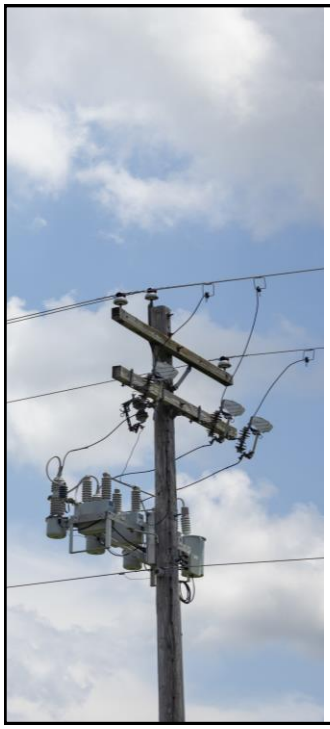

Novel Methods to Detect and Identify Fault and Open-Phase Conditions in Pole-Top Capacitor Banks

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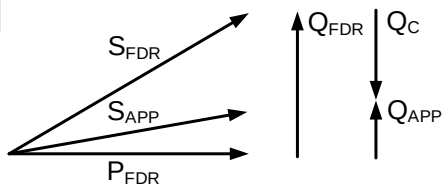
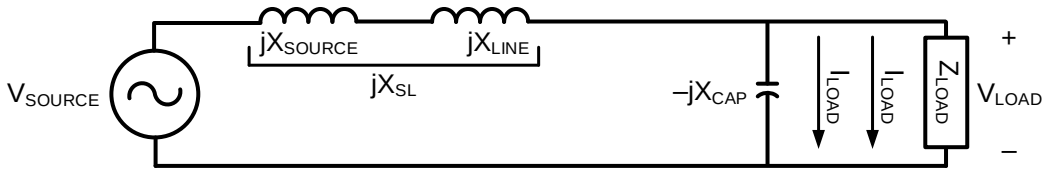
Role of capacitor banks on distribution feeders

- Minimize reactive demand
- Minimize voltage drop
- Reduce line losses

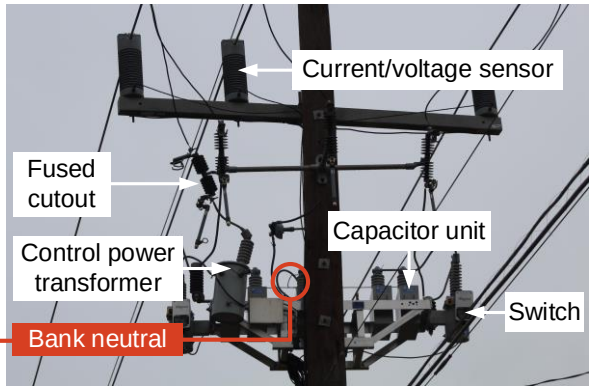


$$PF_{FDR} = \frac{P_{FDR}}{S_{FDR}}$$

$$PF_{APP} = \frac{P_{FDR}}{S_{APP}}$$

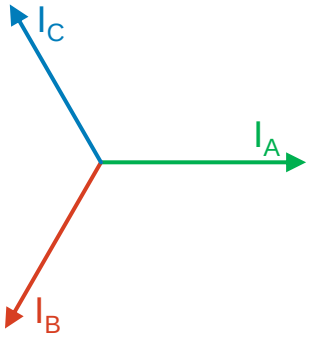


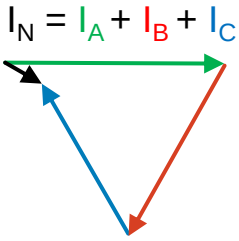
Typical poletop capacitor bank construction



Causes of bank neutral current

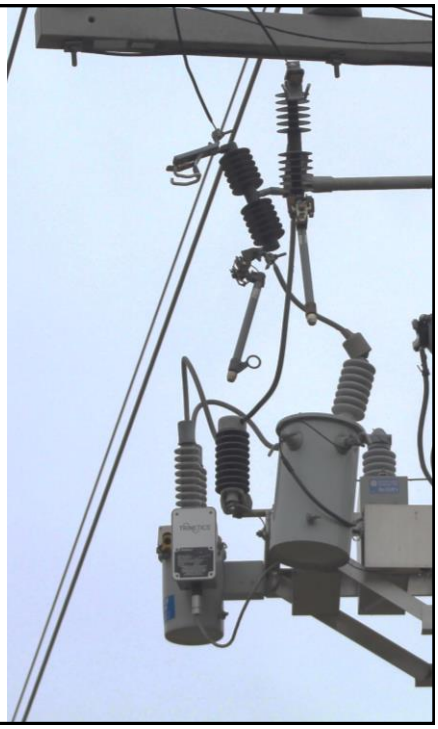
- Open phase
- Element faults
- System unbalance
- Triplen harmonics





Blown fuse

- Fuses can be easily identified in field inspection
- Detection is in control using I_N
- Control can report immediately



Switch failure

- Internal failure is undetectable in field inspections
  - Contact failure
  - Motor operator failure
- Legacy bank switches may not have 52a/b contacts

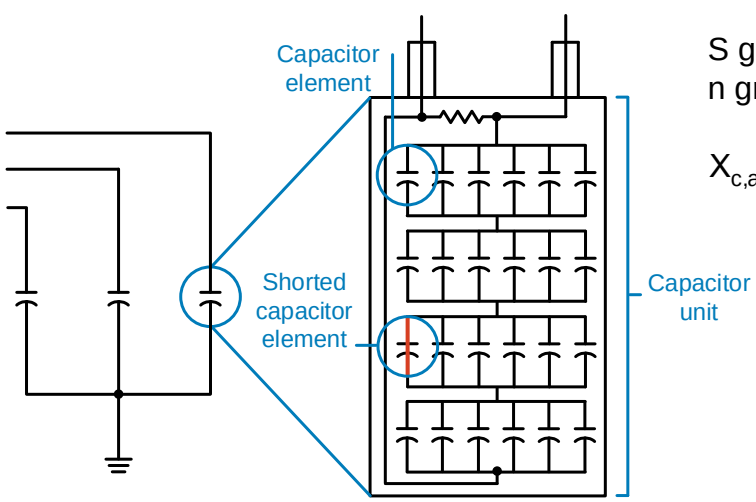
Jumper failure

Connection failure may be hidden behind animal guards

Capacitor element faults

- Fuses blow for capacitor unit faults
  - 125–165% rated phase current
  - Short circuit
- Capacitor unit faults begin as internal capacitor element faults
- Shorted capacitor element
  - Reduces reactive impedance (X_c) of affected phase
  - Increases current on affected phase

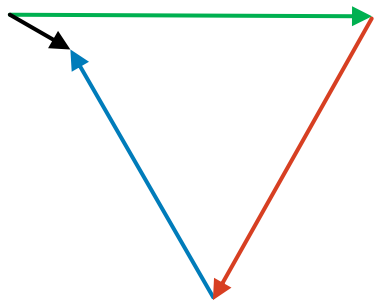
Capacitor element faults



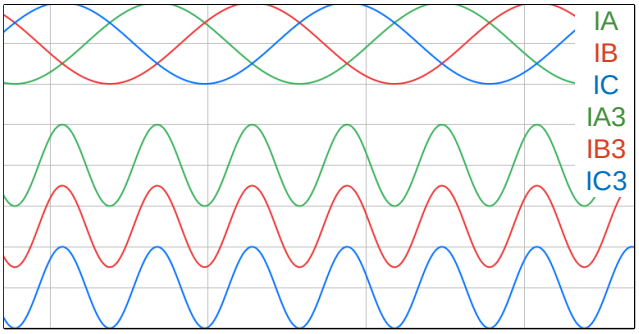
S groups in series
n groups shorted by element

$$X_{c,apparent} = X_{c,rated} \cdot \frac{S-n}{S}$$

System unbalance



Triplen harmonics



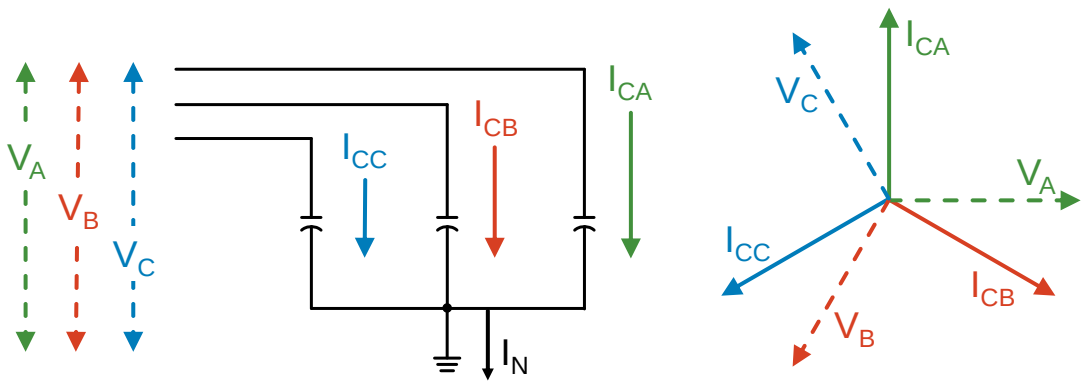
$$I_N = I_A + I_B + I_C$$

I_N magnitude determines condition

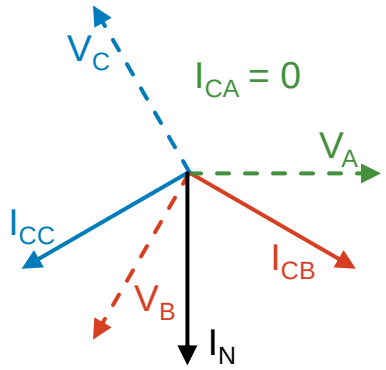
Condition	$\lvert I_N \rvert$
Open phase	≈ 1 pu
System unbalance	<0.03 pu
Element fault	>0.05 pu, <0.25 – 0.65 pu
Triplen harmonics	0*

*Digital filtering can remove harmonic and dc components

Normal (balanced) operation in capacitor bank

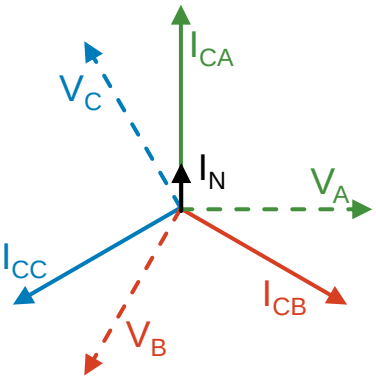


Phase A open



$I_N = I_{CB} + I_{CC}$

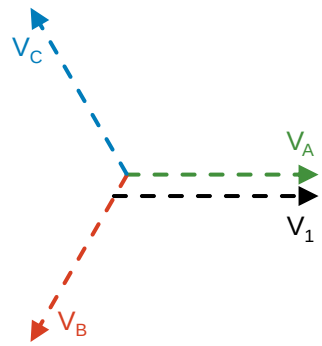
Phase A element fault



$$I_N = \frac{n}{S-n} I_{c,rated}$$

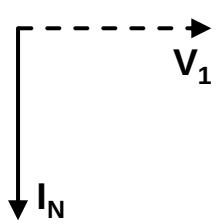
Polarizing voltage

Available voltage	$\overrightarrow{V1}$ (ABC rotation)	$\overrightarrow{V1}$ (ACB rotation)
$\overrightarrow{V_A}$	$\overrightarrow{V1} = \overrightarrow{V_A}$	$\overrightarrow{V1} = \overrightarrow{V_A}$
$\overrightarrow{V_B}$	$\overrightarrow{V1} = \vec{a}\overrightarrow{V_B}$	$\overrightarrow{V1} = \vec{a}^2\overrightarrow{V_B}$
$\overrightarrow{V_C}$	$\overrightarrow{V1} = \vec{a}^2\overrightarrow{V_C}$	$\overrightarrow{V1} = \vec{a}\overrightarrow{V_C}$
$\overrightarrow{V_A}, \overrightarrow{V_B}, \overrightarrow{V_C}$	$\overrightarrow{V_1} = \dfrac{\left(\overrightarrow{V_A} + \vec{a}\overrightarrow{V_B} + \vec{a}^2\overrightarrow{V_C}\right)}{3}$	$\overrightarrow{V_1} = \dfrac{\left(\overrightarrow{V_A} + \vec{a}^2\overrightarrow{V_B} + \vec{a}\overrightarrow{V_C}\right)}{3}$



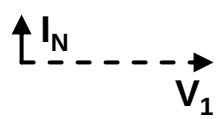
$\overrightarrow{P_N} \approx \overrightarrow{V_1} \bullet \overrightarrow{I_N}$

Phase A open



$$\overrightarrow{P_N} \approx 1\angle -90 \text{ pu}$$

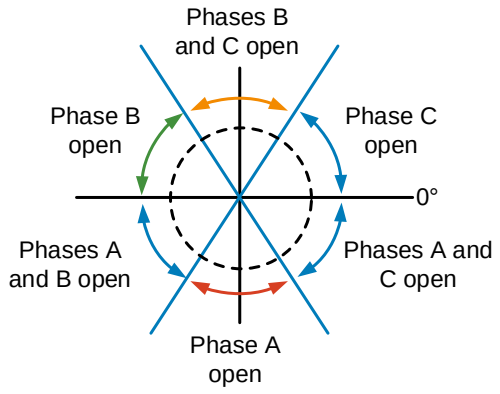
Phase A element fault



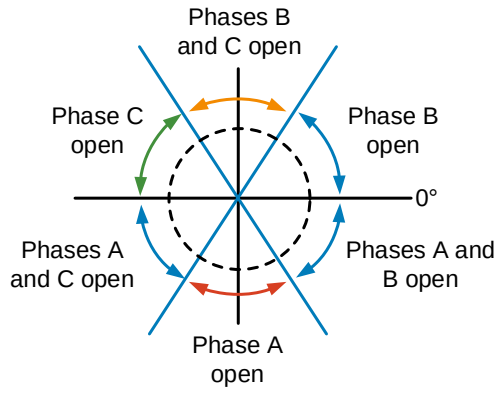
$$\overrightarrow{P_N} \approx \frac{n}{S-n} 1\angle 90 \text{ pu}$$

$\overrightarrow{P_N}$ for each open phase condition

ABC rotation

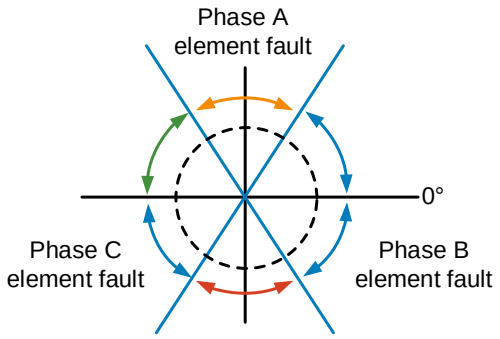


ACB rotation

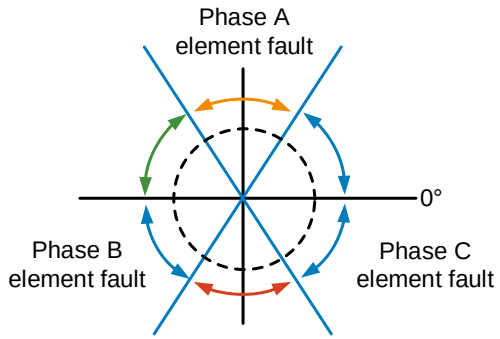


$\overrightarrow{P_N}$ for each faulted phase condition

ABC rotation

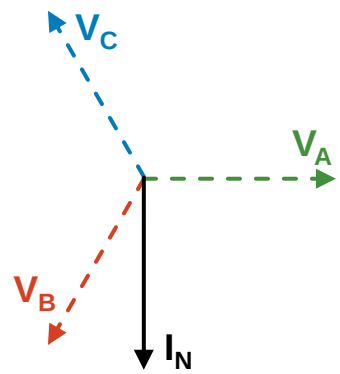


ACB rotation

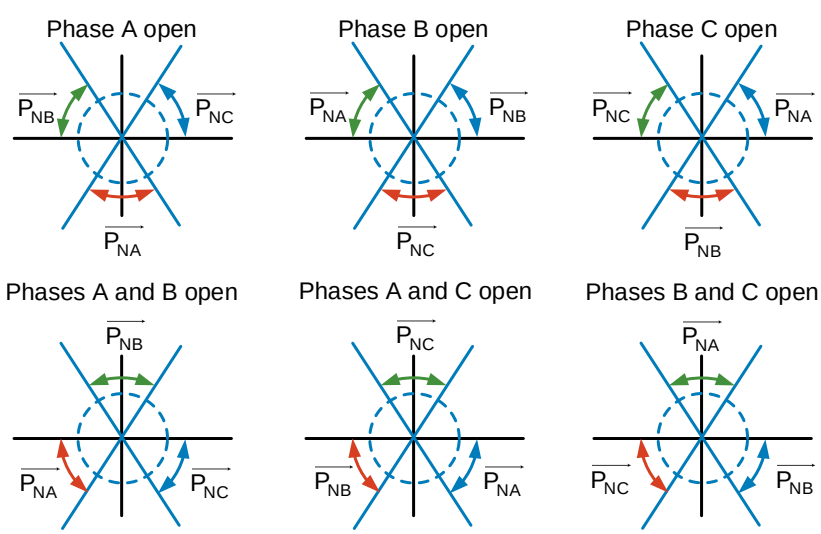


Alternative method with three voltages

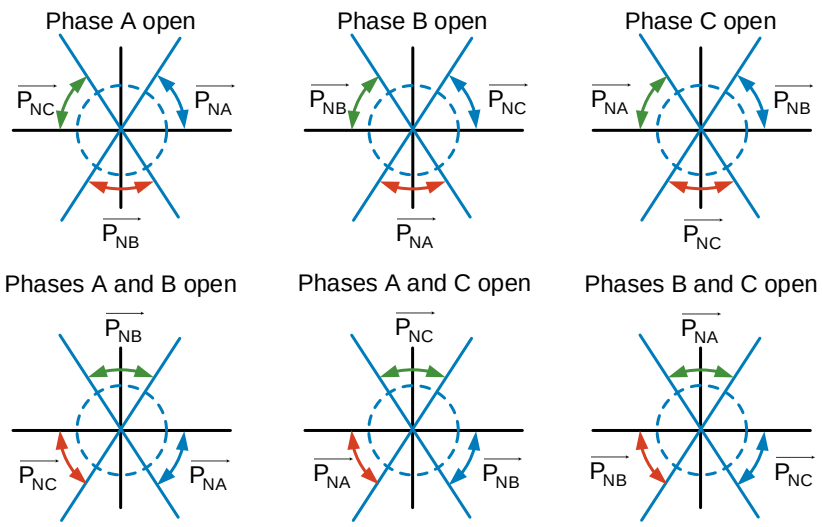
$$\overrightarrow{P_{NA}} \approx \overrightarrow{V_A} \bullet \overrightarrow{I_N}$$
$$\overrightarrow{P_{NB}} \approx \overrightarrow{V_B} \bullet \overrightarrow{I_N}$$
$$\overrightarrow{P_{NC}} \approx \overrightarrow{V_C} \bullet \overrightarrow{I_N}$$



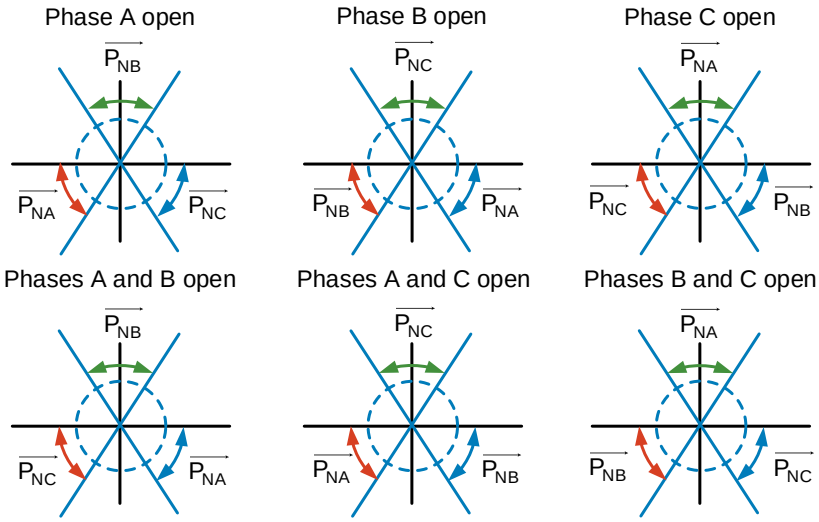
Open-phase conditions – ABC rotation



Open-phase conditions – ACB rotation



Faulted phase conditions



ABC rotation

ACB rotation

Questions?