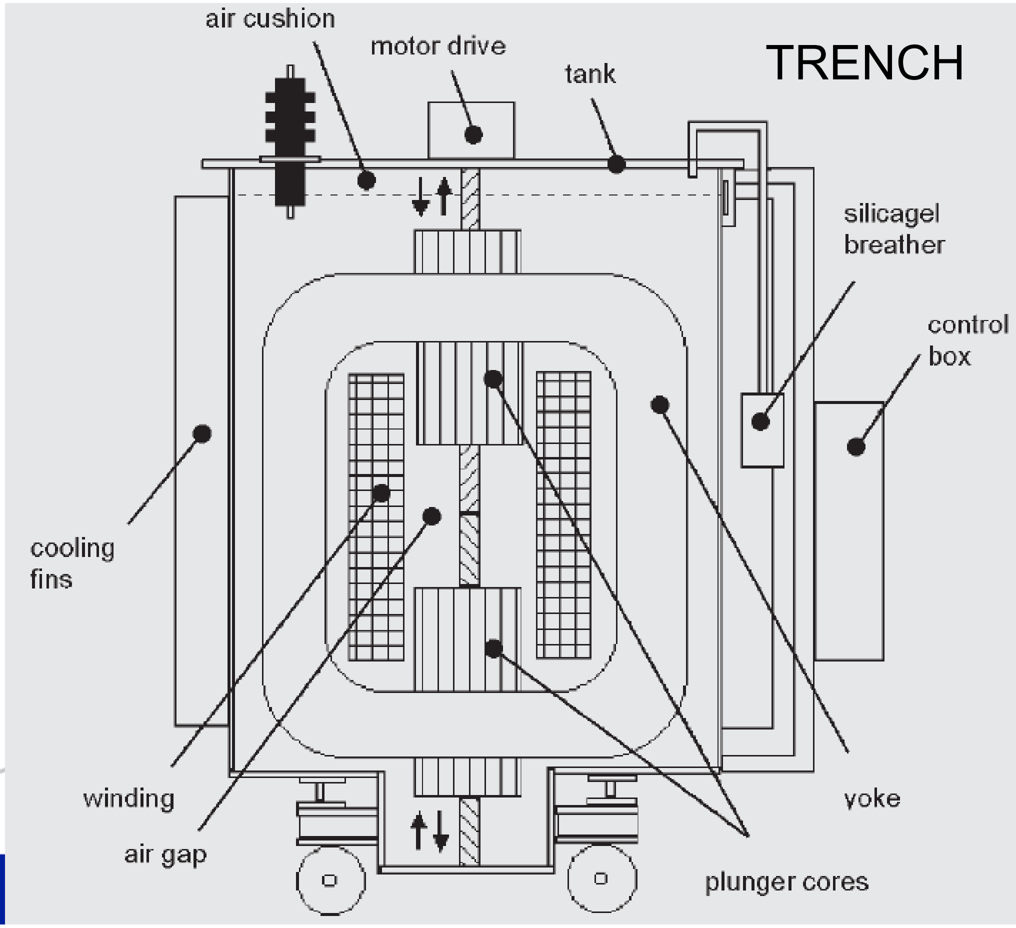


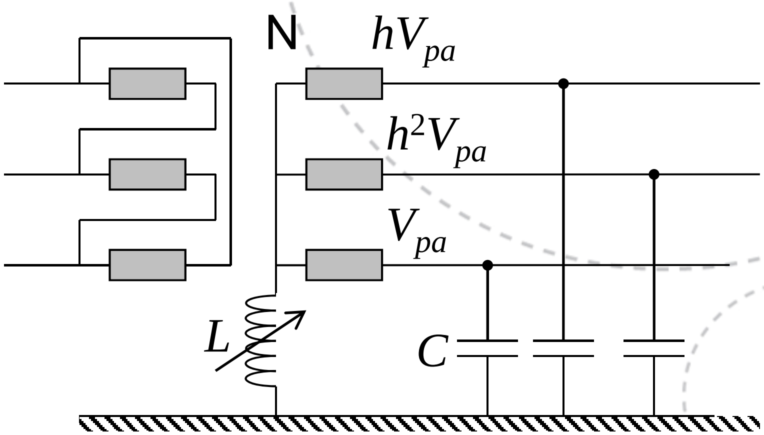
Resonance grounding

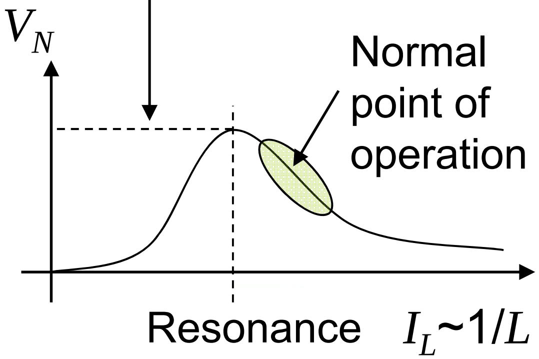
- Inductance added in the neutral point
- Compensate for the capacitive current through C_g; help the arc self extinguish
- The coil can be automatically tuned when the system changes (Petersen-coil (patent from around 1920)
  - Adjust air gap
  - The coil changes it value incrementally and notice how the neutral voltage changes. From a theoretical curve the resonance point is estimated.
- Over-compensation preferred to limit V_N
  - Avoid resonance also when parts of the system become disconnected
- The unit Ampere is used to quantify the coil; $I_L = V_p / \omega L$

Variable inductance

- Adjust air gap



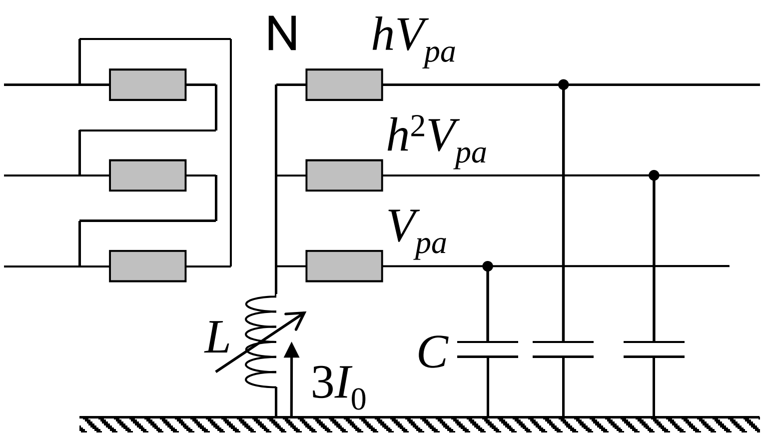




No-fault situation

First attempt to analyze the neutral voltage

- Need to know: Maximum neutral voltage in normal operation. Set U_0 pick-up above this limit



$$I_a = (V_N + V_{pa}) \cdot j\omega C$$

$$I_b = (V_N + h^2 \cdot V_{pa}) \cdot j\omega C$$

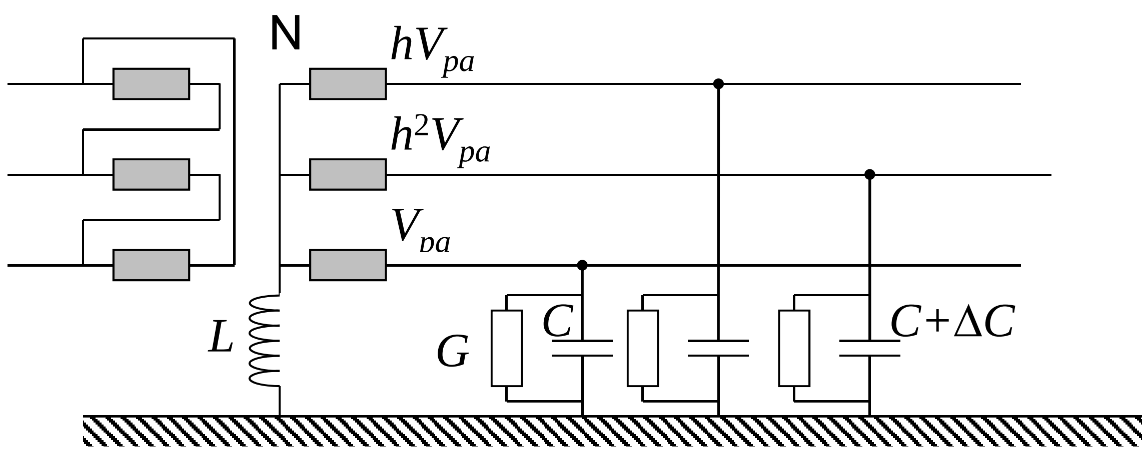
$$I_c = (V_N + h \cdot V_{pa}) \cdot j\omega C$$

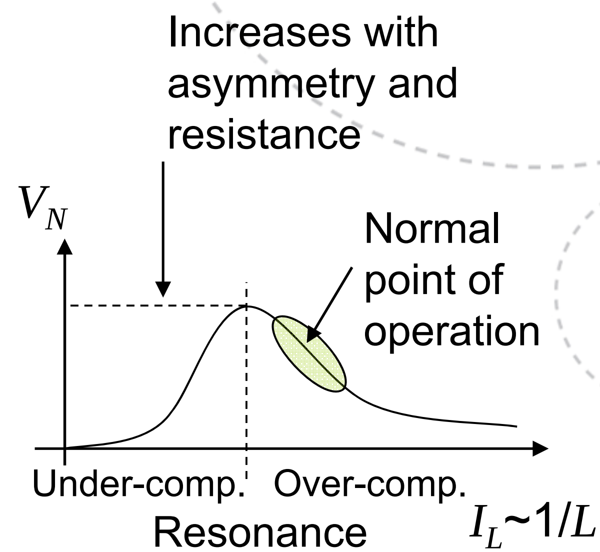
$$3I_0 = (I_a + I_b + I_c) = V_N \cdot j\omega 3C = \frac{-V_N}{j\omega L}$$

$$\Rightarrow V_N = \frac{0}{j\omega 3C + 1/j\omega L} ??$$

- At resonance $j\omega 3C + 1/j\omega L = 0$ and the neutral voltage becomes undefined… ($\rightarrow \infty$)
- Need to add sophistication here…

Effect of asymmetry and conductive line charging





No-fault situation

$$I_a = (V_N + V_{pa}) \cdot (G + j\omega C)$$

$$I_b = (V_N + h^2 \cdot V_{pa}) \cdot (G + j\omega (C + \Delta C))$$

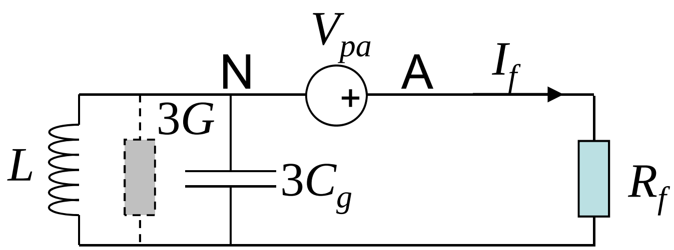
$$I_c = (V_N + h \cdot V_{pa}) \cdot (G + j\omega C)$$

$$3I_0 = (I_a + I_b + I_c) = 3V_N \cdot (G + j\omega C) + (V_N + h^2 \cdot V_{pa}) \cdot j\omega \Delta C = \frac{-V_N}{j\omega L}$$

$$\Rightarrow V_N = \frac{-h^2 \cdot V_{pa} \cdot j\omega \Delta C}{3G + j\omega 3C + j\omega \Delta C + 1/j\omega L} \Rightarrow V_N = \frac{V_p}{1 + \frac{s}{u} - j\frac{d}{u}} \Rightarrow \left|V_{N,\max}\right| \approx \frac{V_p \omega \Delta C}{3G}$$

Resonance grounded system during fault (L=constant)

- Equivalent circuit (fault phase A)



$$I_f = \frac{V_{pa} \cdot (1-\omega^2 L \cdot 3C_g)}{j\omega L + R_f (1-\omega^2 L \cdot 3C_g)}$$

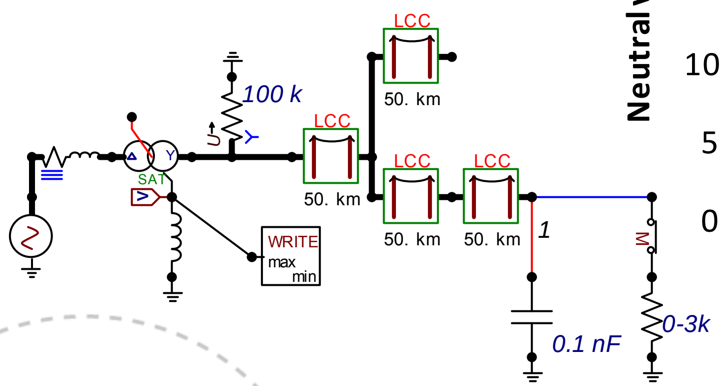
$$V_N = V_0 = \frac{-V_{pa} \cdot j\omega L}{j\omega L + R_f (1-\omega^2 L \cdot 3C_g)} \longrightarrow$$

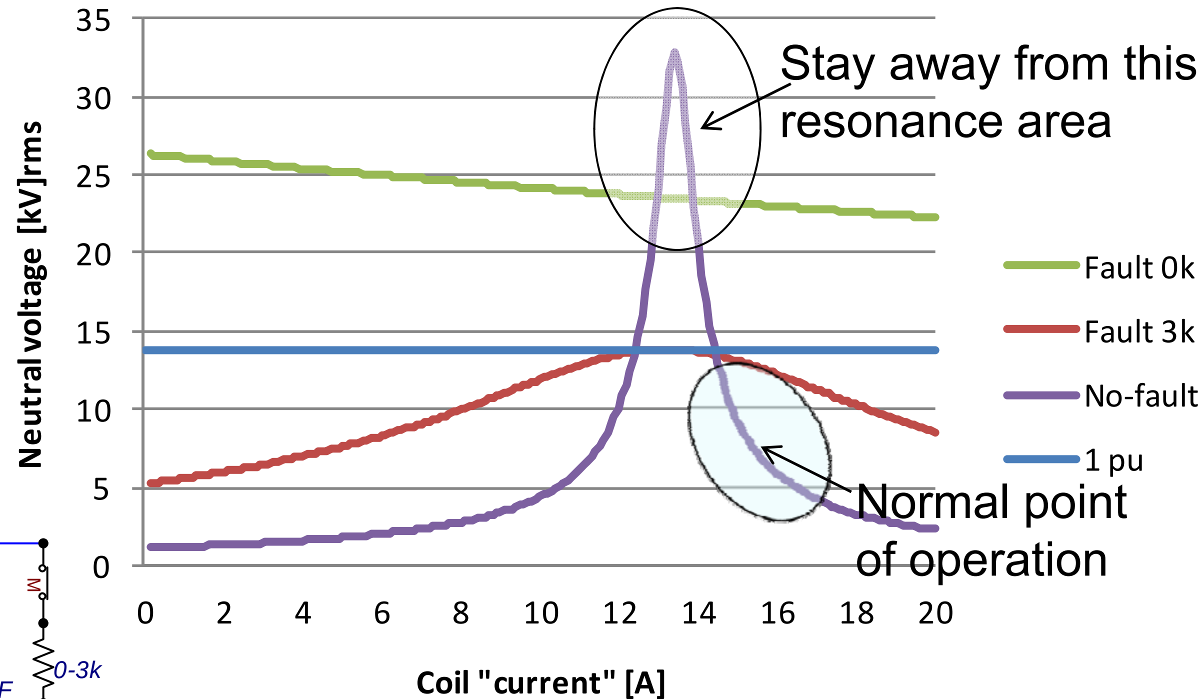
V_{pa} at resonance, also for large R_f

- In reality asymmetry (ΔC) and conductive elements ($G||1/R_f$) affect fault current and V_N
- A resistance across L is often actively connected to "find" the fault (identify faulty feeder)

Example of neutral voltage

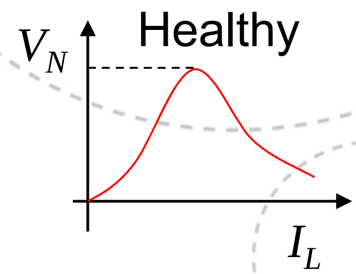
- From ATP simulations
  - In reality the resonance peek is typically lower
  - …and measurements are required

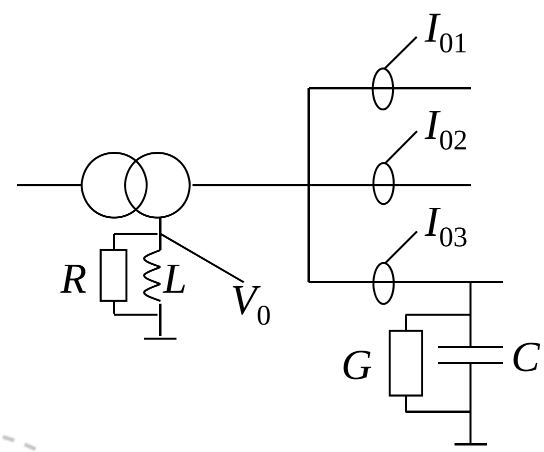


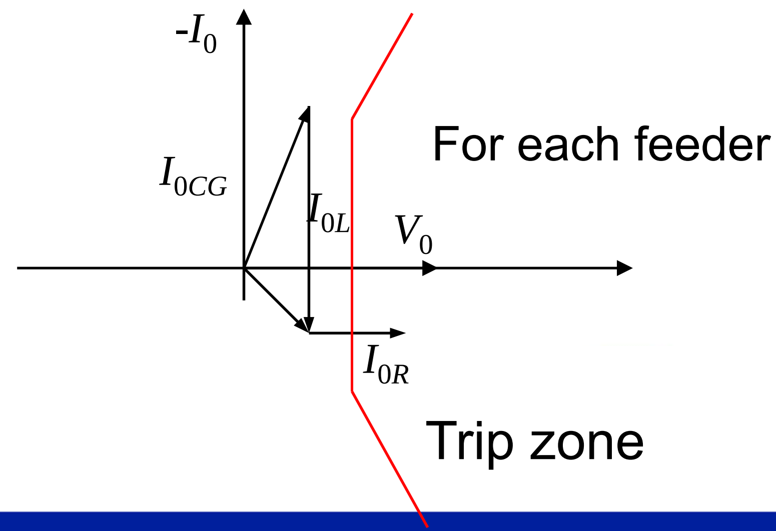


Directional over-current relay – resonance grounded systems

- Start when V_0 goes above a fixed limit; pre-measure the coil response max($V_{N,healty}$);
- After a delay connect resistor R (|| to L)
- Trip if current I_0 enters trip zone (2nd quadrant)
- Trip zone set based on natural conductive current and asymmetry

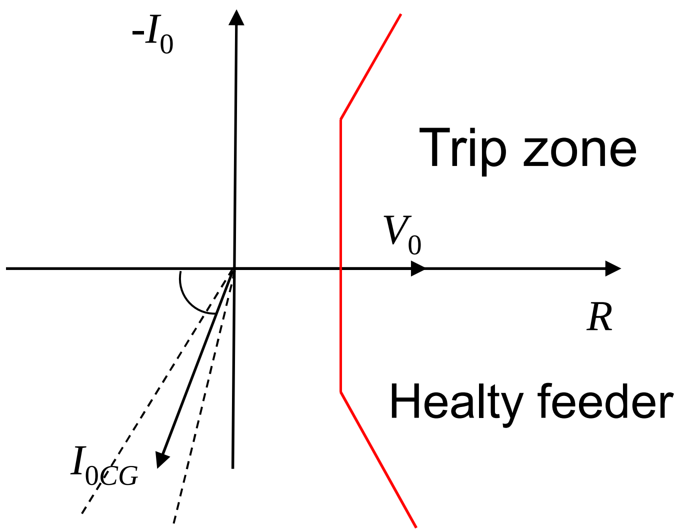


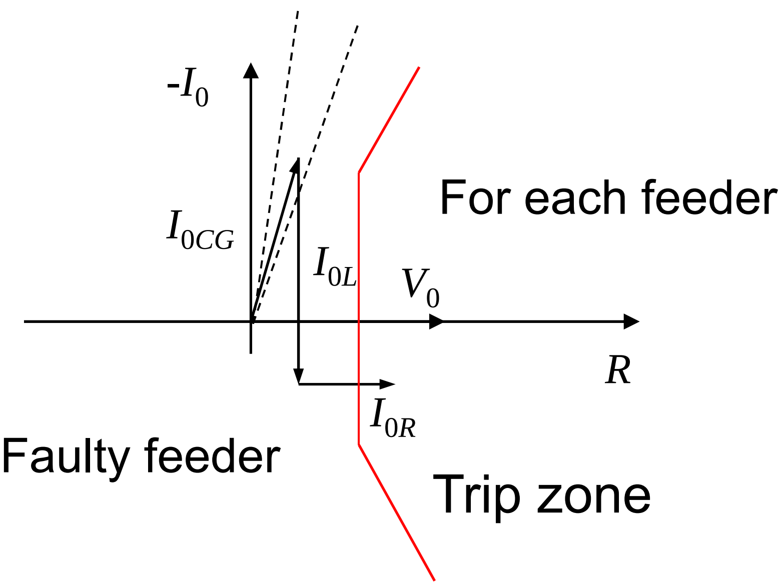




Trip zone

- The resistive component of I_0 (in phase with V_0) is used





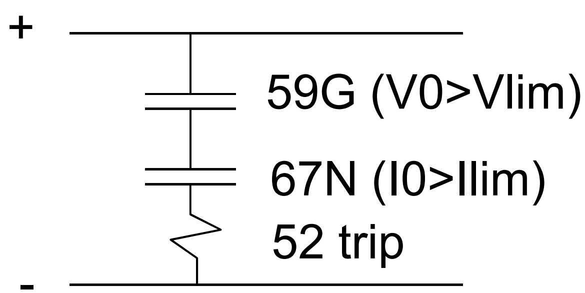
$$
\begin{aligned}
-3I_{0i} &= (I_{ai} + I_{bi} + I_{ci}) \\
&= -V_0 \cdot (3G_i + j\omega 3C_i)
\end{aligned}
$$

Angle quite close to 90°

$$
\begin{aligned}
-3I_{0i} &= -(I_{ai} + I_{bi} + I_{ci}) \\
&= V_0 \cdot (3G_i + j\omega 3C_i) + (V_0 + V_{pa}) / R_f \\
&\approx V_0 \cdot \left(3(G_t - G_i) + j\omega 3(C_t - C_i) + \frac{1}{j\omega L} \right)
\end{aligned}
$$

Relaying logic

- Is zero sequence voltage above threshold?
  - V0>Vlim (type 59G over-voltage relay)
- Is zero sequence current above threshold and in correct quadrant (4th)?
  - I0>Ilim (type 67N directional over-current relay)



Wave/Wischer relays

- Used in the 132 kV resonance earthed system
- Measure the transient surge and use time of arrival principles
- Communication required
- Trip the two relays that first identify the fault
- Sensitive to disturbances like lightning