Bus Protection for Impedance Grounded Systems

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The reason for this paper

- Industrial facilities are installing bus protection to reduce arc flash hazards
- Requires careful design of bus protection
  - CT performance for phase fault protection
  - Sensitivity for ground fault protection

Impedance grounding

- Reduces equipment damage, maintains process uptime
- Low-impedance grounding
  - Limits ground fault current to 200A to 500A
  - Good sensitivity to ground faults
- High-impedance grounding
  - Limits ground fault to 2A to 5A
  - Some sensitivity to ground faults

Arc flash risk

Hazard / Risk Category	Required Minimum Arc Rating of PPE Cal / cm_2
0	N/A
1	4
2	8
3	25
4	40

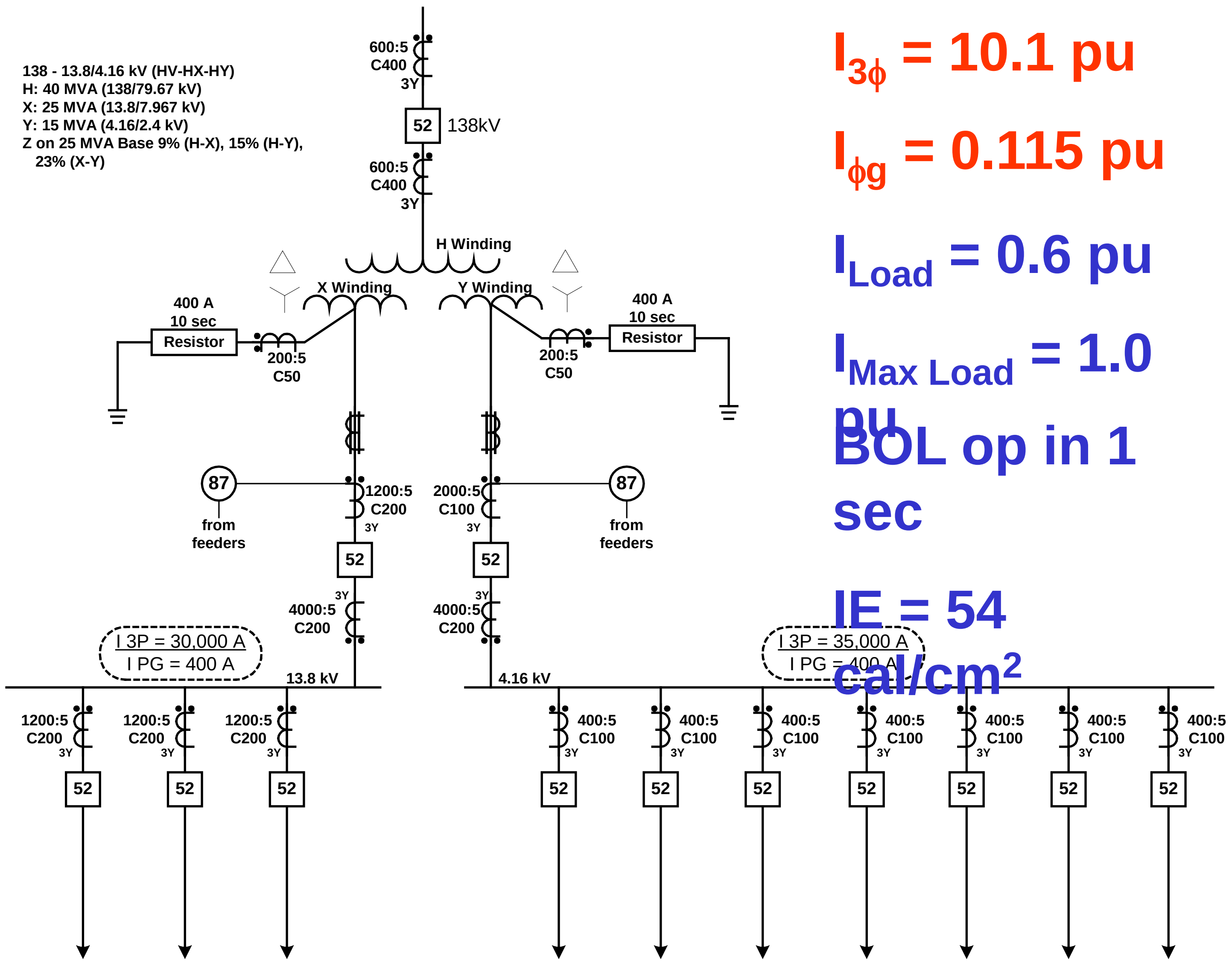
Arc flash incident energy

Arcing time

$$E = C_f E_n \left(\frac{t}{0.2} \right) \left(\frac{610^x}{D^x} \right)$$

Normalized Incident energy based on short-circuit current level

Example system



$I_{3\phi}$ = 10.1 pu

$I_{\phi g}$ = 0.115 pu

I_{Load} = 0.6 pu

$I_{Max\ Load}$ = 1.0 pu

BOL op in 1 sec

IE = 54 cal/cm^2

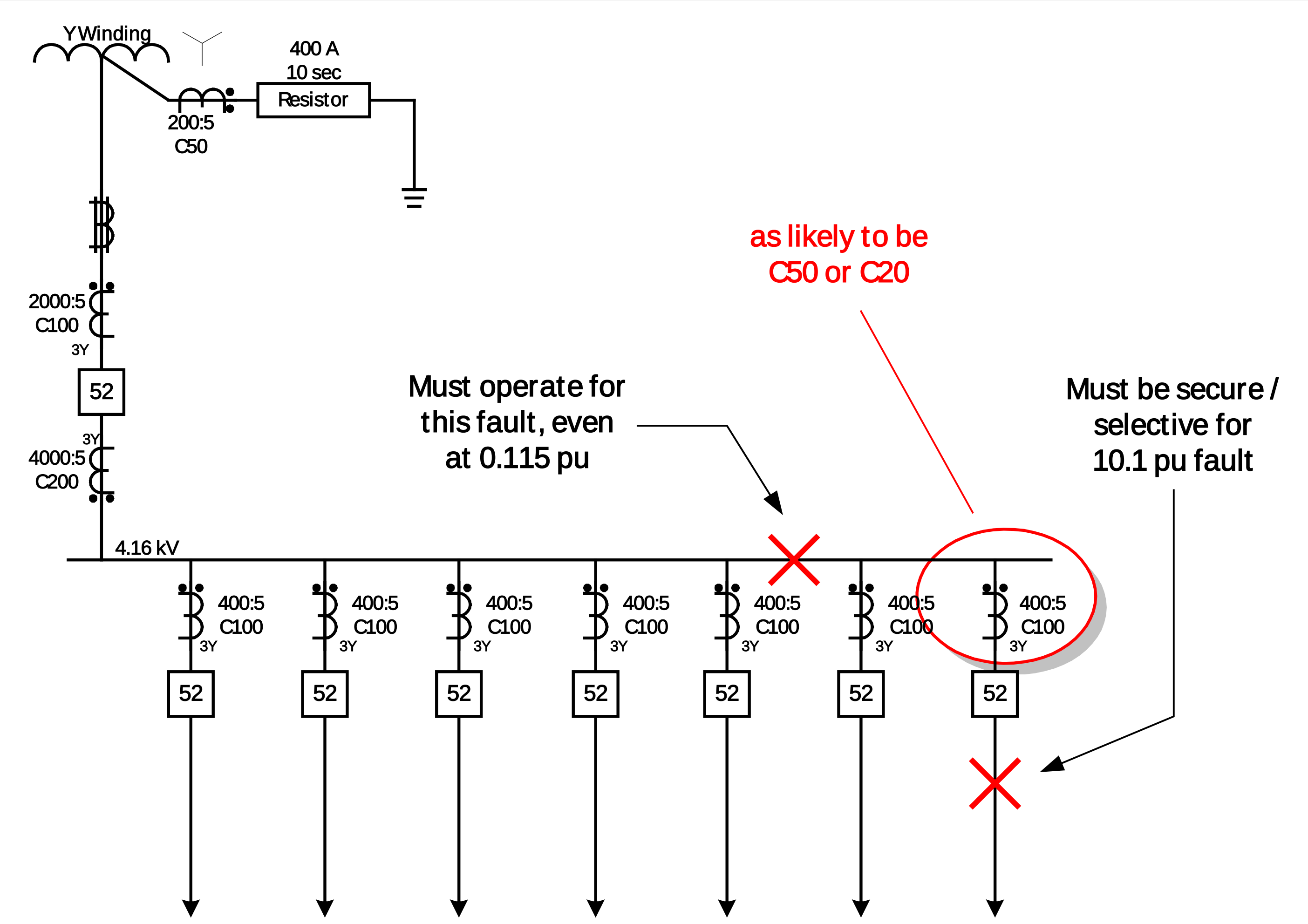
Phase currents for ground fault

$$I_A = 0.65\angle -35^o \ pu$$

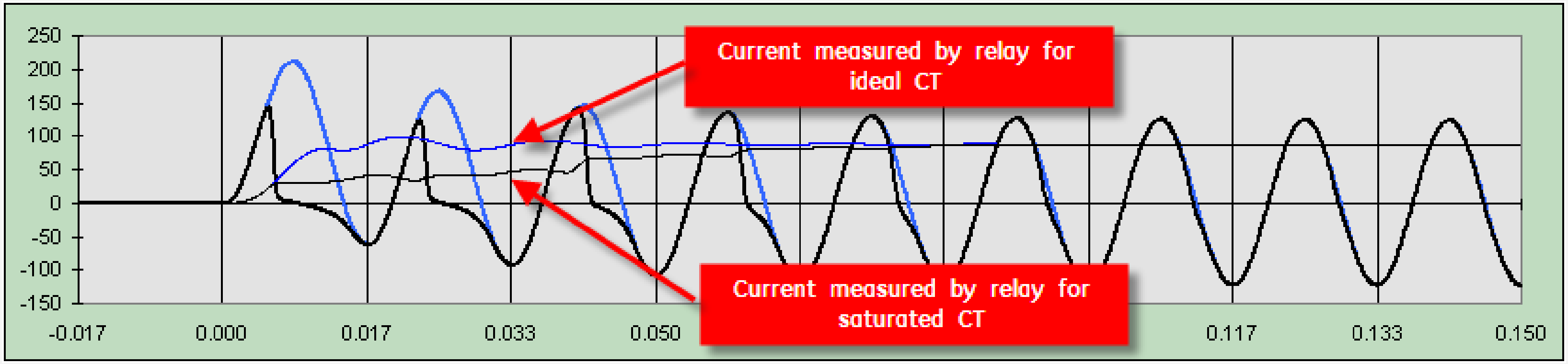
$$I_B = 0.60\angle -145^o \ pu$$

$$I_C = 0.59\angle -93^o \ pu$$

Bus protection requirements



CT saturation



- Relay sees reduced current
- Can result in loss of security or selectivity

Bus protection performance is all about the CTs!

CT Sizing

$$V_X > 2 \times I_{SEC} \times Z_S$$

$$V_X > \sqrt{1 + e^{-2\pi t / (X/R)}} \times I_{SEC} \times Z_S$$

But C37.110 says…

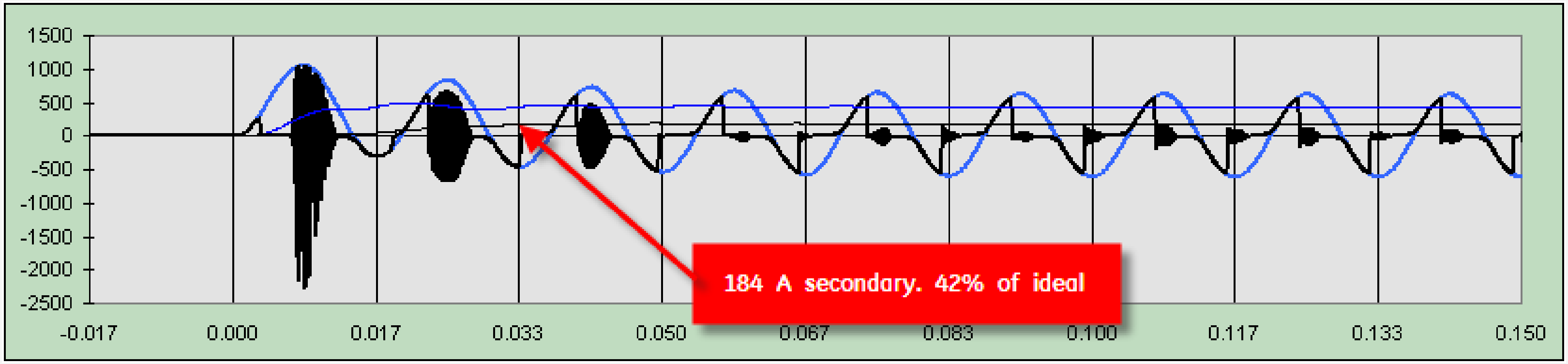
$$V_X > I_{SEC} \times Z_S \times \left(1 + X/R\right)$$

CT performance

$$20 > \frac{I_F}{CT\,primary\,rating} \times \frac{Z_S}{standard\,burden} \times \left(1 + X/R\right)$$

CT Primary Rating	CT Resistance	Accuracy Class	Standard Burden	Per unit saturation voltage	Maximum saturation free current
400	0.129 Ω	C100	1 Ω	384	0.53 pu
450	0.145 Ω	C100	1 Ω	354	0.57 pu
500	0.161 Ω	C100	1 Ω	330	0.61 pu
600	0.193 Ω	C100	1 Ω	293	0.69 pu
400	0.118 Ω	C200	2 Ω	187	1.08 pu
500	0.147 Ω	C200	2 Ω	160	1.26 pu

400:5, C100 CT performance



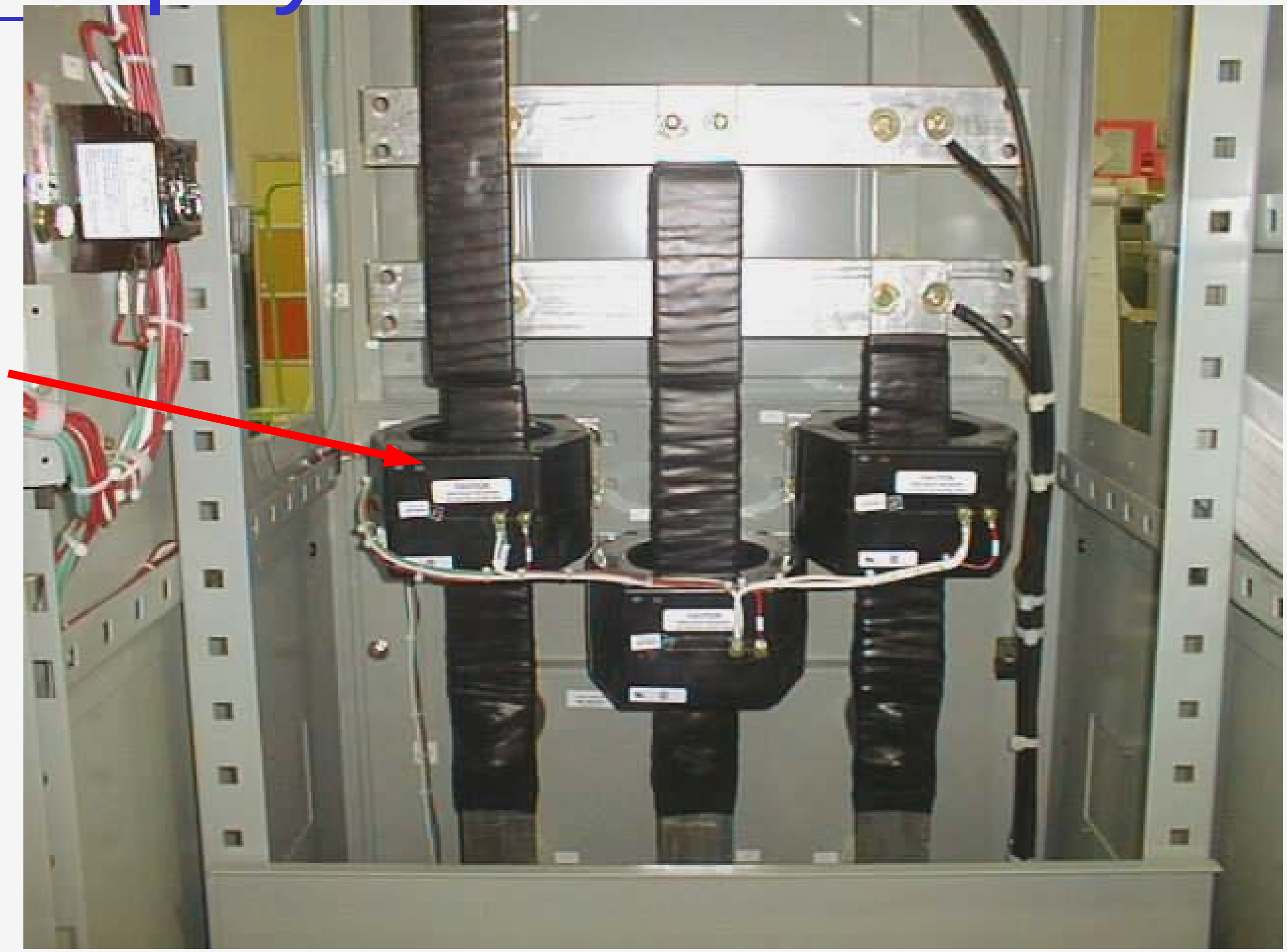
- From PSRC CT Saturation Calculator
- Relay will see ~42% of ideal secondary current for 10.1 pu phase fault

Neutral current vs. Ground current

CT physical dimensions

CT physical dimensions

CTs mounted in rear bus compartment



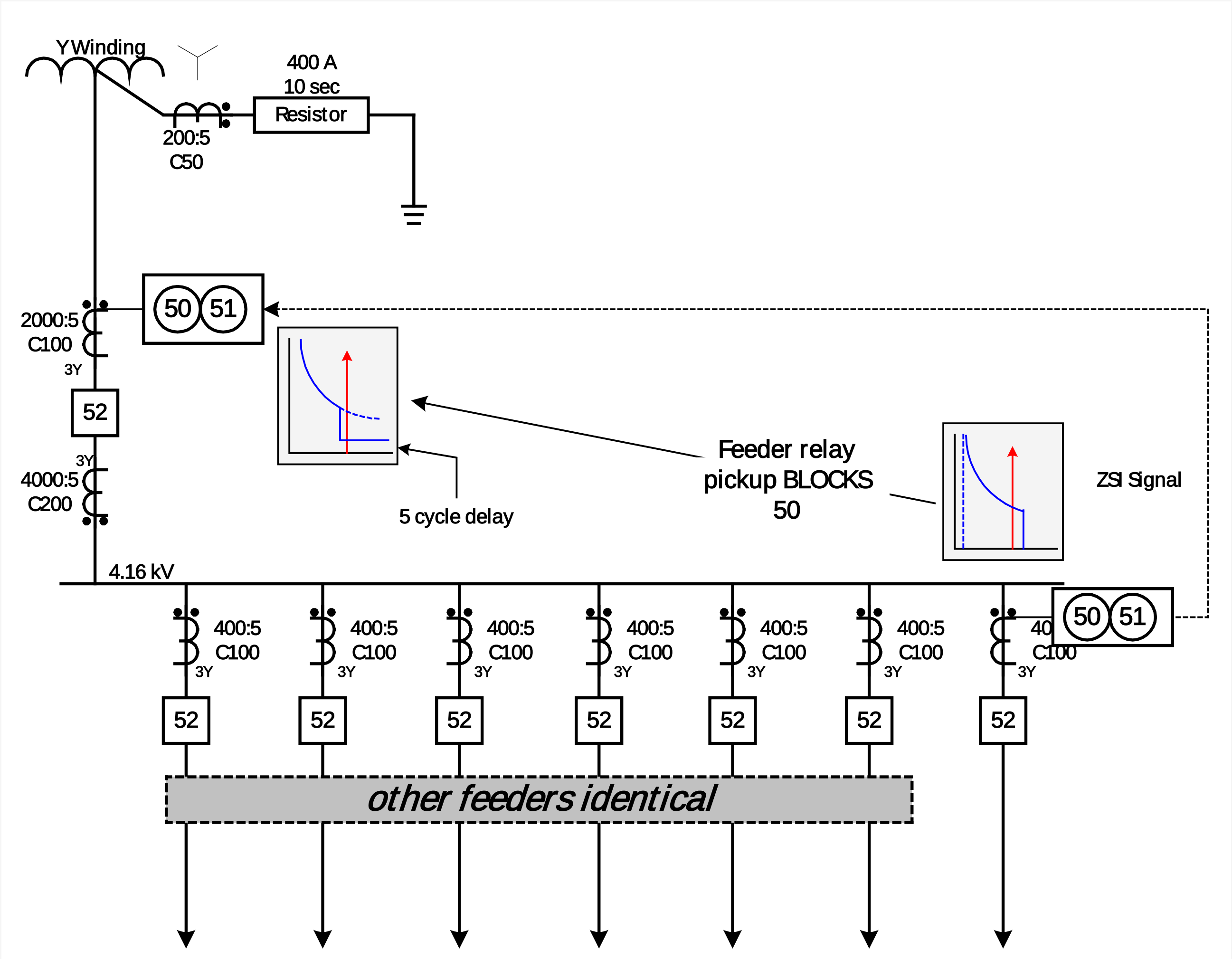
CT physical dimensions

Mounted in MCC

Bus protection methods

- Most common:
  - Zone sequence interlocking (ZSI)
  - High-impedance differential
  - Low-impedance differential

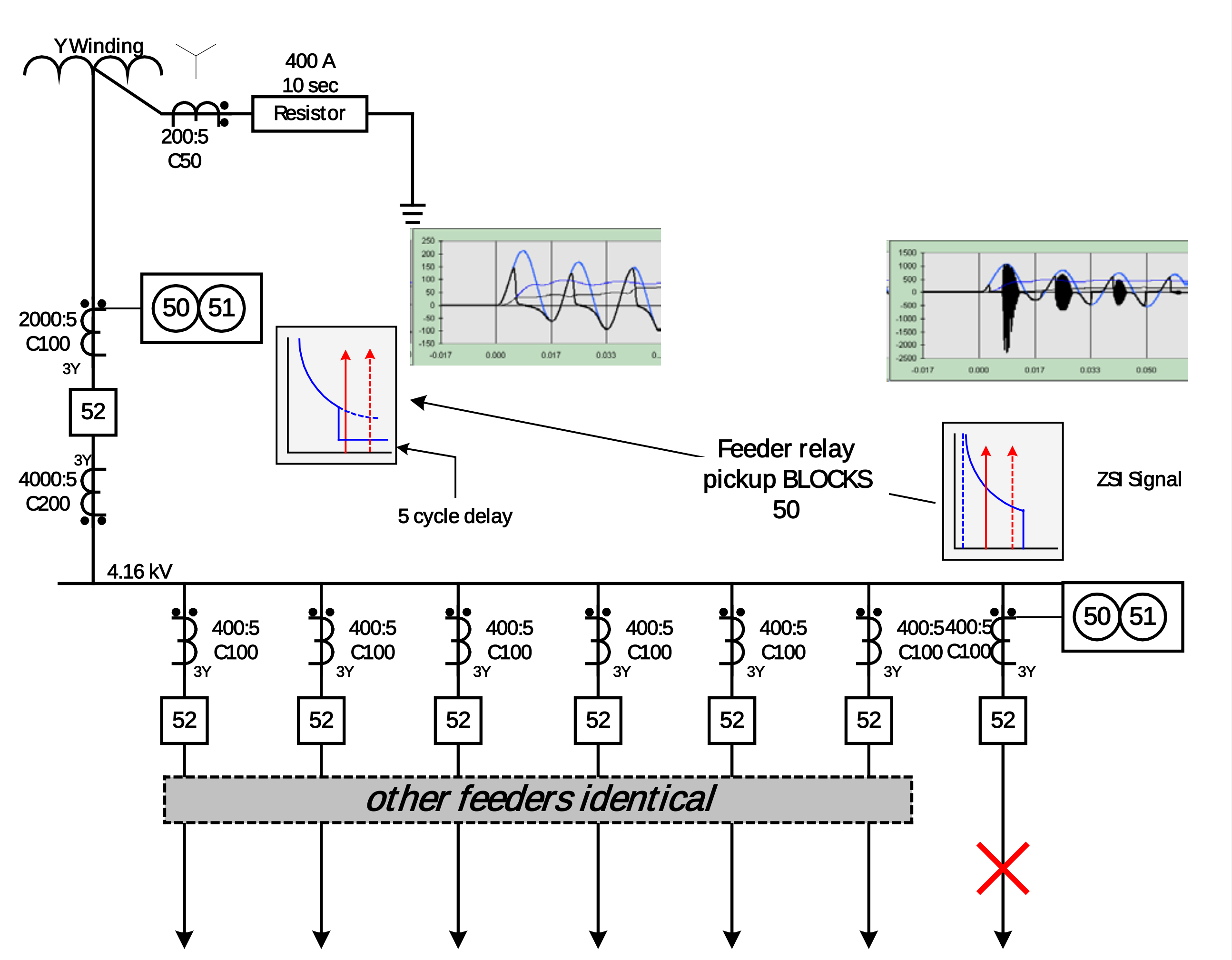
Zone sequence interlocking



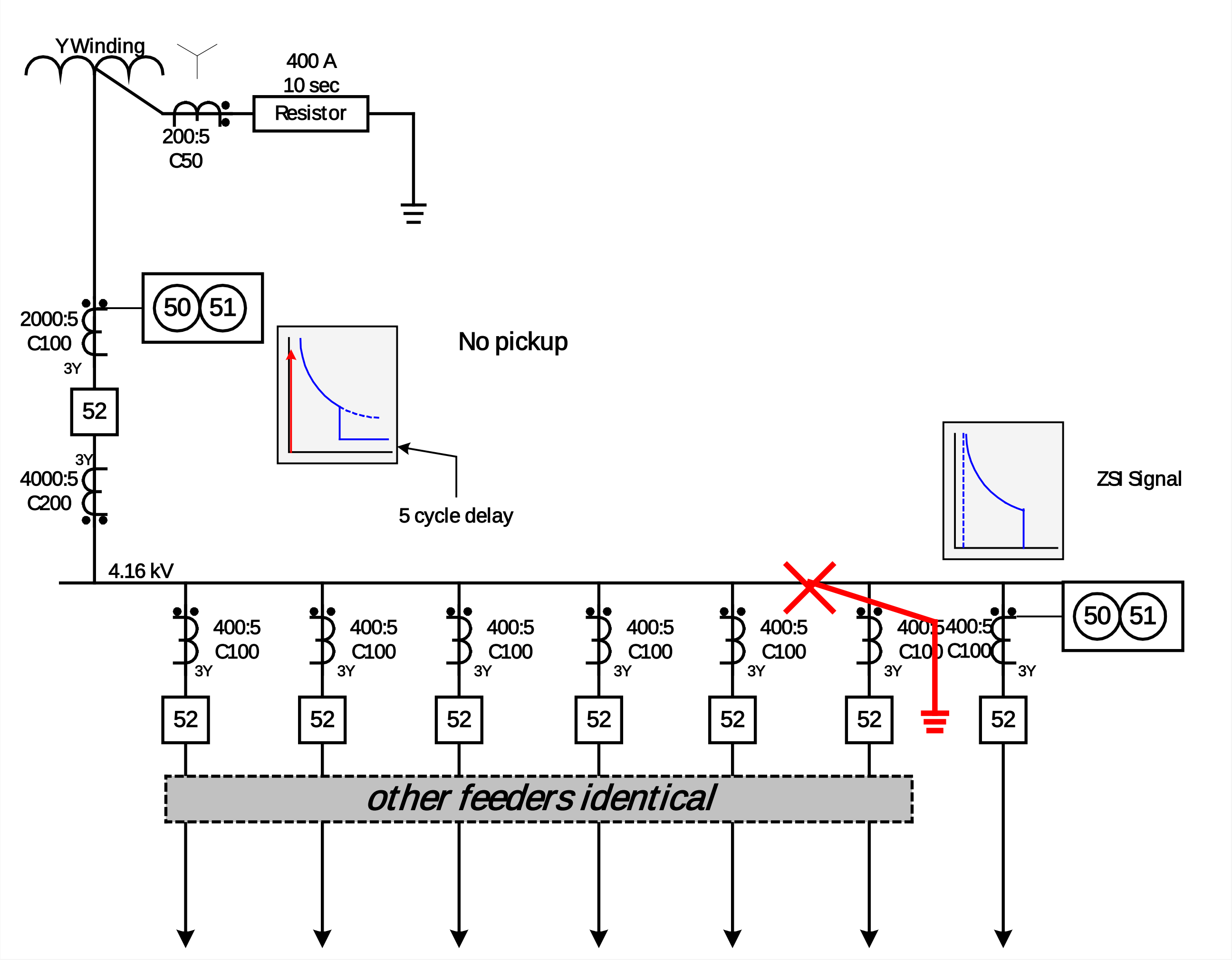
ZSI

- Arc flash
  - – 5 cycle op + 5 cycle breaker = 10 cycles
  - – IE = 9.03 cal/cm2 (Category 3)
- CT requirements
  - – Uses the same feeder CTs as for overcurrent

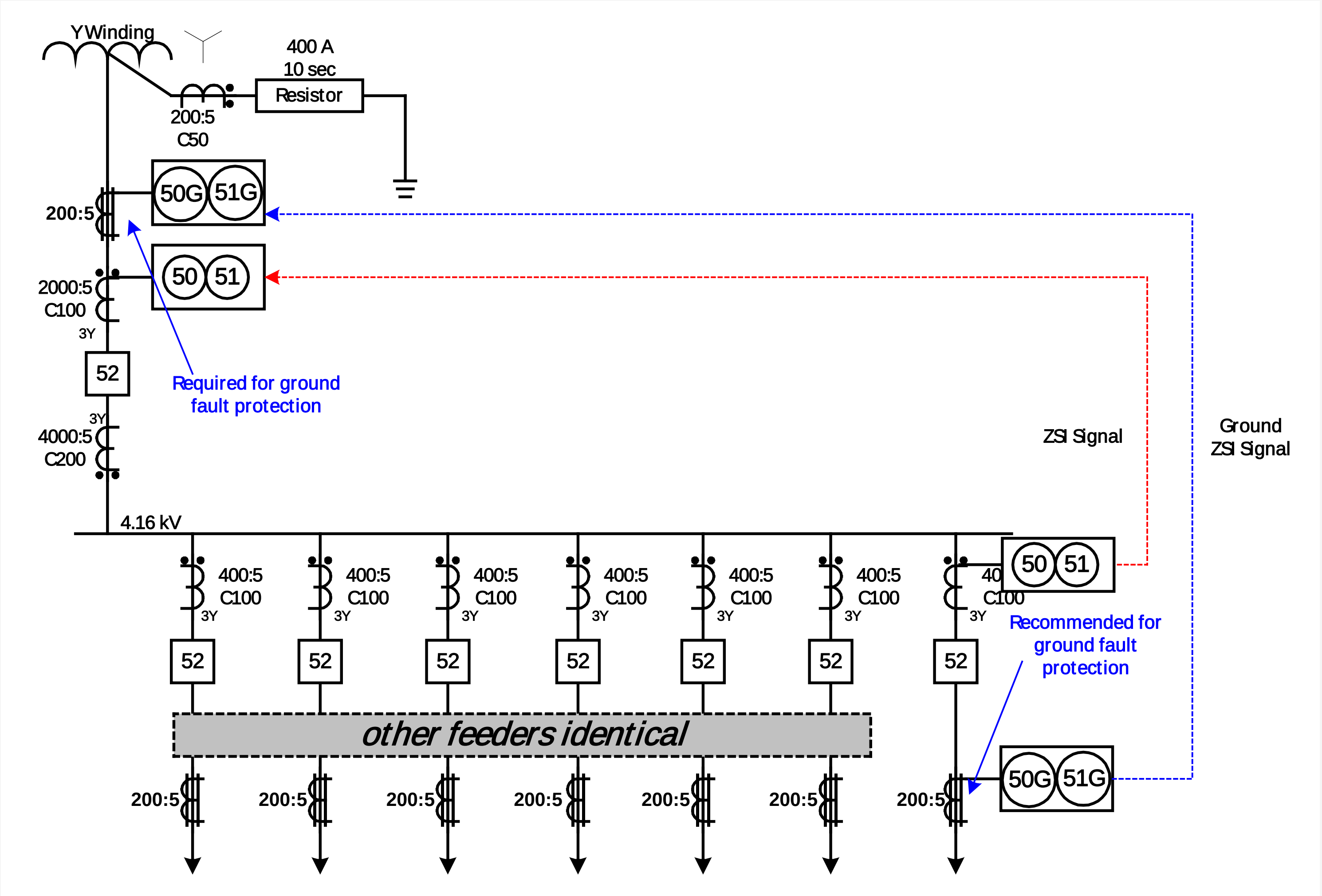
ZSI phase fault



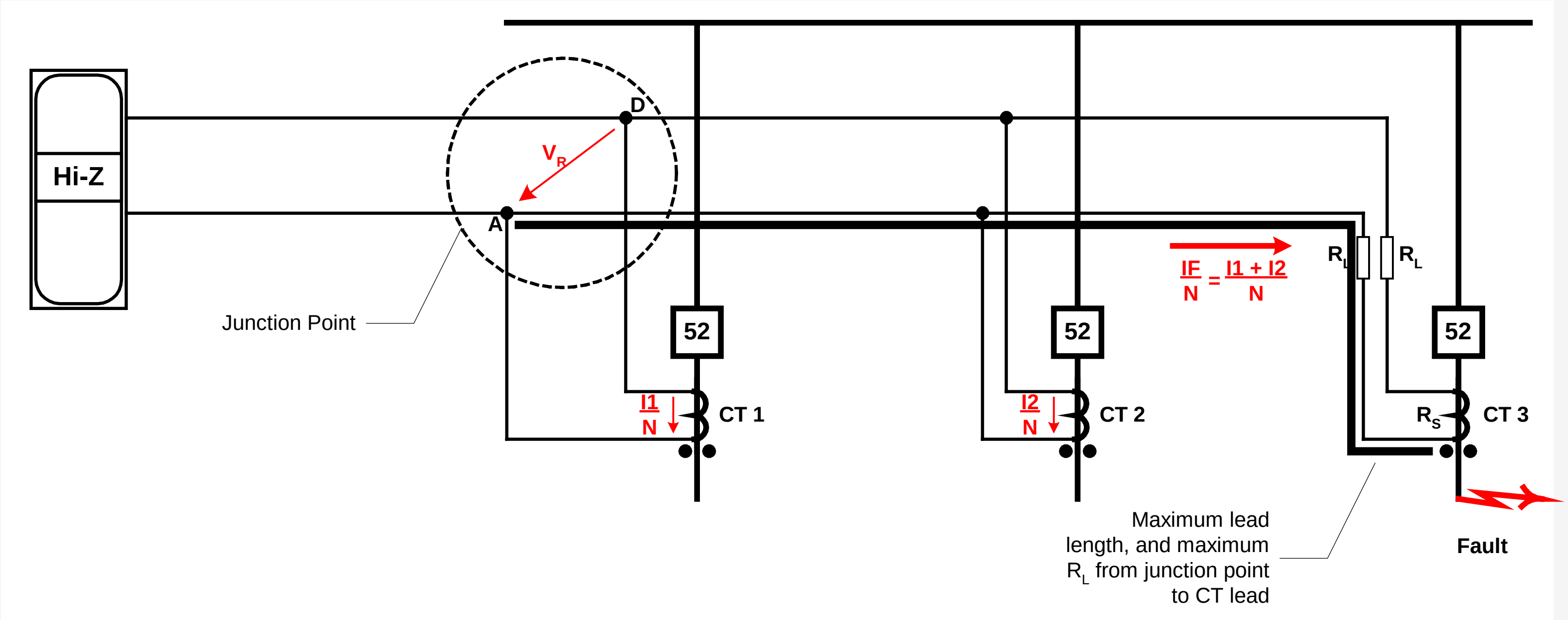
ZSI ground fault



ZSI: complete



High-impedance differential



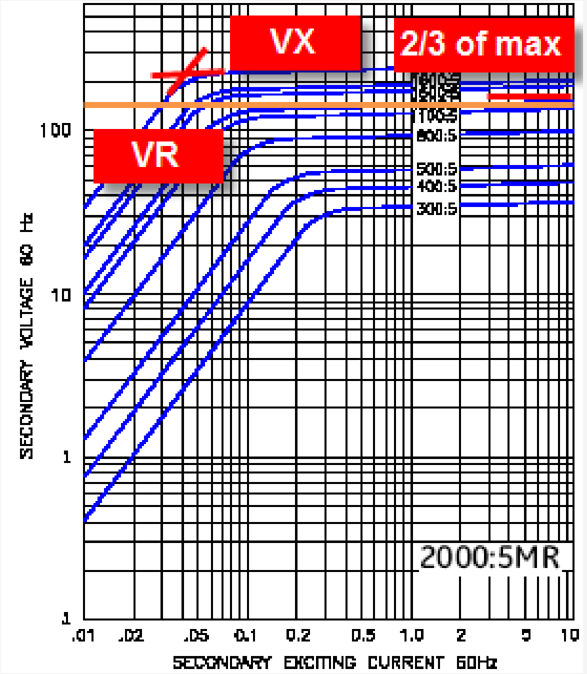
High-impedance

- Arc flash
  - 1 cycle op + 5 cycle breaker = 6 cycles
  - IE = 5.4 cal/cm2 (Category 2)
- CT requirements
  - Dedicated CTs
  - Same accuracy class
  - Same turns ratio (full ratio ideal)
  - Identical secondary burden

High-impedance settings

$$V_R = (k)(1.6)(R_S + PR_L)\frac{I_F}{N}$$

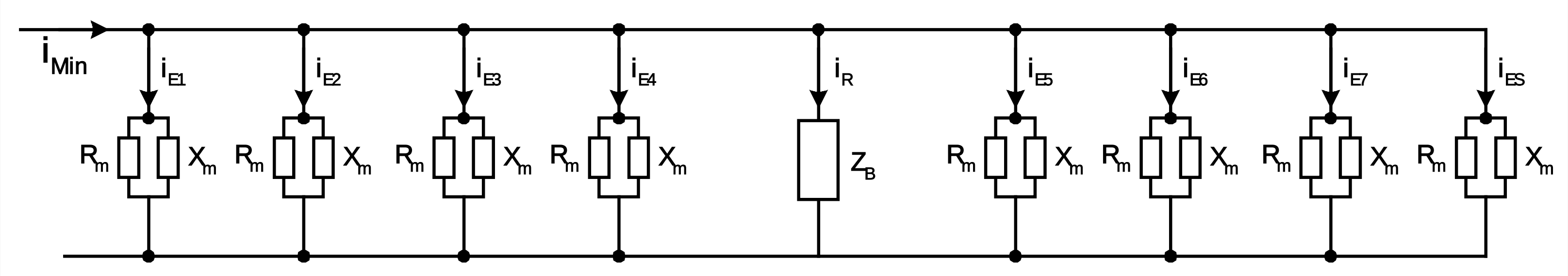
- $V_R < V_X$ worst CT
- $V_R <$ 67% of V_E @ 10A of worst CT



CT selection

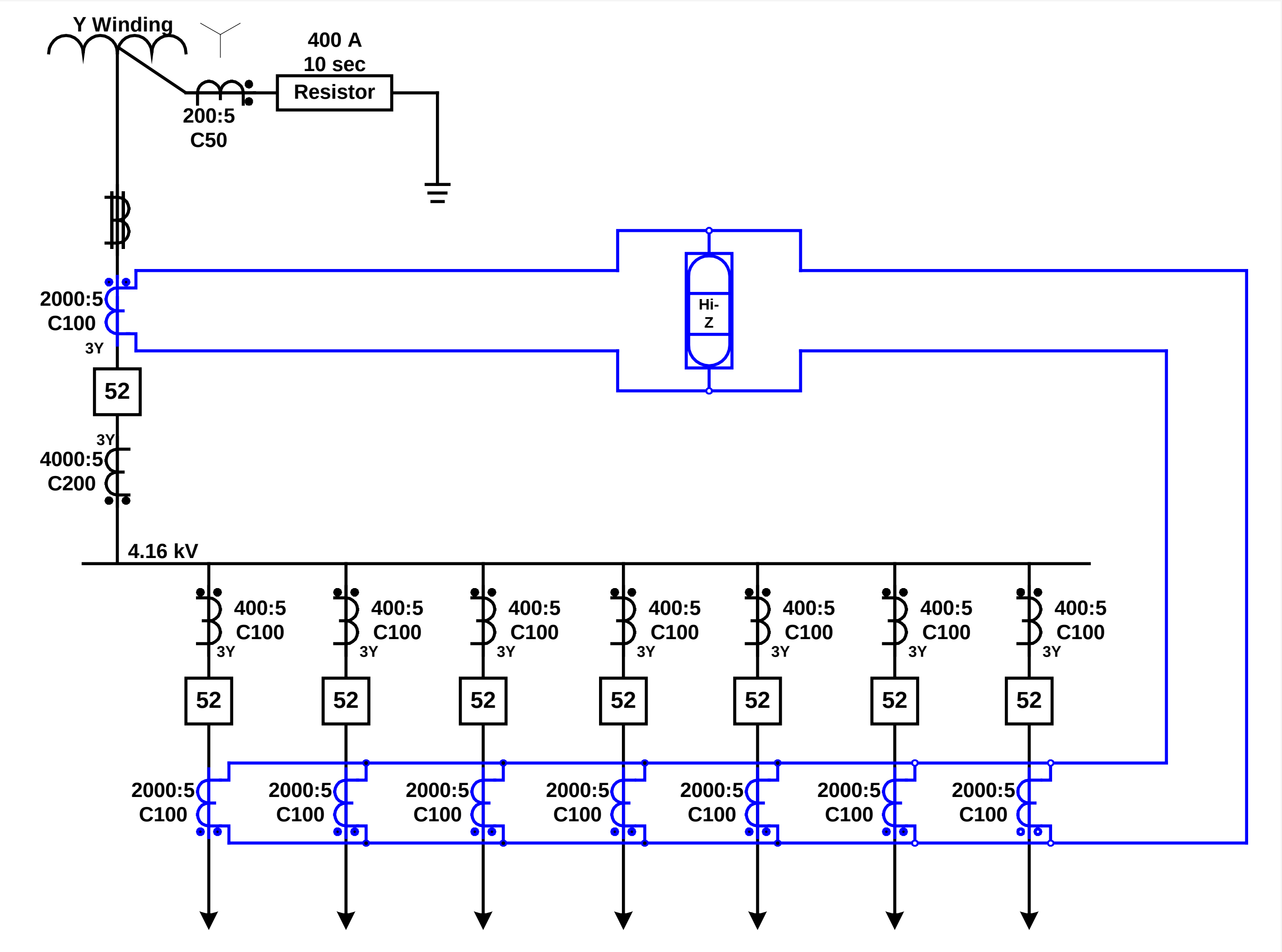
CT Primary Rating	Accuracy Class	Secondary Resistance	Saturation Voltage	67% of Maximum Voltage	k	Setting
1500	C100	0.611	120	103	0.70	120
1600	C100	0.652	128	110	0.70	118
2000	C100	0.815	155	132	0.76	120
2500	C100	0.974	145	177	0.77	110
3000	C100	1.168	175	133	0.82	112
1200	C200	0.387	193	147	0.80	130
1500	C200	0.608	235	191	0.83	142
1600	C200	0.649	251	204	0.84	141
2000	C200	0.588	220	167	0.87	109
2500	C200	0.735	286	204	0.90	106
3000	C200	1.105	326	249	0.90	119
3200	C200	0.859	193	168	0.88	90

High-impedance: ground fault

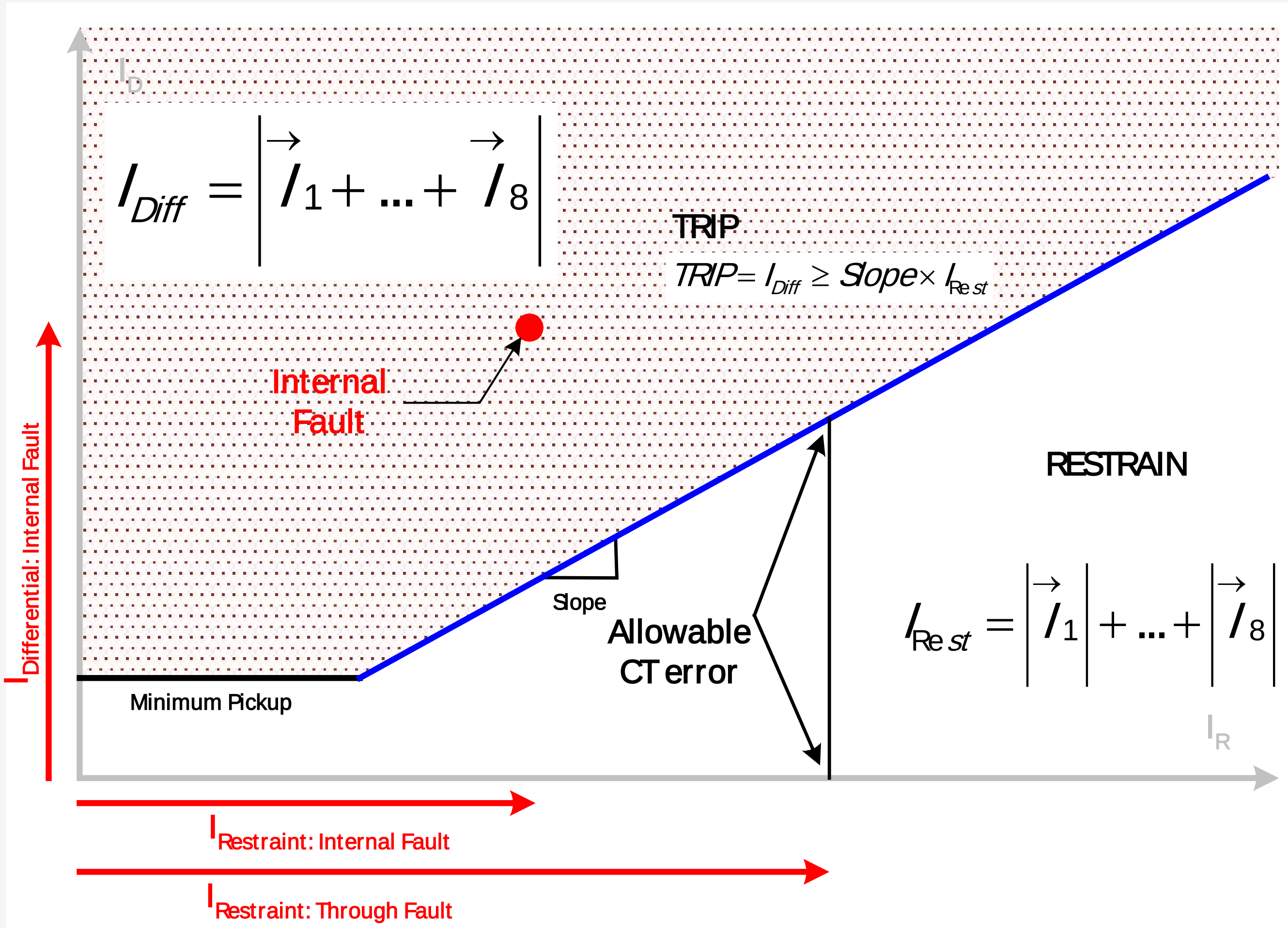


- Minimum operating current for internal fault: 0.028 pu
- Minimum ground fault current: 0.115 pu
- Adequate for ground fault protection

High-impedance: complete



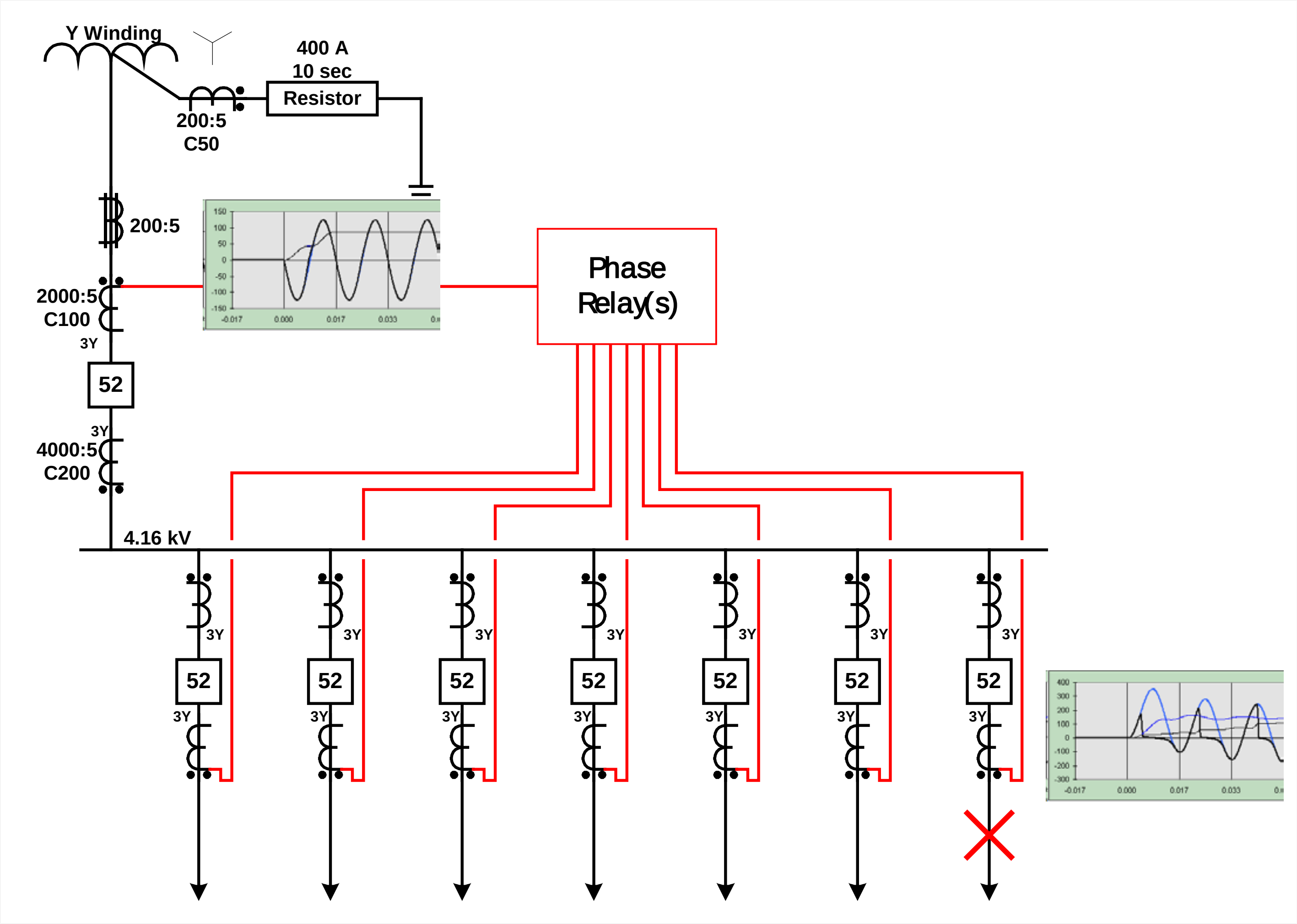
Low-impedance differential



Low-impedance

- Arc flash
  - 1 cycle op + 5 cycle breaker = 6 cycles
  - IE = 5.4 cal/cm2 (Category 2)
- CT requirements
  - Different turns ratio, accuracy class acceptable
  - Effect of CT saturation impacts settings
  - Calculate impact of different CTs on settings

Calculating settings

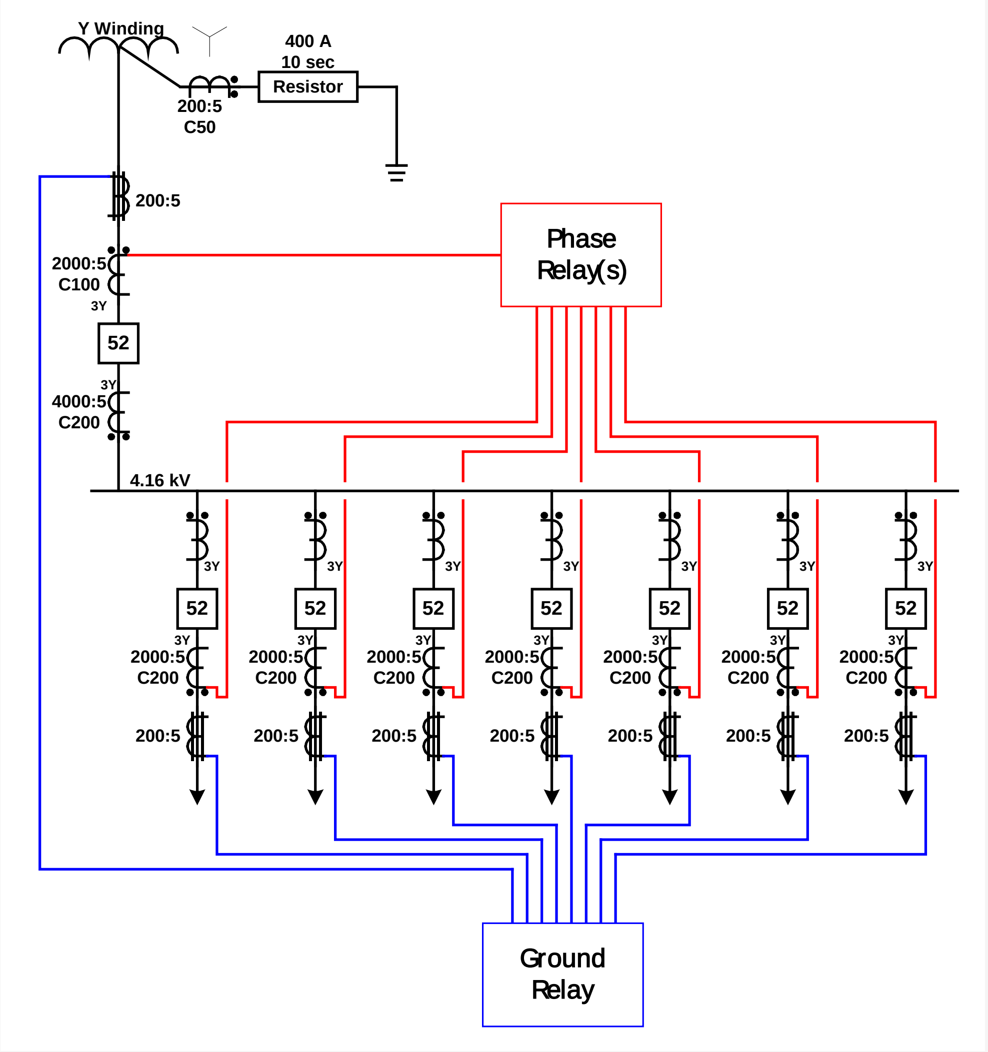


CT selection

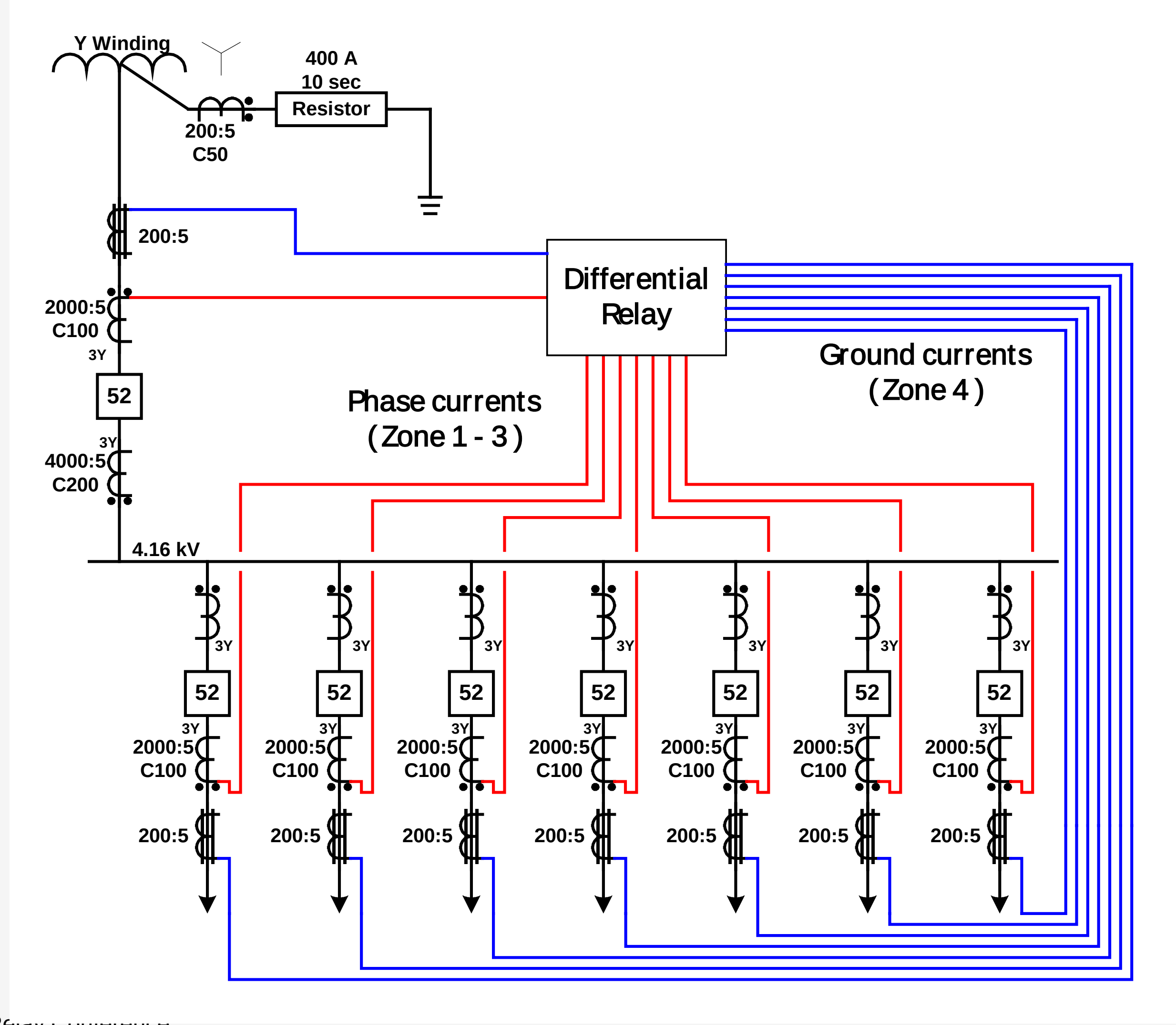
CT Primary Rating	Accuracy Class	Output	Differential Current	Restraint Current	Minimum Slope
400	C100	12%	88%	112%	78%
1200	C50	26%	74%	126%	58%
1600	C100	40%	60%	140%	43%
2000	C100	46%	54%	146%	37%
3000	C100	47%	53%	147%	36%
1200	C200	48%	52%	148%	35%
1600	C200	64%	36%	164%	22%
2000	C200	63%	37%	163%	23%
2500	C200	83%	17%	183%	9%
3000	C200	86%	14%	186%	7%

Low-impedance

- Phase differential pickup > 0.115 pu ground fault current
- Requires ground differential scheme



Low-impedance differential



Comparing bus protection

Zone sequence interlocking	High-impedance differential	Low-impedance differential
Separate protection schemes for phase and ground	Same protection scheme for phase and ground	Separate protection schemes for phase and ground
No special CT requirements	Extensive CT requirements	Careful selection of CTs
May require core balance CTs for ground protection	Requires dedicated CTs	Requires core balance CTs for ground protection
Retrofit: - core balance CTs if necessary - communications wiring for blocking signal	Retrofit: - Dedicated CTs for scheme - CT wiring to junction point.	Retrofit: - May require CT replacement - Wiring from every CT to relay location - Core balance CTs for ground
10 cycle total clearing time	6 cycle total clearing time	6 cycle total clearing time
Incident energy (this example): 9.03 cal/cm²	Incident energy (this example): 5.4 cal/cm²	Incident energy (this example): 5.4 cal/cm²

Summary

- Any of these bus protection schemes will reduce incident energy for arc flash
- Any of these schemes can work for ground fault protection of bus
- These schemes only work if CT issues are properly addressed

Bus protection performance is all about the CTs!

For more information

- C37.110 IEEE Guide for the Application of Current Transformers Used for Protective Relaying Purposes
- IEEE PSRC CT Saturation Calculator www.pes-psrc.org
- Blackburn, Protective Relaying, Principles and Applications
- IEEE Recommended Practice for Protection and Control of Industrial and Commercial Power Systems (the Buff Book)