University of Idaho

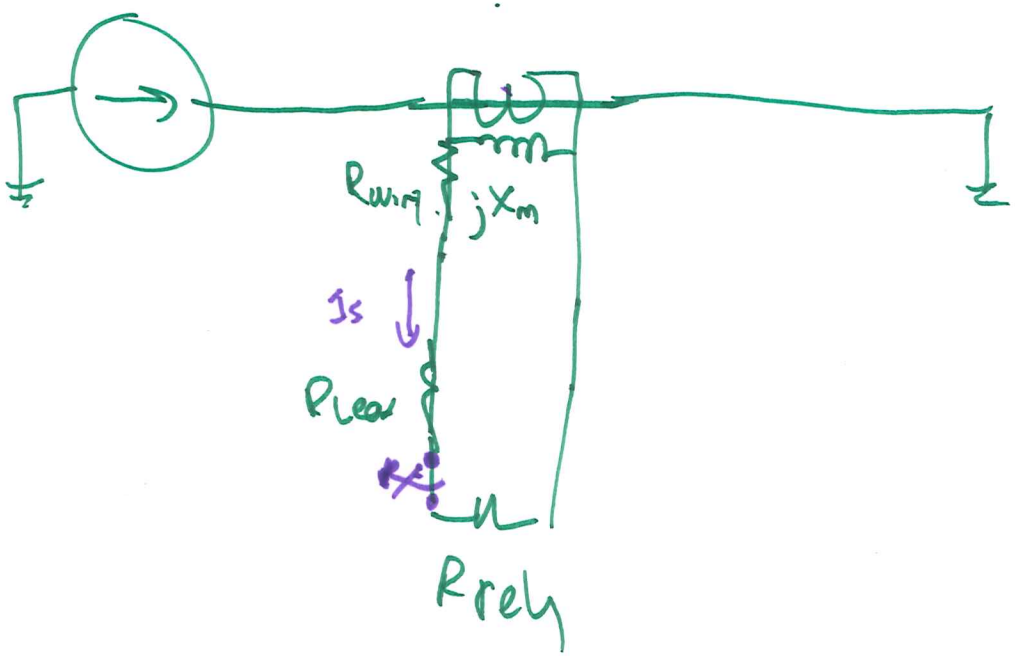
ECE 525

POWER SYSTEM PROTECTION AND RELAYING

SESSION no. 10

HW 2

Problem 4



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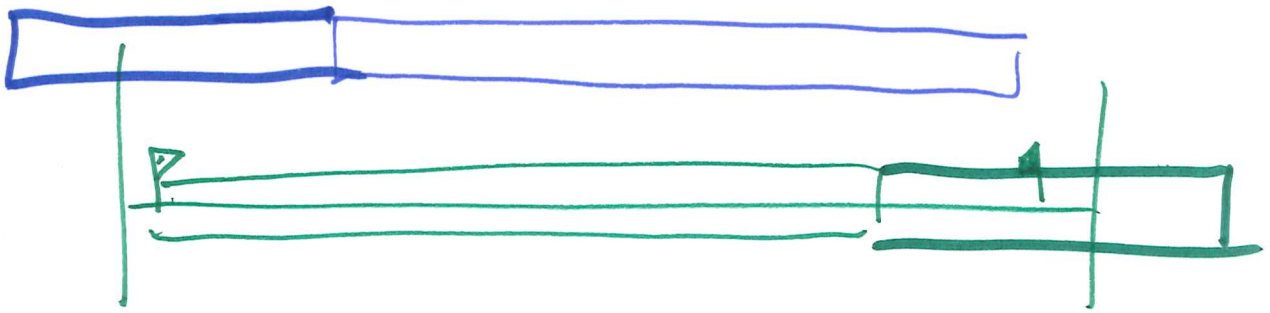


POTT, other - comm aided distance

ECE 525: Lecture 9

For the CCVT given below

Main Data:

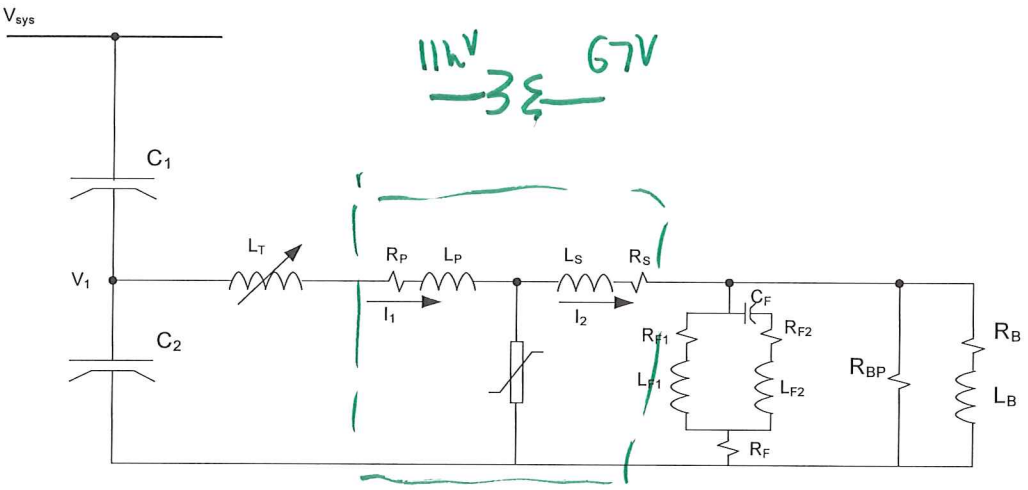
$V_{LL} := 345kV$ $V_{sec\_nominal} := 67V$ $f_{nominal} := 60Hz$

Transformer Data:

- $V_{C2} := 11kV$

$R_P := 300ohm$ $L_p := 5.6H$

$R_s := 0.034ohm$ $L_s := 0.0253mH$



a) Determine the value of C_1 if: $C_2 := 135nF$

$\omega := 2 \cdot \pi \cdot 60Hz$

The voltage divider is:

$$V_{C2} = \frac{V_{LL}}{\sqrt{3}} \cdot \frac{\frac{1}{\omega \cdot C_2}}{\frac{1}{\omega \cdot C_1} + \frac{1}{\omega \cdot C_2}}$$

Rearranging:

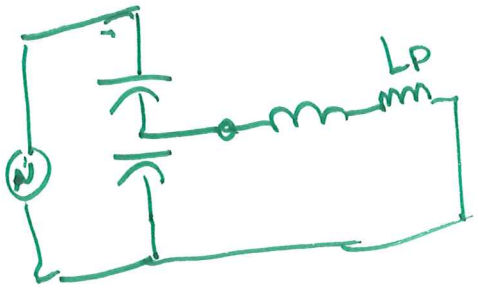
$$\frac{1}{\omega \cdot C_1} + \frac{1}{\omega \cdot C_2} = \frac{V_{LL}}{\sqrt{3} \cdot V_{C2}} \cdot \left(\frac{1}{\omega \cdot C_2} \right)$$

Then: $$\frac{1}{\omega \cdot C_1} = \left(\frac{1}{\omega \cdot C_2}\right) \cdot \left[\left(\frac{V_{LL}}{\sqrt{3} \cdot V_{C2}}\right) - 1\right]$$

$$C_1 := \left[\left(\frac{\omega}{\omega \cdot C_2}\right) \cdot \left[\left(\frac{V_{LL}}{\sqrt{3} \cdot V_{C2}}\right) - 1\right]\right]^{-1} \qquad C_1 = 7.89 \cdot nF$$

As a check:

$$\left(\frac{V_{LL}}{\sqrt{3}} \cdot \frac{\frac{1}{\omega \cdot C_2}}{\frac{1}{\omega \cdot C_1} + \frac{1}{\omega \cdot C_2}}\right) = 11 \cdot kV$$



b) Determine the tuning inductance, L_T

$$C_{equiv} := C_1 + C_2$$

$$L_T := \left[\frac{1}{\left(2 \cdot \pi \cdot f_{nominal}\right)^2 \cdot C_{equiv}} - L_p\right] \qquad L_T = 43.64 \cdot H$$

60Hz LC resonance

c) Given the following burden and ferro-resonance filter information calculate the magnitude and phase error in the voltage across the burden under steady-state nominal conditions.

Burden

$R_b := 400.9 \cdot \Omega$ $L_b := 1.84 \cdot H$ $R_{bp} := 785 \cdot \Omega$

Ferroresonance Filter

$R_{F1} := 1.06 \cdot \Omega$ $R_{F2} := 4.24 \cdot \Omega$ $C_F := 13.8 \cdot 10^{-6} \cdot F$

$L_{F1} := 0.1 \cdot H$ $L_{F2} := 0.394 \cdot H$ $R_F := 40 \cdot \Omega$

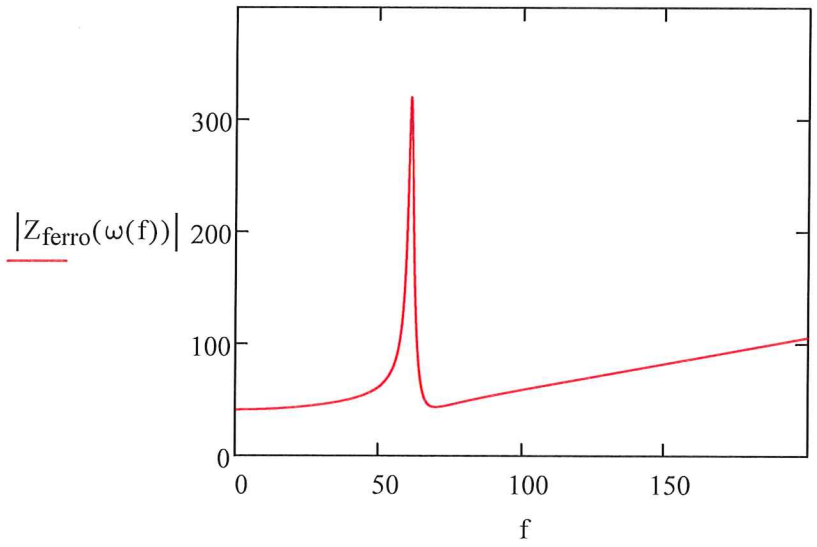
- The impedance of the ferroresonance filter is ~~much higher than that of the burden~~, so it can be neglected. But if it is included, it has a 60Hz impedance of:

$f := 0, 0.001Hz .. 200Hz$ $\omega(f) := 2 \cdot \pi \cdot f$

$$Z_{ferro}(\omega) := R_F + \left(\frac{1}{R_{F1} + j\cdot\omega\cdot L_{F1}} + \frac{1}{\frac{1}{j\cdot\omega\cdot C_F} + R_{F2} + j\cdot\omega\cdot L_{F2}} \right)^{-1}$$

$$\left|Z_{ferro}(2\cdot\pi\cdot 60Hz)\right| = 233.65\,\Omega$$

$$\arg\left(Z_{ferro}(2\cdot\pi\cdot 60Hz)\right) = 44.6\cdot deg$$



Reset ω

$$\omega := 2\cdot\pi\cdot 60Hz$$

- Equivalent burden impedance:

$$Z_{Burden} := \left(\frac{1}{R_{bp}} + \frac{1}{R_b + j\cdot\omega\cdot L_b} \right)^{-1}$$

$$\left|Z_{Burden}\right| = 457.78\,\Omega$$

$$\arg\left(Z_{Burden}\right) = 29.65\cdot deg$$

- Parallel Burden with Filter:

$$Z_{para} := \left(\frac{1}{Z_{ferro}(\omega)} + \frac{1}{Z_{Burden}} \right)^{-1}$$

$$\left|Z_{para}\right| = 155.88\,\Omega$$

$$\arg\left(Z_{para}\right) = 39.56\cdot deg$$

- Secondary winding:

$$Z_{sec\_winding} := R_s + j\cdot\omega\cdot L_s \qquad Z_{sec\_winding} = (0.03 + 0.01i)\,\Omega$$

- Primary impedances:

$$Z_{c1} := \frac{1}{j\cdot\omega\cdot C_1} \qquad Z_{c2} := \frac{1}{j\cdot\omega\cdot C_2} \qquad Z_T := j\cdot\omega\cdot L_T$$

$$Z_{prim\_winding} := R_P + j\cdot\omega\cdot L_p$$

- Refer primary impedances to secondary: $a := \frac{11kV}{67V}$

$$Z'_{c1} := \frac{Z_{c1}}{a^2} \qquad Z'_{c1} = -12.47i\,\Omega \qquad Z'_{c2} := \frac{Z_{c2}}{a^2} \qquad Z'_{c2} = -0.73i\,\Omega$$

$$Z'_T := \frac{Z_T}{a^2} \qquad Z'_T = 0.61i\,\Omega \qquad Z'_{prim\_winding} := \frac{Z_{prim\_winding}}{a^2}$$

$$Z'_{prim\_winding} = (0.01 + 0.08i)\,\Omega$$

- Equivalent impedance seen from souce, referred to secondary:

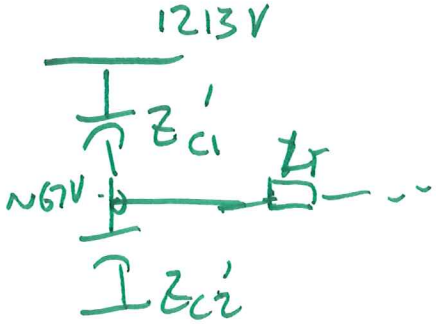
$$Z_{equiv\_CCVT} := Z'_{c1} + \left[\frac{1}{Z'_{c2}} + \frac{1}{\left(Z'_T + Z'_{prim\_winding} + Z_{sec\_winding} + Z_{para}\right)}\right]^{-1}$$

$$Z_{equiv\_CCVT} = (0 - 13.2i)\,\Omega$$

- Total current drawn by CCVT from source (secondary amps)-includes both capacitors referred to secondary, so use sysetm voltage not Vc2

$$V_{Line\_sec} := \frac{V_{LL}}{a\cdot\sqrt{3}} \qquad V_{Line\_sec} = 1213.22\,V$$

$$I_{total} := \frac{V_{Line\_sec}}{Z_{equiv\_CCVT}} \qquad I_{total} = (0.02 + 91.9i)\,A$$



- Current Divider between C2 and VT:

$$I_{VT} := I_{total}\cdot\left[\frac{Z'_{c2}}{Z'_{c2} + \left(Z'_T + Z'_{prim\_winding} + Z_{sec\_winding} + Z_{para}\right)}\right]$$

$$\left|I_{VT}\right| = 0.43\,A$$

- Voltage across burden

$$V_{burden} := I_{VT}\cdot Z_{para} \qquad \left|V_{burden}\right| = 66.98\,V \qquad \arg\left(V_{burden}\right) = 0.01\cdot deg$$

- Error Calculations

$$V_{rated\_sec} := \left(\frac{V_{LL}}{\sqrt{3}}\cdot\frac{\frac{1}{\omega\cdot C_2}}{\frac{1}{\omega\cdot C_1} + \frac{1}{\omega\cdot C_2}}\right)\cdot\frac{1}{a} \qquad V_{rated\_sec} = 67\,V$$

Magnitude Error:

$$V_{rated\_sec} - \left|V_{burden}\right| = 0.02\,V$$

Percent Magnitude Error:

$$\frac{V_{rated\_sec} - \left|V_{burden}\right|}{V_{rated\_sec}} = 0.03\cdot\%$$

- Since reference voltage is at 0 degrees

$$Angle\_error := \arg\left(V_{burden}\right) \qquad Angle\_error = 0.01\cdot deg$$

Define units for angle smaller than degree

$$arcmin := \frac{deg}{60} \qquad Angle\_error = 0.47\cdot arcmin$$ in minutes of arc

$$arcsec := \frac{arcmin}{60} \qquad Angle\_error = 28.3\cdot arcsec$$ in seconds of arc

"Emerging" Technologies

- CTs without iron cores
  - Linear couplers
  - Rogowski coils
  - optical CTs
  - optical VTs

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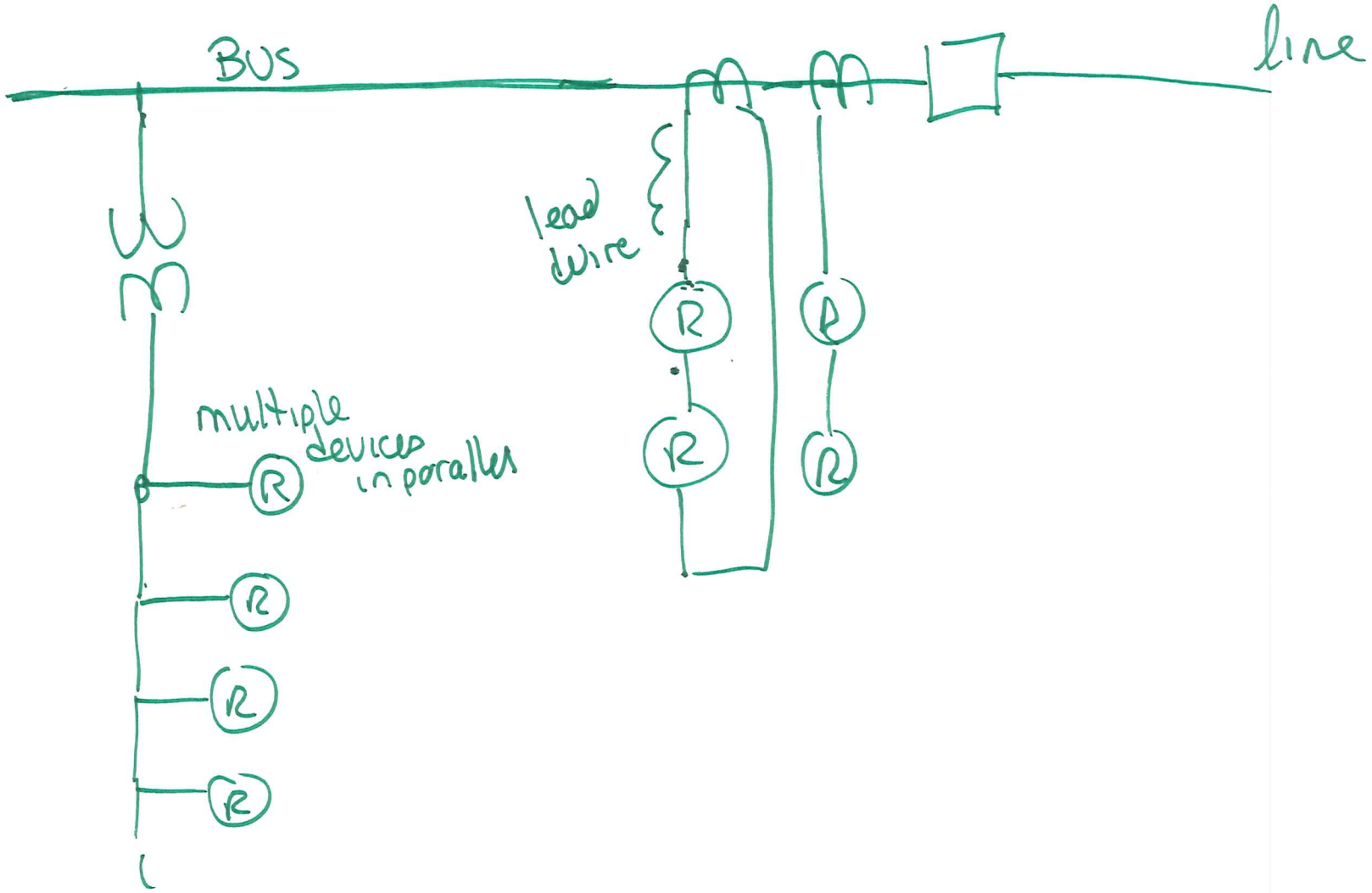
Most Applications



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- "Relays" or metering devices subscribe to measurements off that network
- provides opportunity to combine measurements

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IEC 61850

→ Communication inside a substation

- initial driver - interoperability between vendors

→ Process Bus/Sampled Values

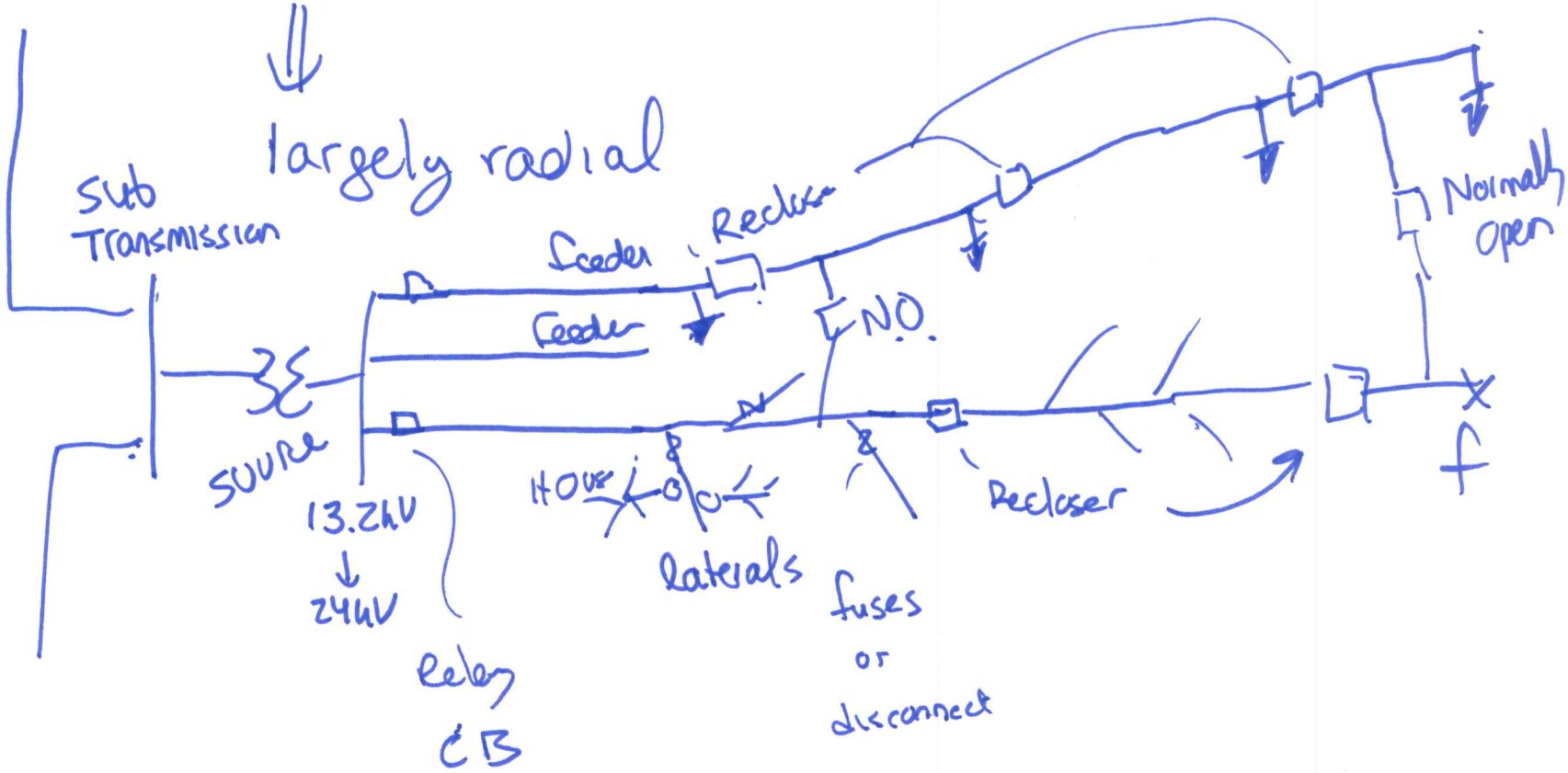
→ measurement devices (CT, PT/VT etc)

→ physical connection to device that calculates/processes measurement

→ Broadcast them on a substation network

Distribution System Protection

→ Now vs Future



→ primary protected with overcurrent relays

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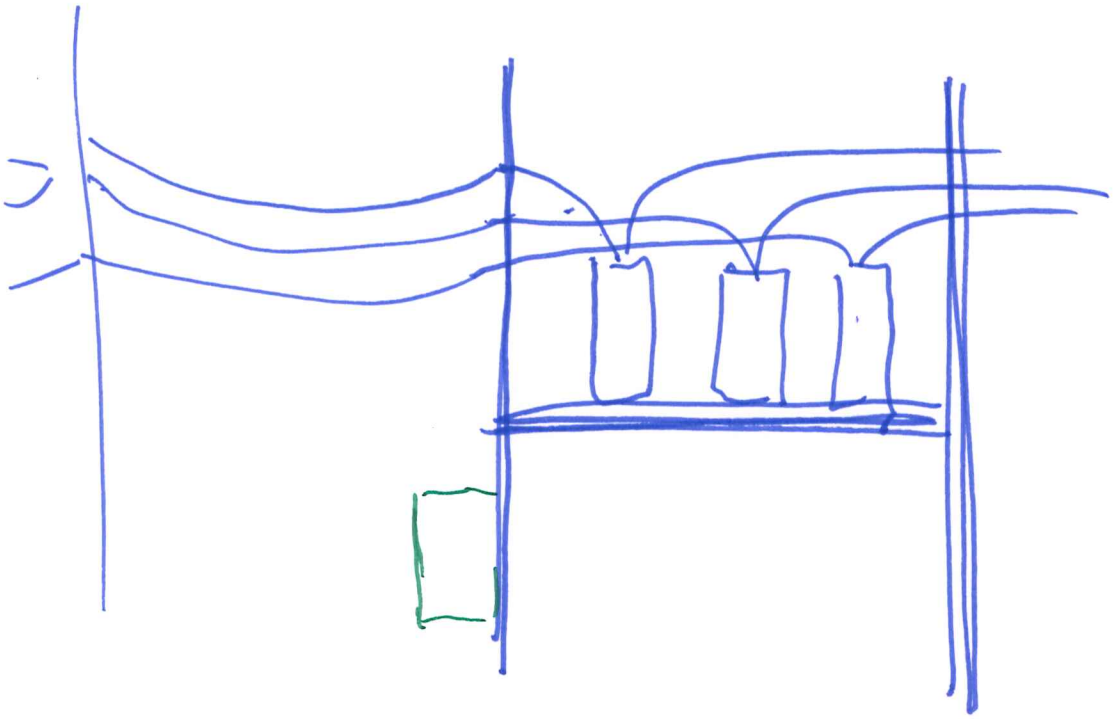

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Complications

- Increased reconfigurability
- Distributed generation
  - Household or building generation
    - PV
      - complicate protection coordination