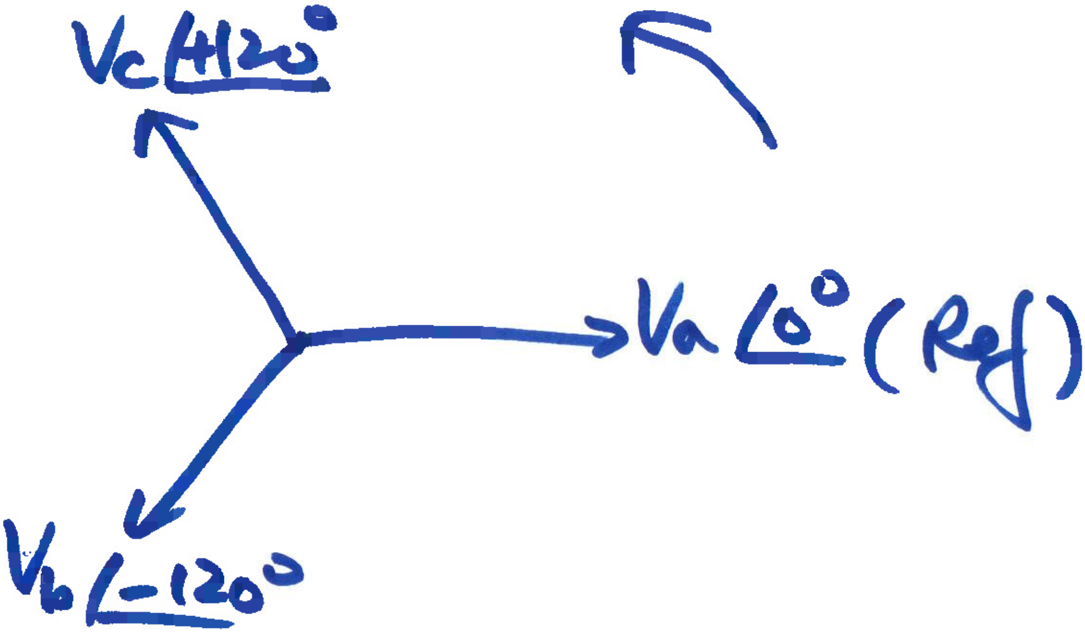
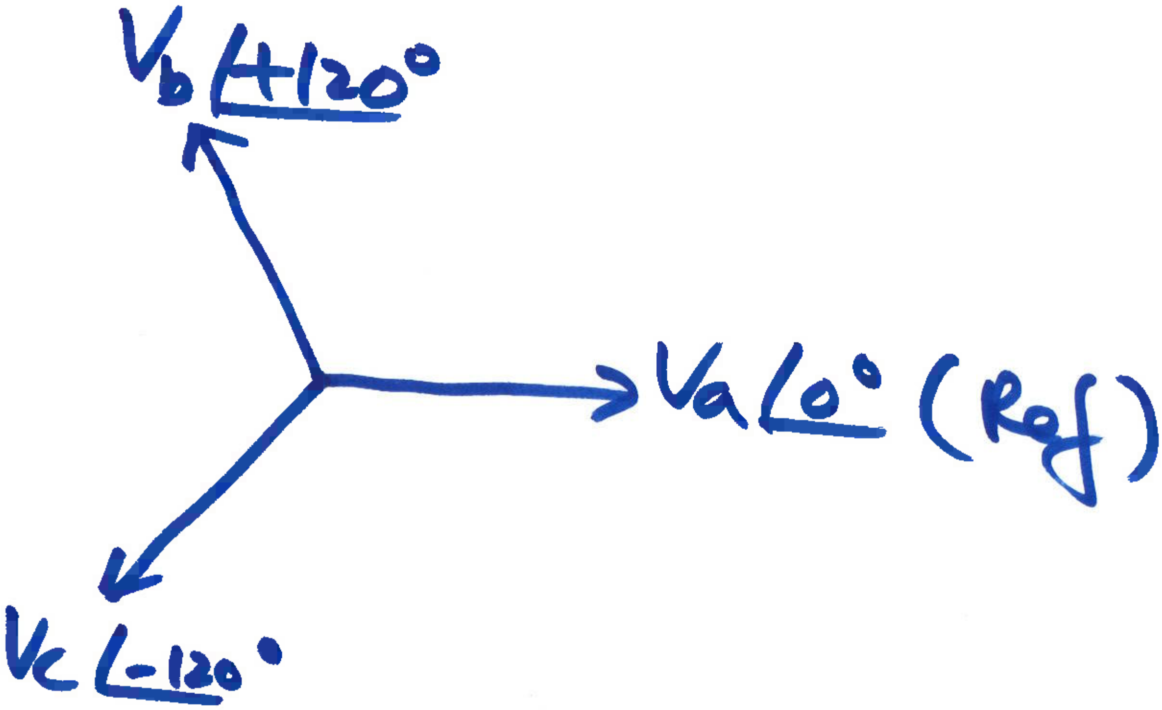


PPS - a, b, c



NPS - a, c, b

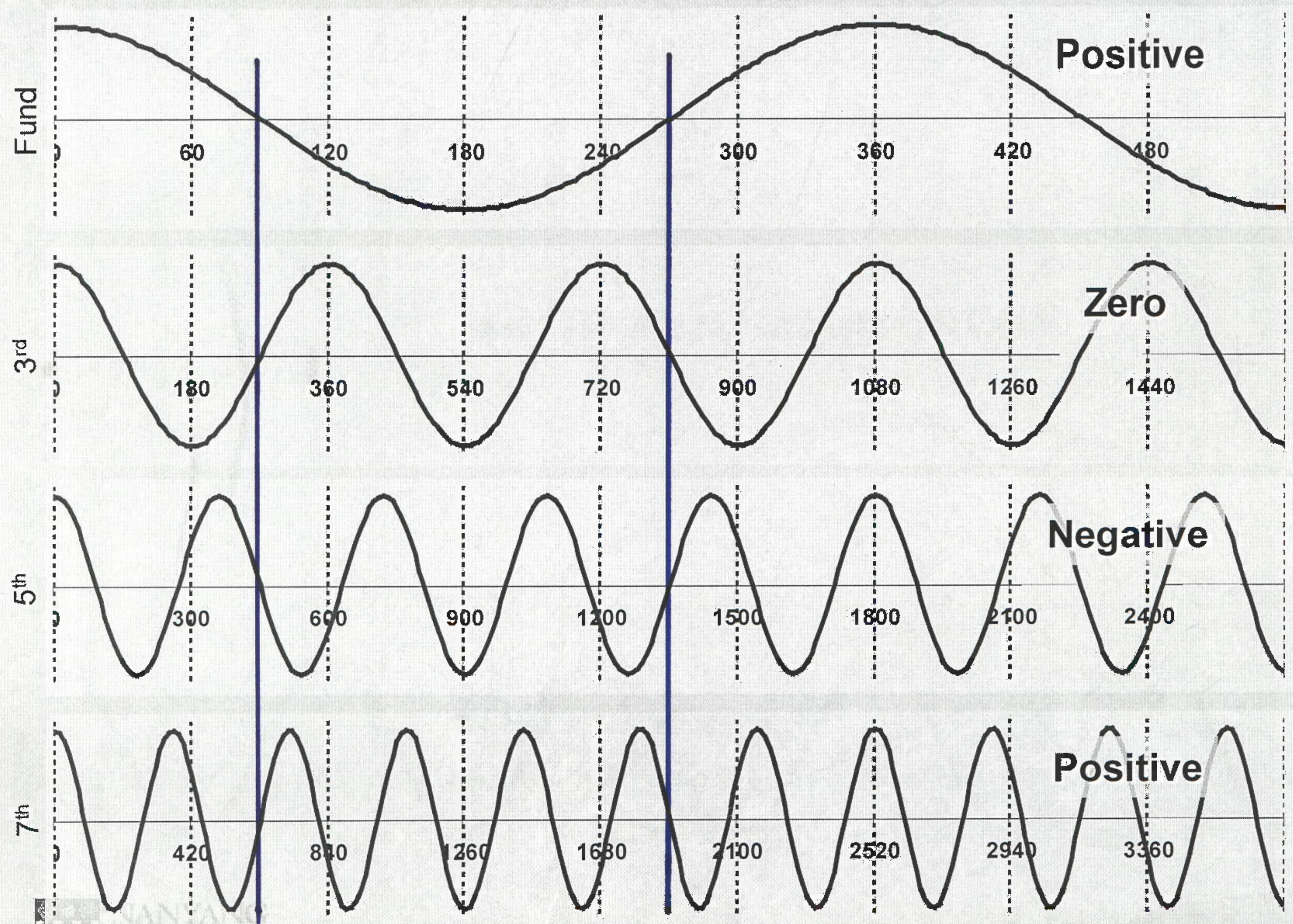
$\longrightarrow V_a \angle 0^\circ$

$\longrightarrow V_b \angle 0^\circ$

$\longrightarrow V_c \angle 0^\circ$

ZPS

Harmonic sequences 1-phase



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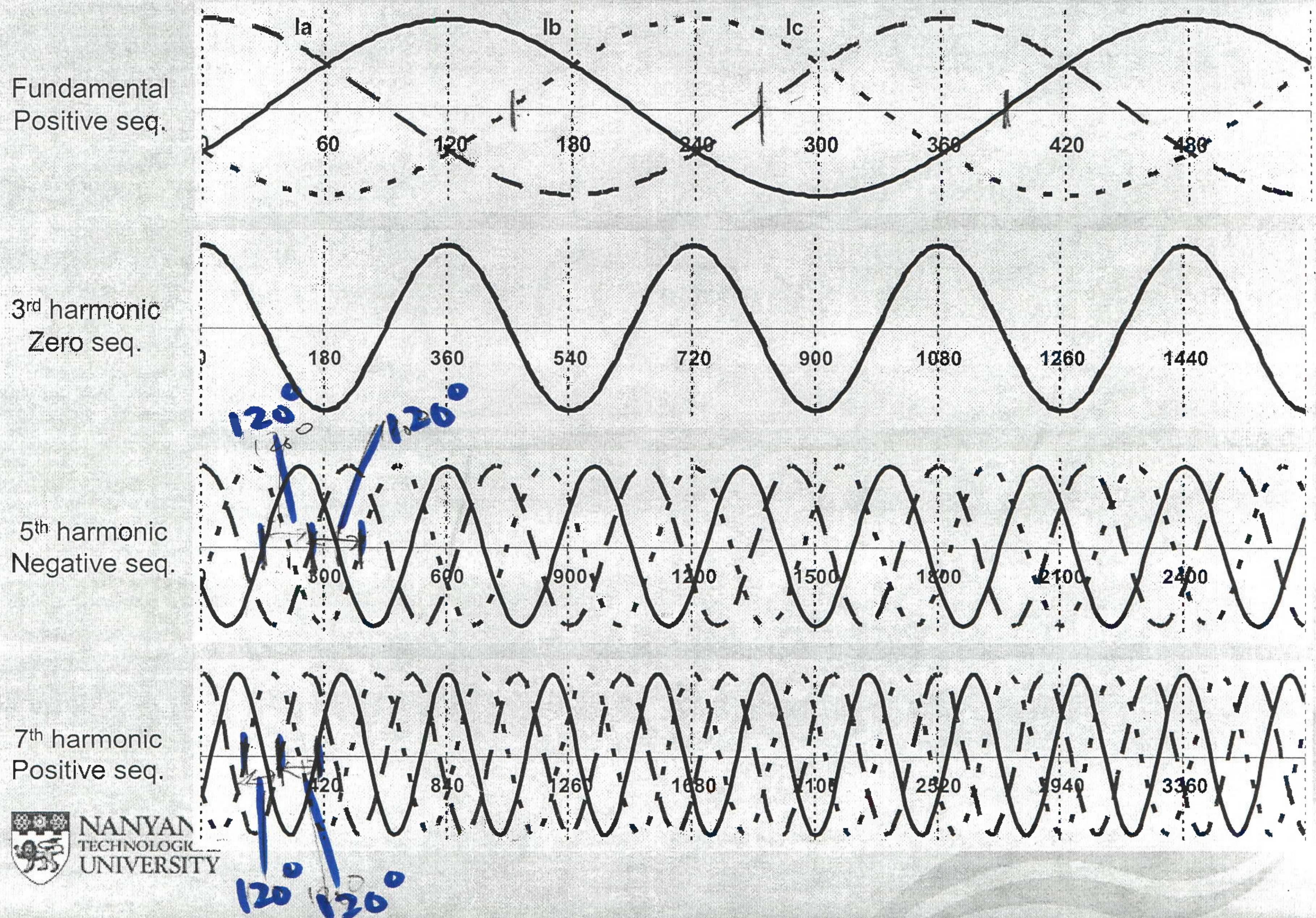
33

25

Harmonic sequences 3-phase



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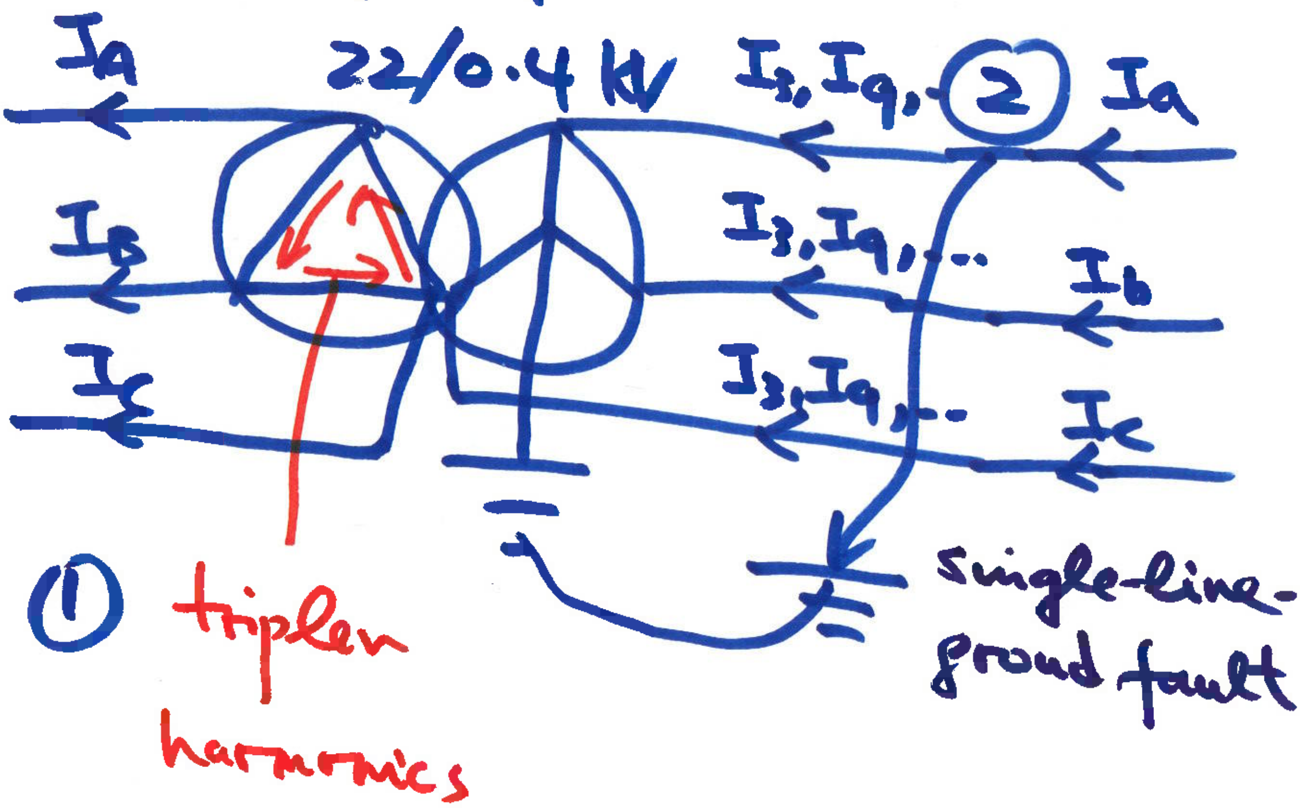
34
26

$$\downarrow X_{L,h} = 2\pi f\, h \downarrow L = X_{L,1}\, h$$

$$\downarrow X_{C,h} = \frac{1}{2\pi f\, h \uparrow C} = \frac{X_{C,1}}{h}$$

Distribution Transformer

1MVA



Complex Power

$$\bar{S} = \sqrt{3}\, V_L I_L \angle \phi$$

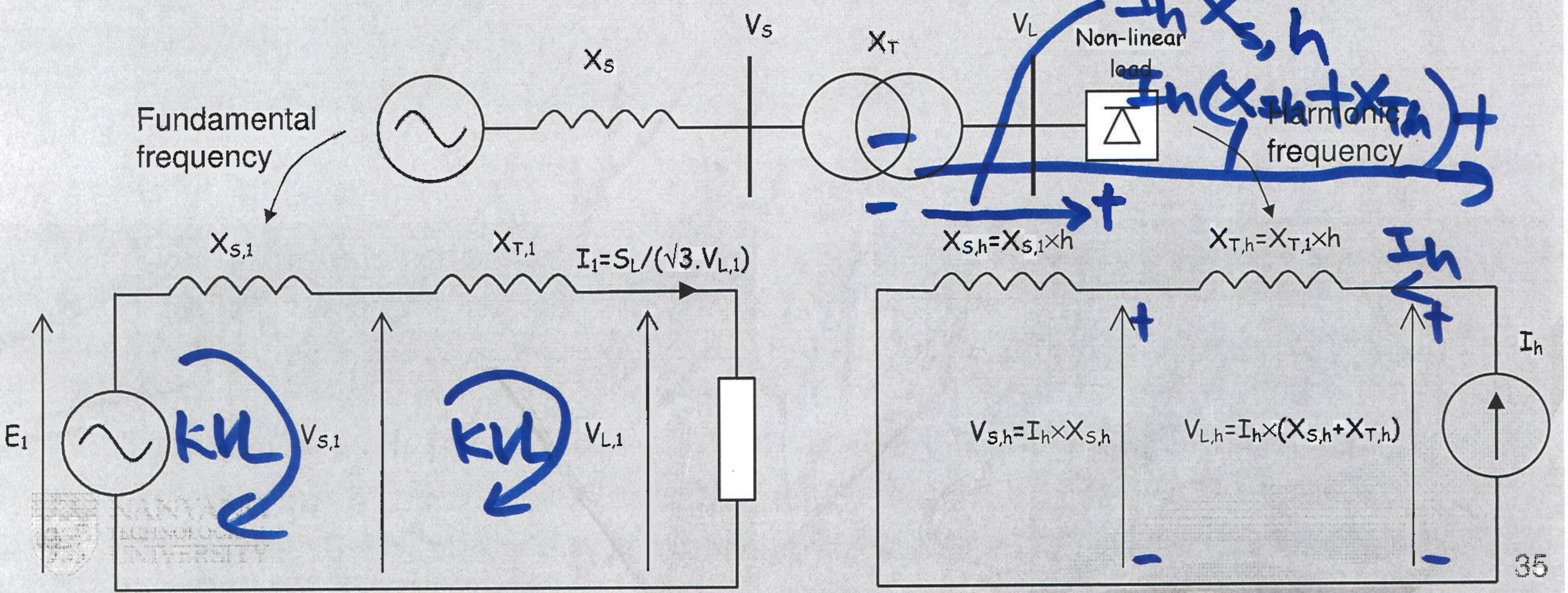
$$= S \angle \phi$$

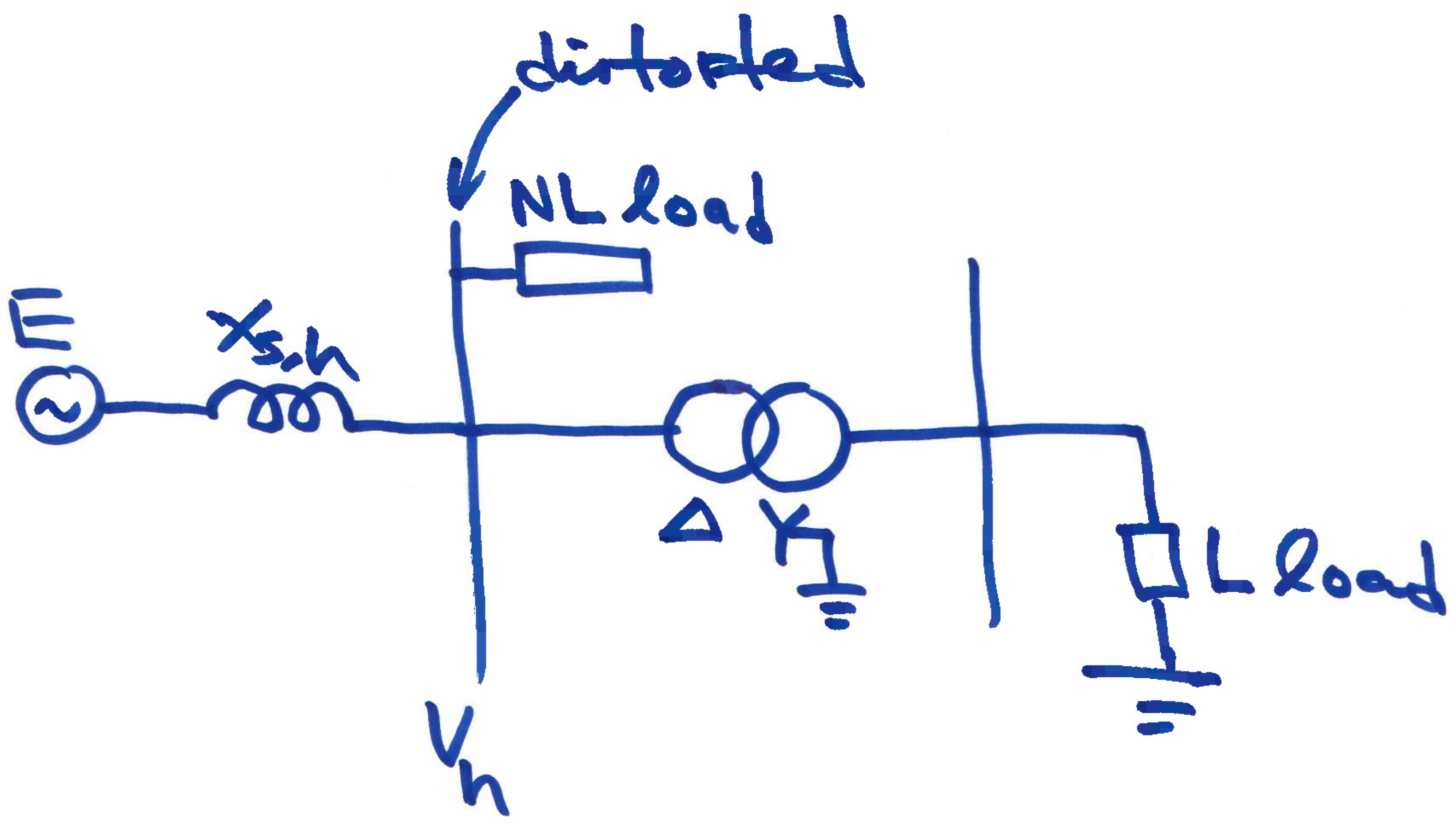
$$S = \sqrt{3}\, V_L I_L$$

$$\therefore I_L = \frac{S}{\sqrt{3}\, V_L}$$

Visualizing system response to harmonics

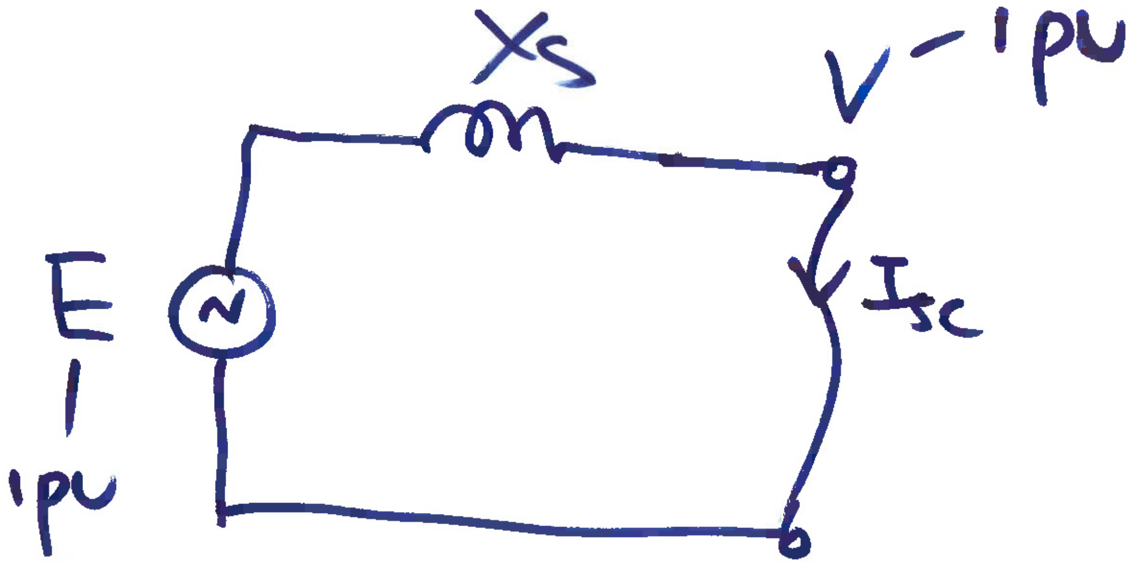
- System responds differently to currents and voltages of different frequencies
  - Separate individual harmonic responses from the fundamental response
  - At fundamental frequency, voltages are dependent on the voltage drops across system impedances due to the power or current flow as drawn by the load
  - At a harmonic frequency, non-linear load acts as harmonic current source, injecting harmonic current into the supply system
    - Results in harmonic voltage as the current flows through the system impedance





distorted
NL load
E
$X_{s,h}$
Δ
Y
L load
V_h

Short-circuit Test



Short Circuit Capacity

$$SCC = V I_{sc} \quad \text{VA, KVA, MVA}$$

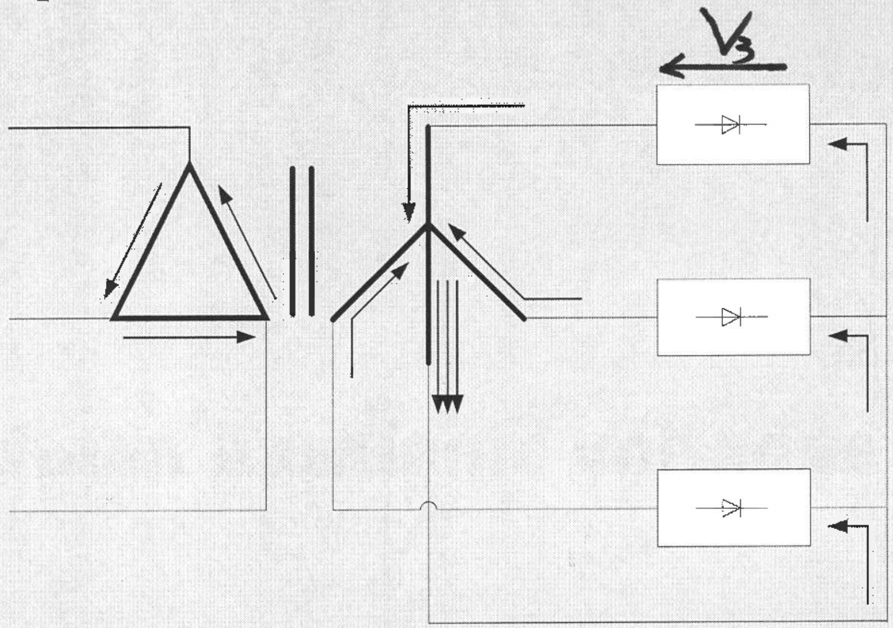
$$= V \frac{E}{X_s}$$

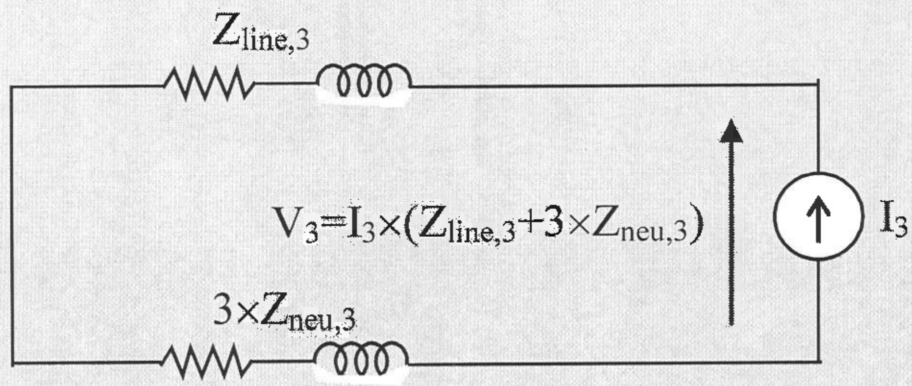
(V – 1pu, E – 1pu)

$$= \frac{1}{X_s}$$

$$X_s = \frac{1}{SCC}$$

Triplen harmonic voltages





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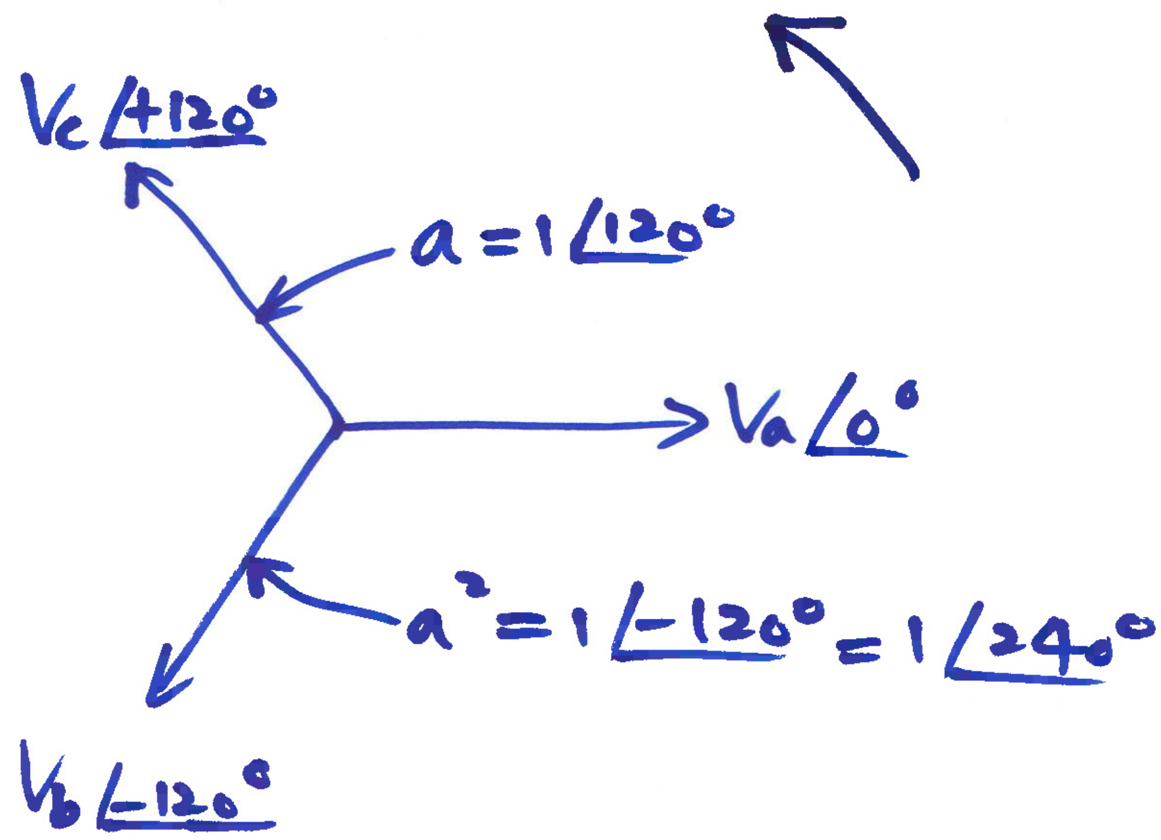
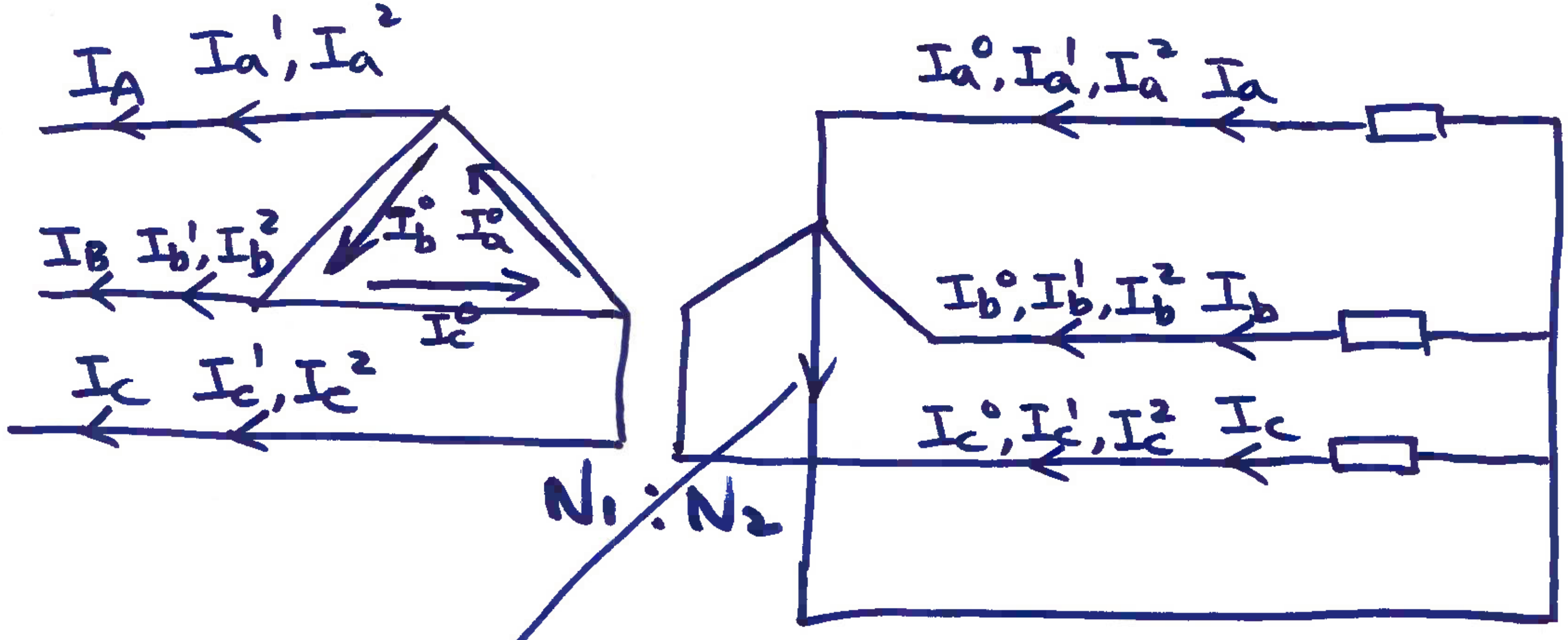
38

$$V_3 = I_3 Z_{line,3} + 3 I_3 Z_{neu,3}$$

$$= I_3 \left(Z_{line,3} + 3 Z_{neu,3} \right)$$


$V_c \angle +120^\circ$
$a = 1\angle 120^\circ$
$V_a \angle 0^\circ$
$a^2 = 1\angle -120^\circ = 1\angle 240^\circ$
$V_b \angle -120^\circ$



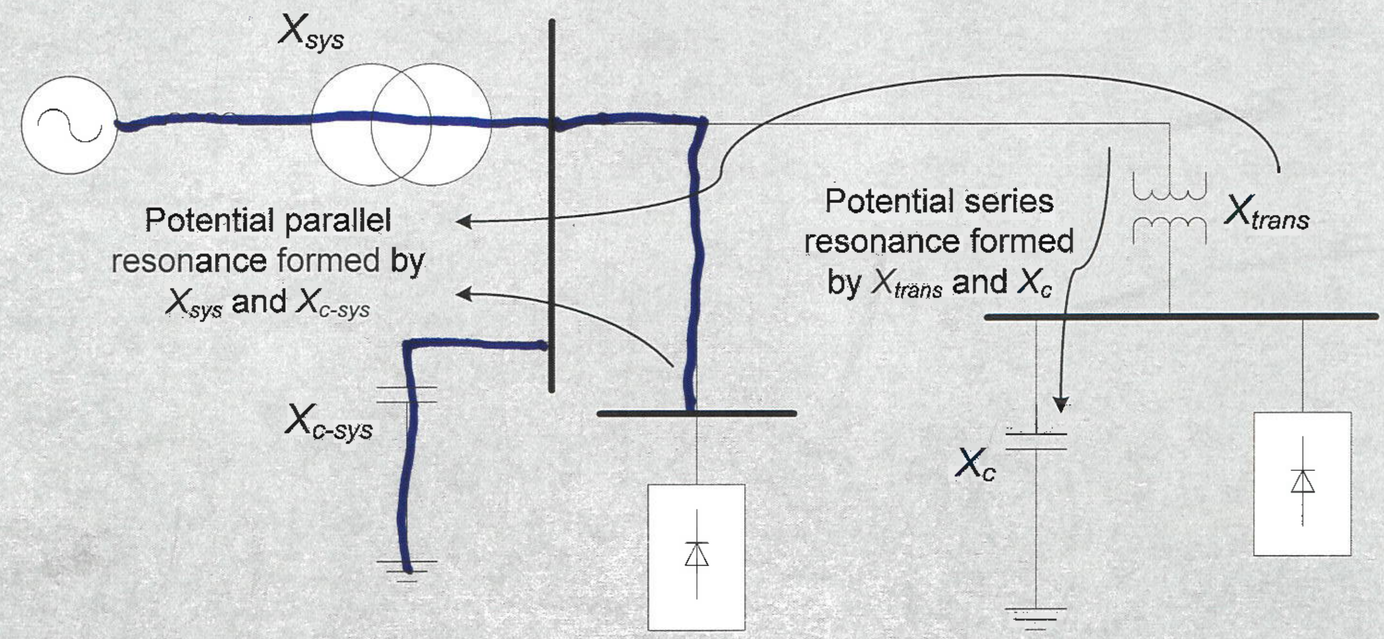
$$I_N = I_a + I_b + I_c$$
$$= I_a^0 + I_b^0 + I_c^0 = 3I_a^0$$

$$I_A = \frac{I_a}{a} = \frac{I_a}{\frac{N_1}{N_2}} = \frac{N_2}{N_1} I_a$$

$$a = \frac{N_1}{N_2}$$

Parallel and series resonances

- Resonance occurs when an inductive reactance equal to a capacitive reactance at or near a characteristic harmonic frequency
  - Parallel resonance involving supply system and substation capacitors or supply system with power factor correction capacitor
  - Series resonance made up of distribution transformer and power factor improvement capacitor



- A resonance point becomes problematic only when there is a harmonic source that excites (kick-starts) the resonance effect

Harmonic frequency is close to or equal to the resonance frequency

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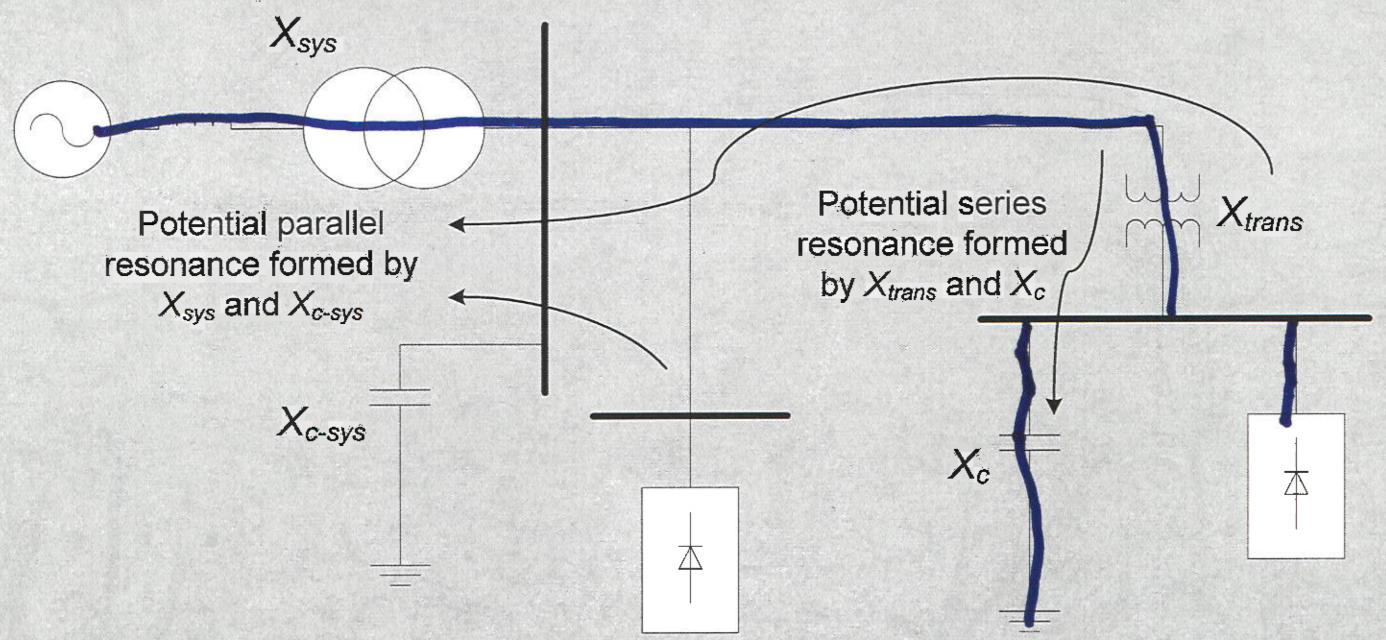

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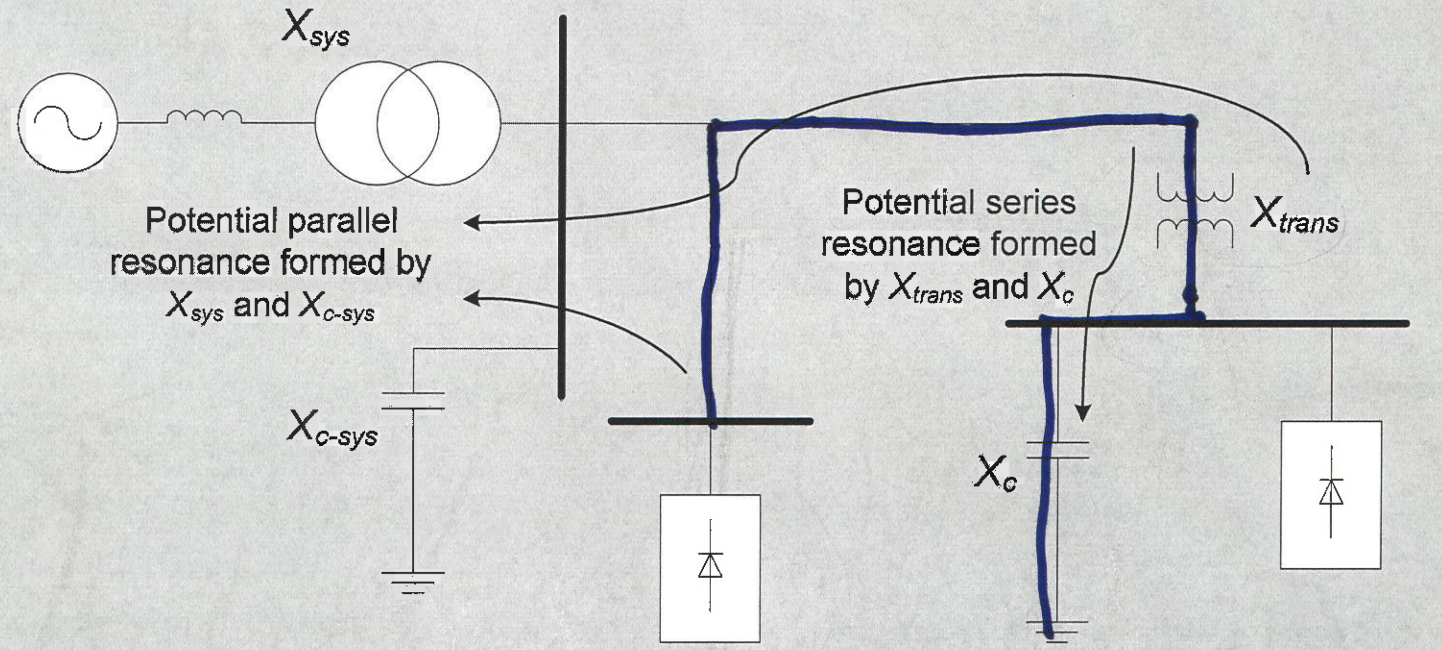

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  Harmonic frequency is close to or equal to the resonance frequency

47

At resonance

$$X_L = X_C$$

$$2\pi f L = \frac{1}{2\pi f C}$$

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

resonance frequency

e.g. 150 Hz

$$X_{s,1} = 2\pi f L_s$$

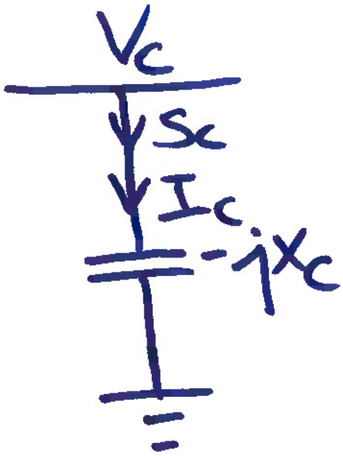
$$X_{s,h} = 2\pi f h L_s = \underline{\underline{h X_{s,1}}}$$

$$X_{T,1} = 2\pi f L_T$$

$$X_{T,h} = 2\pi f h L_T = \underline{\underline{h X_{T,1}}}$$

$$X_{c,1} = \frac{1}{\omega C} = \frac{1}{2\pi f C_1}$$

$$X_{c,h} = \frac{1}{2\pi f h C_1} = \underline{\underline{\frac{X_{c,1}}{h}}}$$



$$Z_c = \frac{1}{j\omega C} = \frac{j}{jj\omega C} = -j\frac{1}{\omega C} = -jX_c$$

$$X_c = \frac{1}{\omega C}$$

$$S_c = V_c I_c^*$$
$$= V_c\left(\frac{V_c}{-jX_c}\right)^* = \frac{V_c V_c^*}{jX_c}$$
$$= \frac{V_c^2}{jX_c} = -j\frac{V_c^2}{X_c}$$
$$= -jQ_c$$

1 pu

$$Q_c = \frac{V_c^2}{X_c} \Rightarrow X_c = \frac{V_c^2}{Q_c}$$

Scap

$$\therefore X_c = \frac{1}{S_{cap}}$$

$$h = \sqrt{\frac{X_{c,fund}}{X_{s,fund}}}$$

$$= \sqrt{\frac{\frac{1}{S_{cap}}}{\frac{1}{S_{sc}}}}$$

$$= \sqrt{\frac{S_{sc}}{S_{cap}}}$$

$$\frac{V_{ch}}{V_h} = \frac{1}{j\underbrace{\omega_h}_{2\pi f\times 5}\underbrace{C}_{400\times 10^{-6}}.\underbrace{R_T}_{0.1}} = \frac{-j\overbrace{X_{c,h}}^{1.592}}{\underbrace{R_T}_{0.1}}$$

$$= \frac{1}{j\,2\pi\times 50\times 5\times 400\times 10^{-6}\times 0.1}$$

$$= \underline{-j\,15.92}$$

$$Z = R_T + jX_{T,h} + (-jX_{c,h})$$

At resonace, $X_{T,h} = X_{c,h}$

$\therefore Z = R_T$ (low impedance)

Concurrent parallel and series resonances

- At frequency lower than the series resonant frequency,
  - The series branch of transformer inductive impedance and capacitor reactance becomes capacitive as X_c increases with decreasing frequency $\uparrow X_c = \frac{1}{2\pi f C \downarrow}$
  - This branch will result in a parallel resonance with the system impedance (which is inductive) at a frequency slightly lower than the series resonant frequency

$$f_p = f_{fund}\sqrt{\frac{X_{C,fund}}{X_{S,fund} + X_{L,fund}}}$$