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Neutral Grounding Resistors

How to size and specify

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Standards for NGRs

- IEEE 32-1972 (R 1990) "IEEE Standard Requirements, Terminology, and Test Procedures for Neutral Grounding Devices"
- IEEE C57.32-2015 "IEEE Standard for Requirements, Terminology, and Test Procedures for Neutral Grounding Devices"
- CSA C22.2 No. 295-15 "Neutral grounding devices"
- IEC 60076 25

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Terminology

- Rated Voltage
- Rated Current
- Rated Time
- Maximum Temperature
- Temperature Coefficient of Resistance

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Rated Voltage

Since the active material used in resistors has an appreciable temperature coefficient, the resistance is materially changed during the time of operation causing the current to decrease. When the product of the fault current and resistance at 30 °C exceeds 80% of the line-to-neutral voltage of the circuit, the resistor shall be rated for constant voltage and the rated voltage shall be taken equal to the line-to-neutral voltage.

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Rated Voltage test

System Voltage	Neutral Voltage	IEEE C57.32 Test (kV)	CSA Test (kV)
480	277	1.554	1.554
600	347	1.694	1.694
1200	692	3.557	5
2400	1386	5.116	5
4160	2400	7.400	15
7200	4156	11.351	19
13800	7967	19.925	26
14400	8313	20.704	36
27600	15935	37.853	60

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Rated Current

- The initial current through the resistor.

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Rated Time

- Rated time shall be 10 seconds, 1 minute, 10 minutes, extended time, or continuous(steady-state).
- Extended time shall not exceed an average of 90 days per year.

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10 s and 1 min. ratings

- The rated-time temperature rise of 10-second and 1-minute devices shall be taken as the sum of the steady-state rise and the additional rise caused by the application of rated voltage for rated time.

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Ten-Minute Ratings

- The rated-time temperature rise of 10-minute devices shall be taken as the sum of the steady-state rise, if specified, otherwise 0°C rise if not specified, and the additional rise caused by the application of rated voltage for rated time.

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Extended-Time Ratings

- The rated-time temperature rise of extended time devices shall be taken as the temperature rise above ambient resulting from application of rated voltage for rated time.

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Steady-State Time Ratings

- The rated temperature rise of a steady-state device shall be taken as the temperature rise above ambient resulting from application of rated voltage for rated time.

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Maximum Temperature

Temperature Rise			
		IEEE	CSA
Steady State for continuous current ratings	Steady state (hot-spot)	385	375
Rated Time for thermal current ratings less than Steady-State	Extended-time (hot-spot)	610	600
	Ten-minute (hot-spot)	610	600
	Less than 10 min (hot-spot)	760	750

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Temperature Coefficient of Resistance

$$\alpha = \frac{R_2 - R_1}{R_1(\theta_2 - \theta_1)} \qquad R_2 = R_1\left[1 + \alpha(\theta_2 - \theta_1)\right]$$

- Where;
  - R_1 is the initial resistance(Ω)
  - R_2 is the final resistance(Ω)
  - T_1 is the Initial Temperature (^oC)
  - T_2 is the final Temperature(^oC)
  - α is the Temperature coefficient of resistance(1/ ^oC)

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Temperature Coefficient of Resistance

Alloy	Temperature Coefficient of Resistance (1/°C) α	
AISI 304	0.00092	
AISI 430	0.00146	
18SR	0.000358	
1JR	0.00024	

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Example 1

347 V 5 A Continuous resistor.

Rated Voltage= 347 V

Rated Current = 5 A

Rated Time = Continuous

Max Temperature Rise = 385^{o}C

Temperature Coefficient of Resistance = Not Specified

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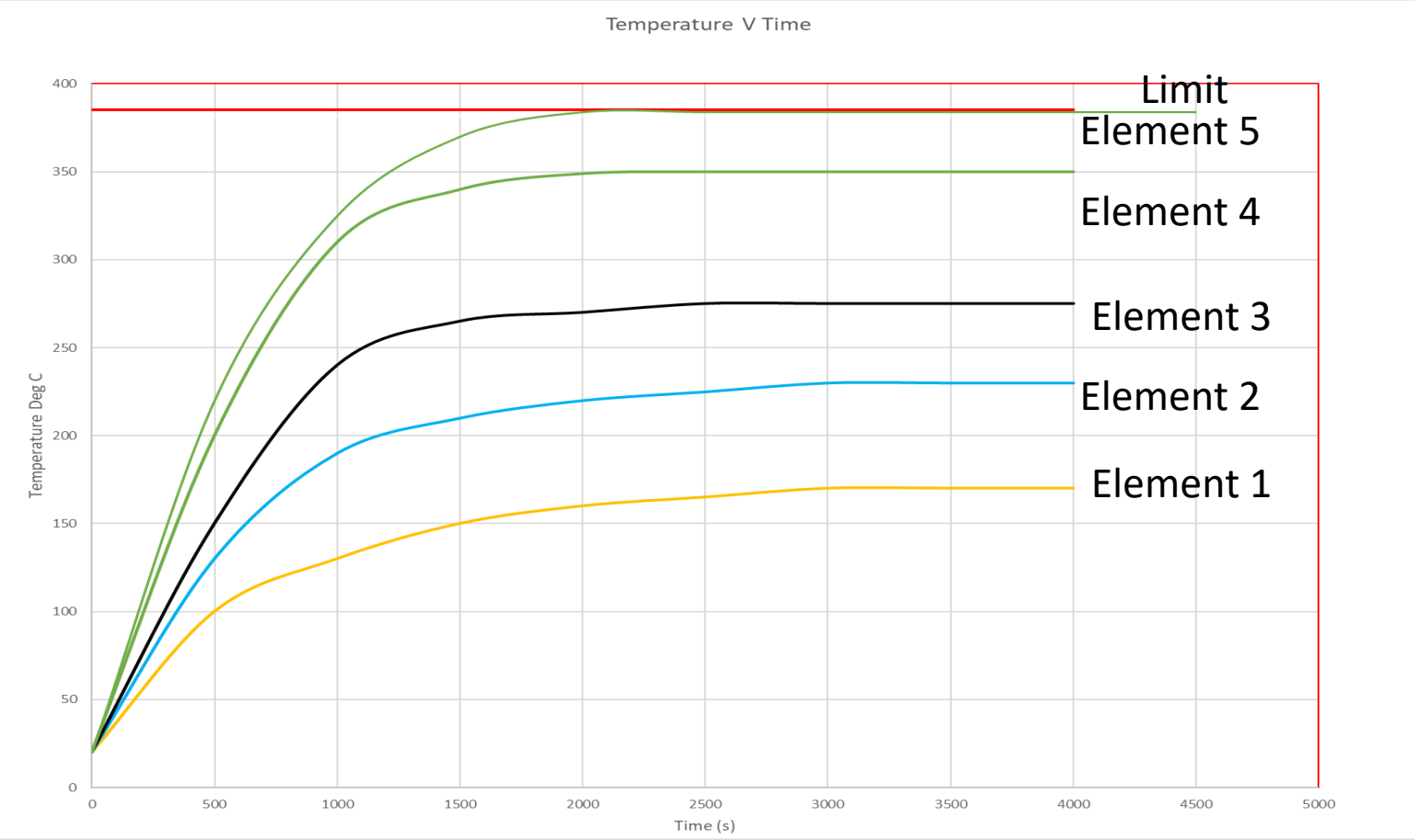
Find correct element



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Resistance change

69.4 Ω 385 °C

$$R_2 = R_1\left[1 + \alpha(\theta_2 - \theta_1)\right]$$

Alloy	Temperature Coefficient of Resistance (1/°C) α	Percent change in Resistance	Current decrease as a percentage
AISI 304	0.00092	35% Increase to 93.98 Ω	26.15% to 3.7 A
AISI 430	0.00146	56 % Increase to 108.41 Ω	36% to 3.2 A
18SR	0.000358	13.7 % Increase to 78.96 Ω	12% to 4.39 A
1JR	0.000241	9 % Increase to 75.8 Ω	9.1 % to 4.6 A

First 2 rows violate CSA Standard as the current decreases by more than 20%

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Example 2

2400 V 400 A 10 s resistor.

Rated Voltage= 2400 V

Rated Current = 400 A, continuous portion not specified

Rated Time = 10 s.

Max Temperature Rise = 760^{o}C

Temperature Coefficient of Resistance = Not Specified

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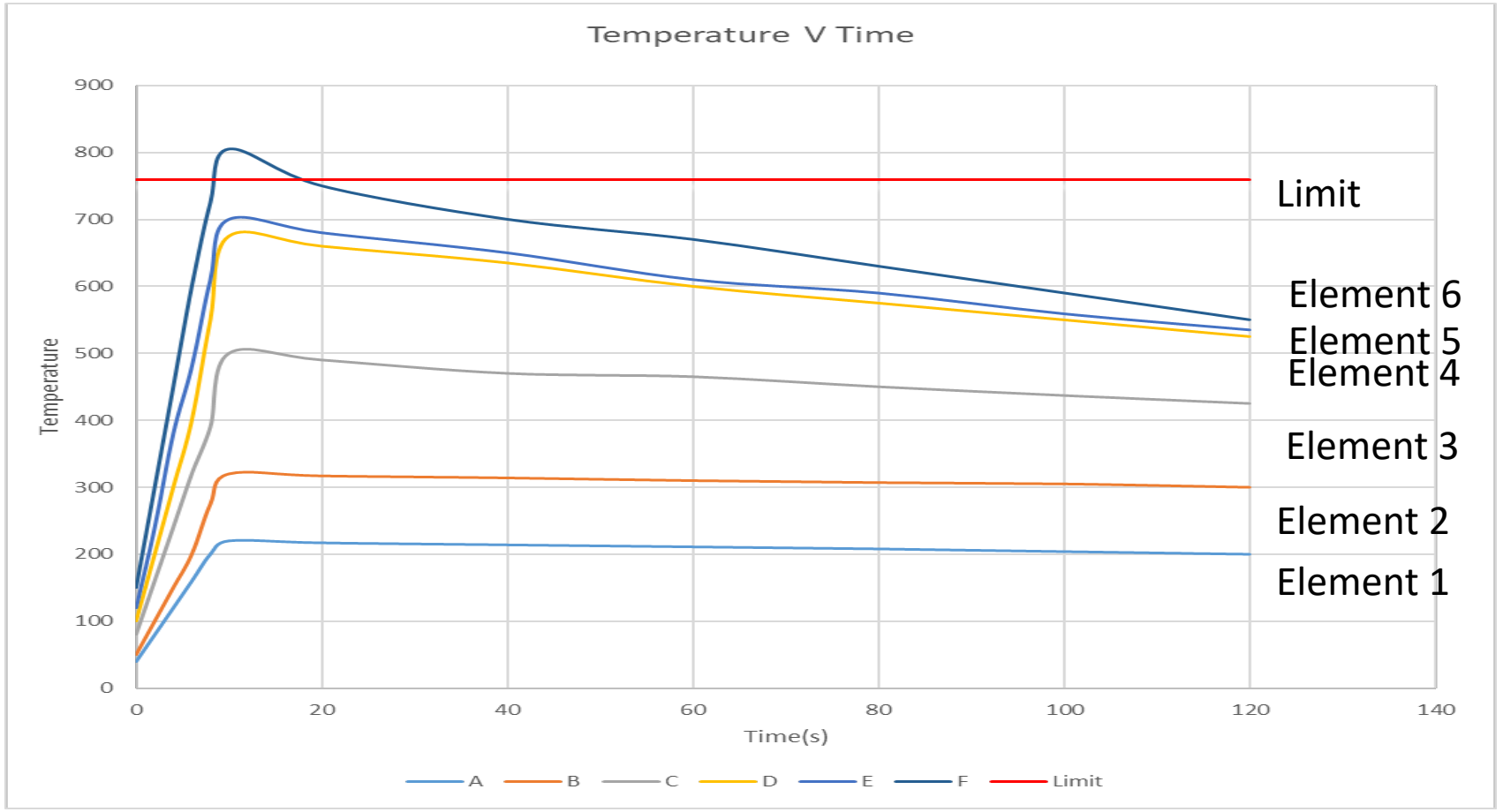
Find correct element



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Resistance change

6 Ω 760°C

$$R_2 = R_1\left[1 + \alpha(\theta_2 - \theta_1)\right]$$

Alloy	Temperature Coefficient of Resistance (1/°C) α	Percent change in Resistance	Current decrease as a percentage
AISI 304	0.00092	70% Increase to 10.2 Ω	41.1% to 235 A
AISI 430	0.00146	110 % Increase to 12.65 Ω	52.5% to 189 A
18SR	0.000358	27 % Increase to 7.63 Ω	21% to 314 A
1JR	0.000241	18 % Increase to 7.1 Ω	15.4 % to 338 A

First 3 rows violate CSA Standard as the current decreases by more than 20%
First 2 rows violate IEEE C57.32 as resistance increases by more than 67%

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Example 3

2400 V 400 A 10 s resistor. 20 A continuous portion

Rated Voltage= 2400 V

Rated Current = 400 A, 20 A continuous

Rated Time = 10 s.

Max Temperature Rise = 760^{o}C

Temperature Coefficient of Resistance = Not Specified

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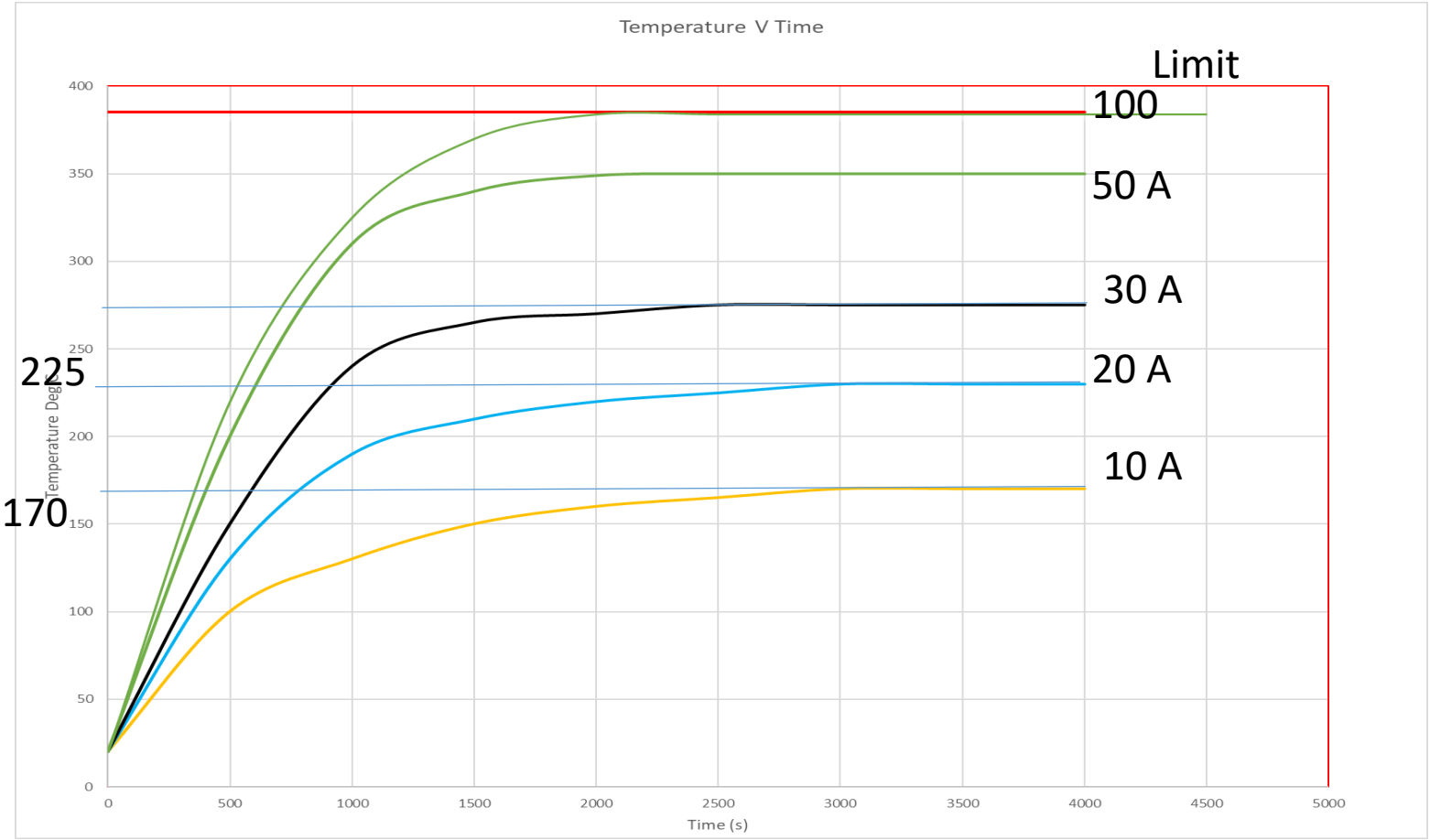
Properties of Element X(continuous)

Determine
Temperature rise
of 20 A continuous
Current ~ 225 ºC



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Find new temperature rise

- Max temperature rise of 760 ^{o}C
- The initial current of 20 A continuous produces a temperature Rise of 225 ^{o}C
- This initial current and temperature limits the temperature rise of a 400 A fault to 760 ^{o}C - 225 ^{o}C = 535 ^{o}C

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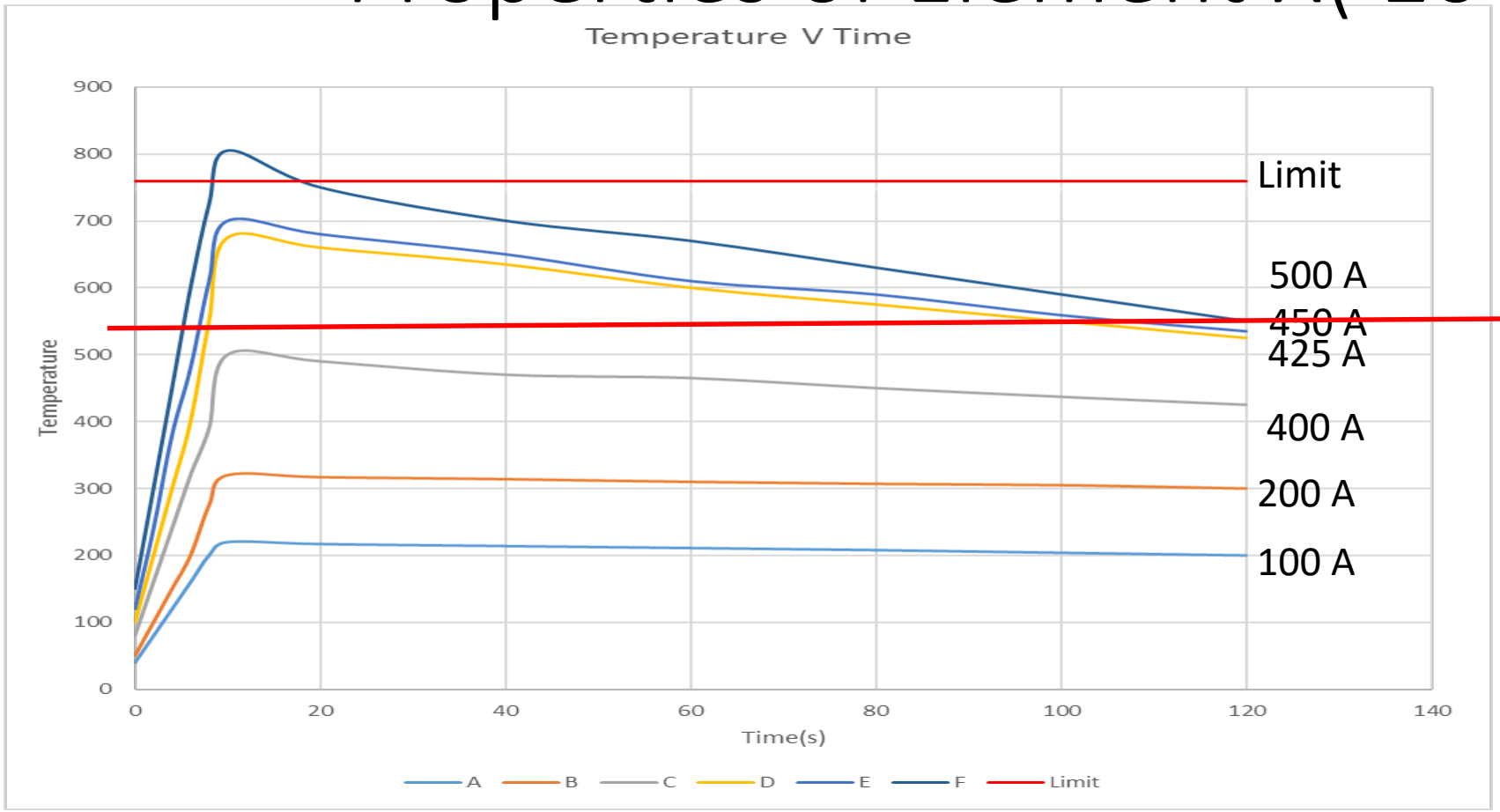
Properties of Element X(10 s)



Limit

500 A

450 A

425 A

400 A

200 A

100 A

New Temperature Rise limit

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Determine new Temperature rise limit

- The rated-time temperature rise of 10-second and 1-minute devices shall be taken as the sum of the steady-state rise and the additional rise caused by the application of rated voltage for rated time.
- Steady state rise = 225 ^{o}C
- Fault current for 10 s. = 500 ^{o}C
- Sum 725 ^{o}C < 760 ^{o}C

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Resistance change due to 20 A C

6 Ω 225°C

$$R_2 = R_1\left[1 + \alpha(\theta_2 - \theta_1)\right]$$

Alloy	Temperature Coefficient of Resistance (1/°C) α	Percent change in Resistance	Current decrease as a percentage
AISI 304	0.00092	20% Increase to 7.2 Ω	17 % to 331 A
AISI 430	0.00146	33 % Increase to 7.9 Ω	25% to 301 A
18SR	0.000358	8 % Increase to 6.5 Ω	7% to 370 A
1JR	0.000241	5 % Increase to 6.3 Ω	5 % to 380 A

Row 2 violate CSA Standard as the current decreases by more than 20%

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Resistance change

6 Ω 760°C

$$R_2 = R_1\left[1 + \alpha(\theta_2 - \theta_1)\right]$$

Alloy	Temperature Coefficient of Resistance (1/°C) α	Percent change in Resistance	Current decrease as a percentage
AISI 304	0.00092	70% Increase to 10.2 Ω	41.1% to 235 A
AISI 430	0.00146	110 % Increase to 12.65 Ω	52.5% to 189 A
18SR	0.000358	27 % Increase to 7.63 Ω	21% to 314 A
1JR	0.000241	18 % Increase to 7.1 Ω	15.4 % to 338 A

First 3 rows violate CSA Standard as the current decreases by more than 20%
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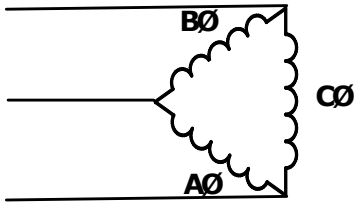
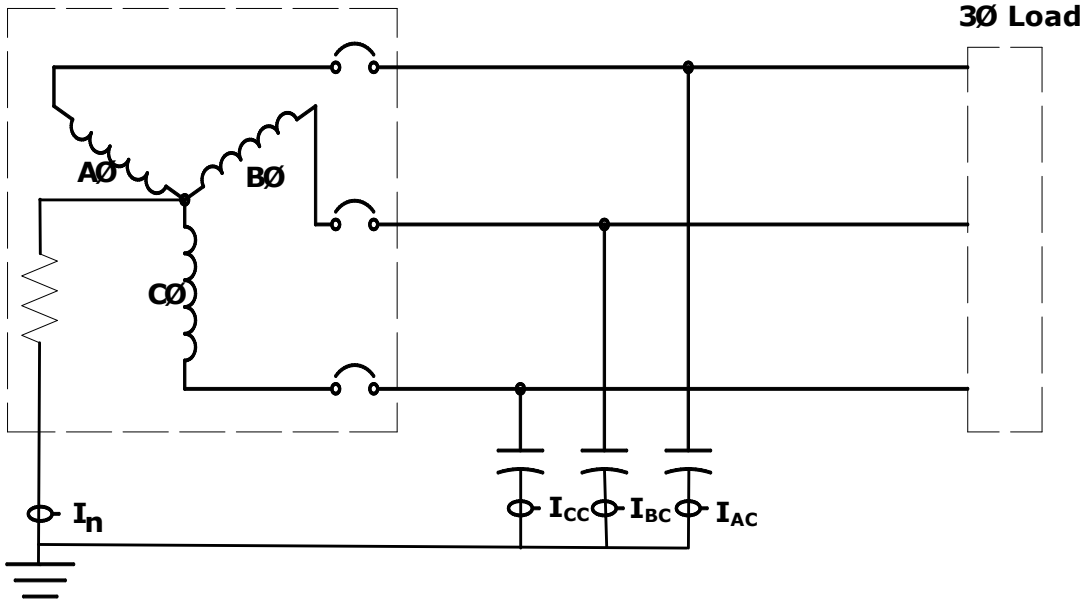
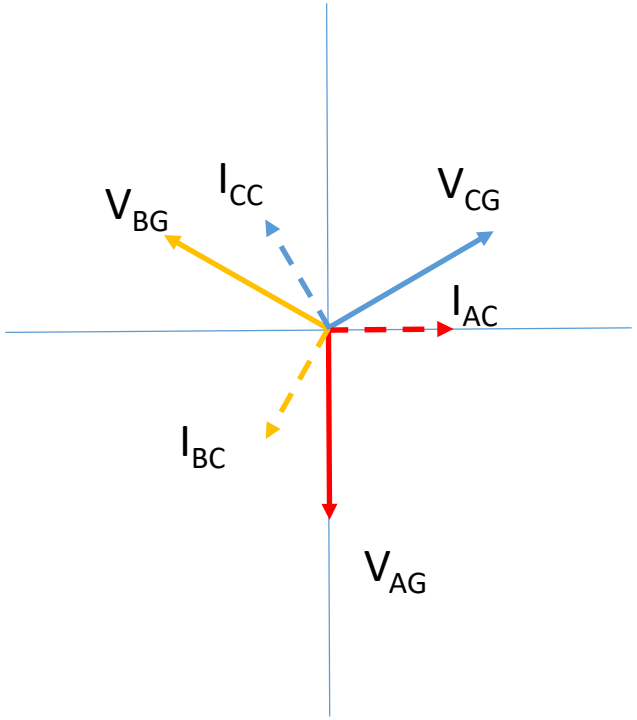
Capacitive charging current







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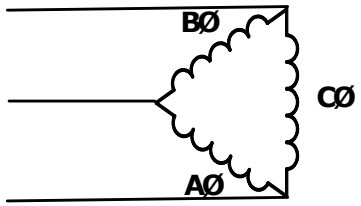
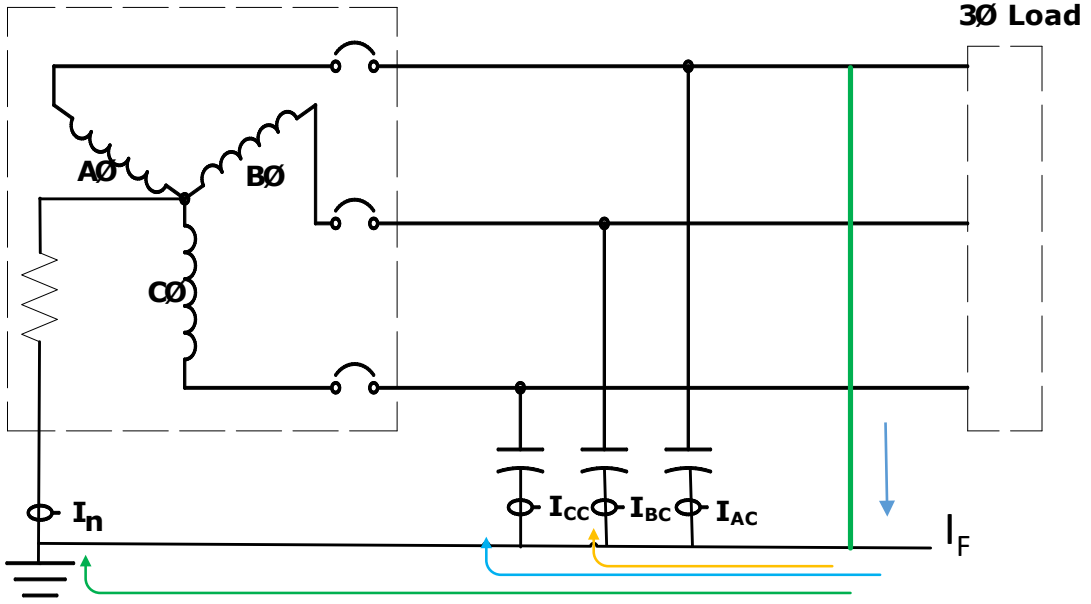
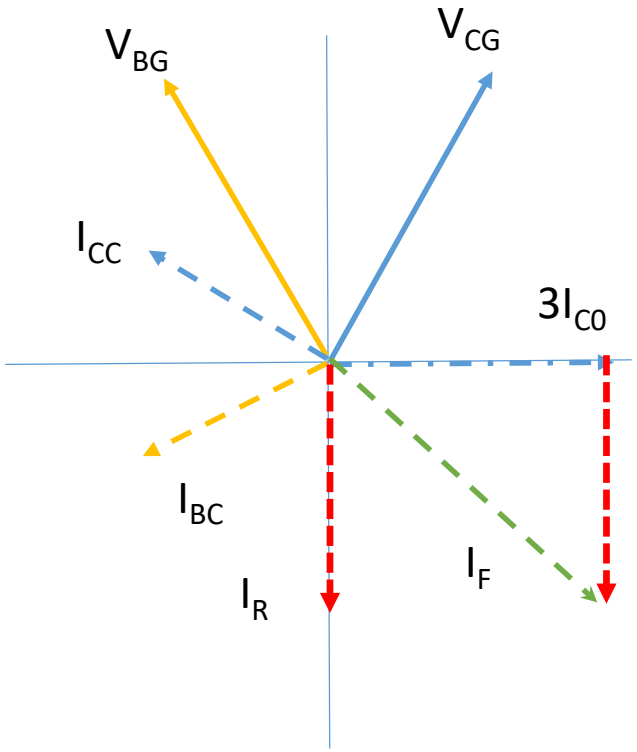
Capacitive charging current







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High Resistance Grounding

- Effective high resistance grounding $I_R \geq 3I_{CO}$
- $I_R \leq 10$ A
  - If Rated Voltage <5kV. [Arc Flash Mitigation]
  - If Rated Voltage >5kV [look at insulation levels]

Voltage		Insulation
< 5000		100 %
>5000	Ground fault on system < 1 min.	100 %
	1 min < t < 1 hour	133 %
	t > 1 hour	173%

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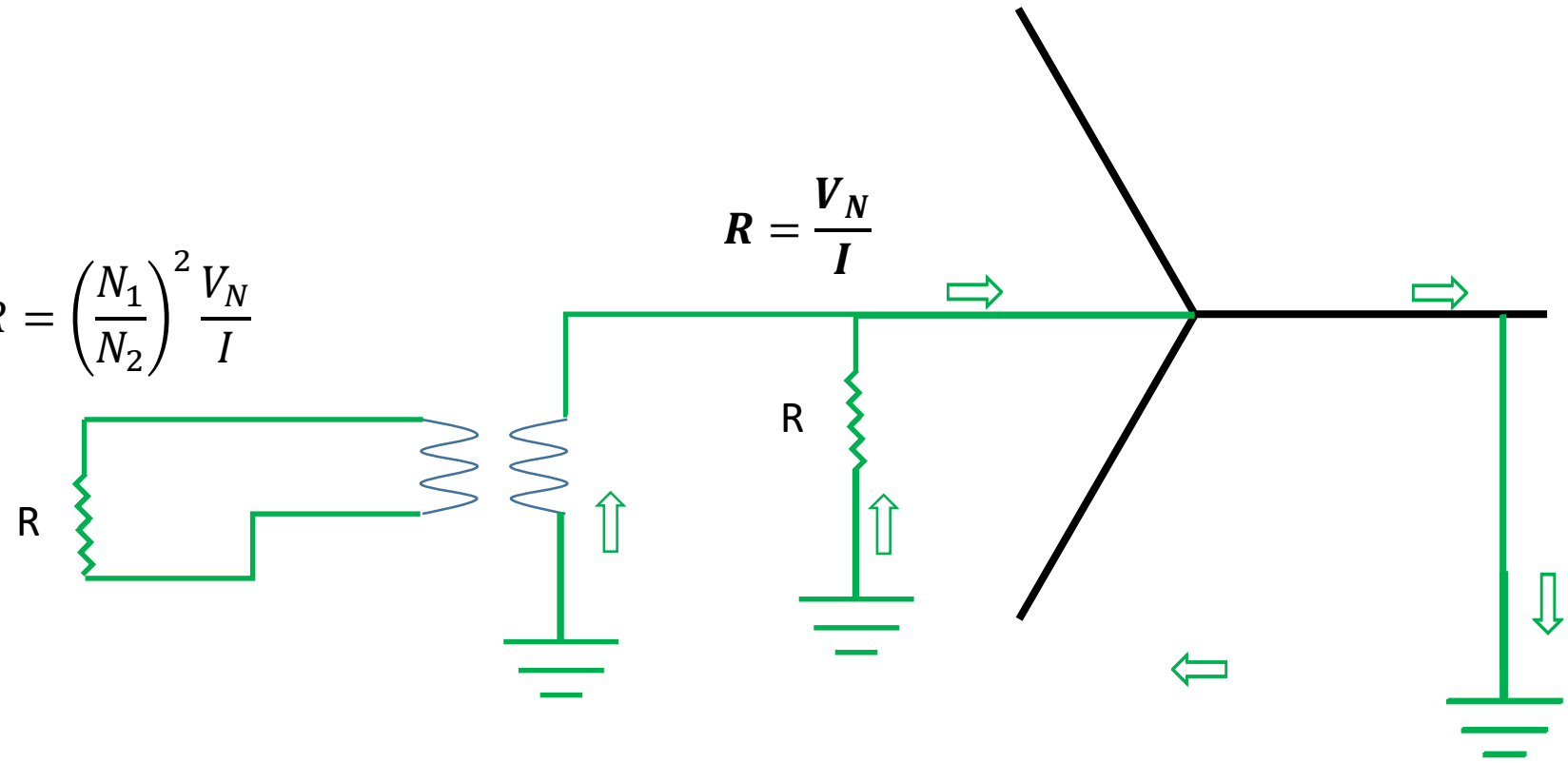
$$R = \left(\frac{N_1}{N_2}\right)^2 \frac{V_N}{I}$$

$$\boldsymbol{R = \frac{V_N}{I}}$$



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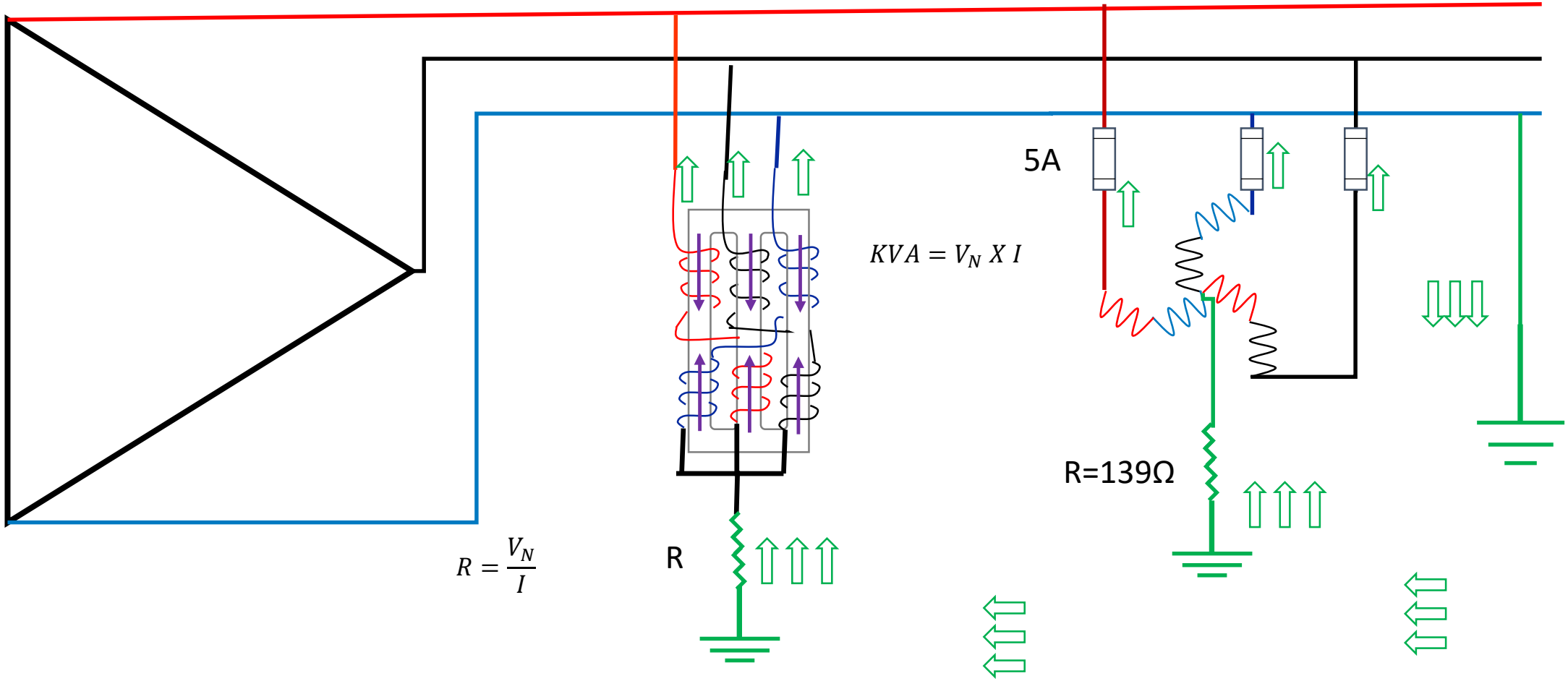

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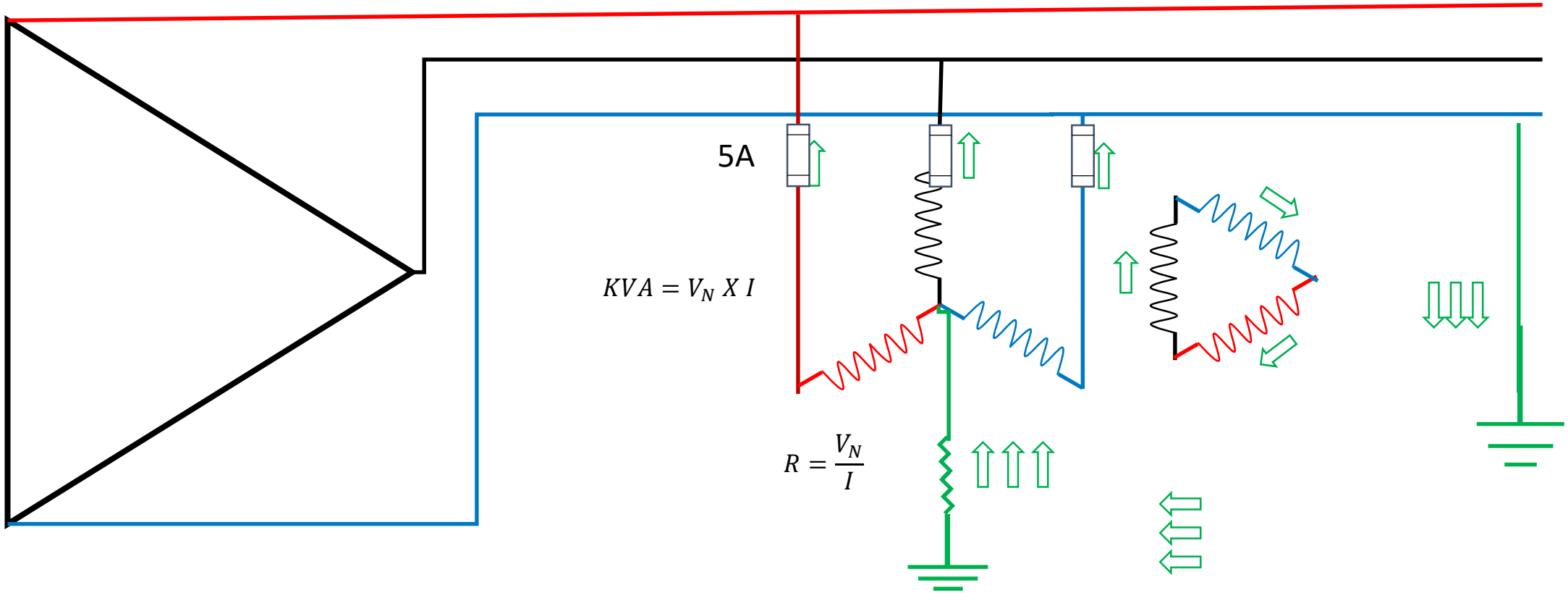

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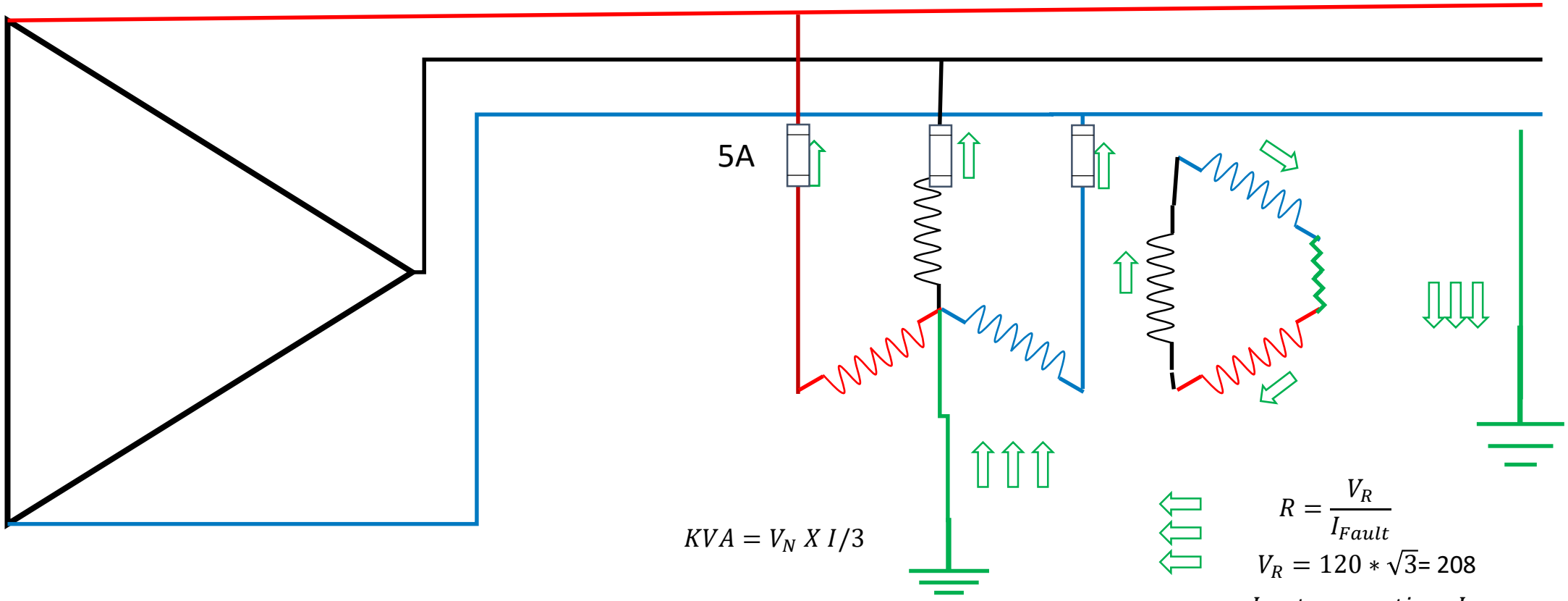

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Low Resistance Grounding

- If Charging Current > 10 A, rule out HRG

- Next step is to determine minimum pickup for ground fault on protection scheme
- Choose a safe value greater than the minimum pickup to set resistor current 3-5 X minimum pickup.

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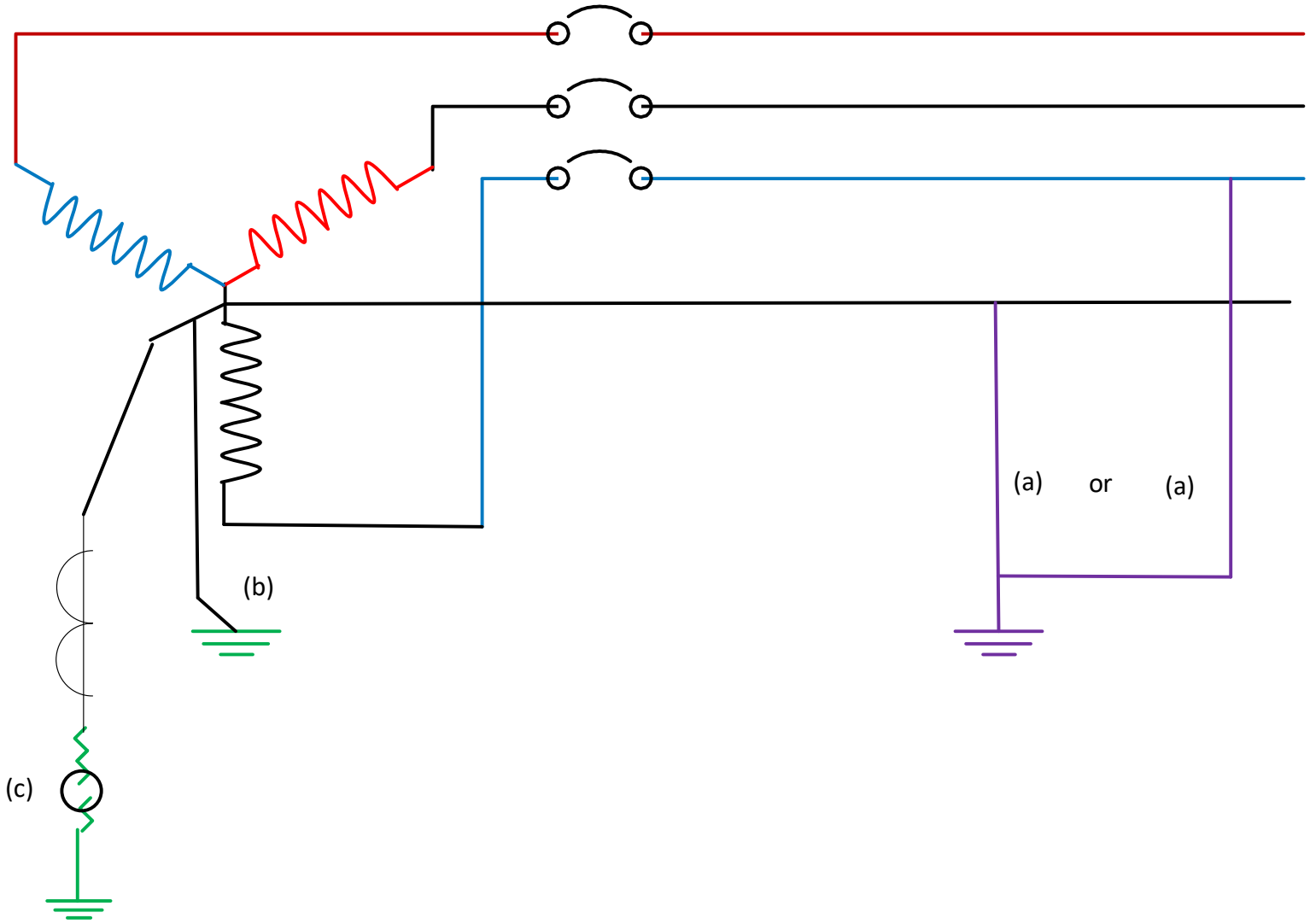

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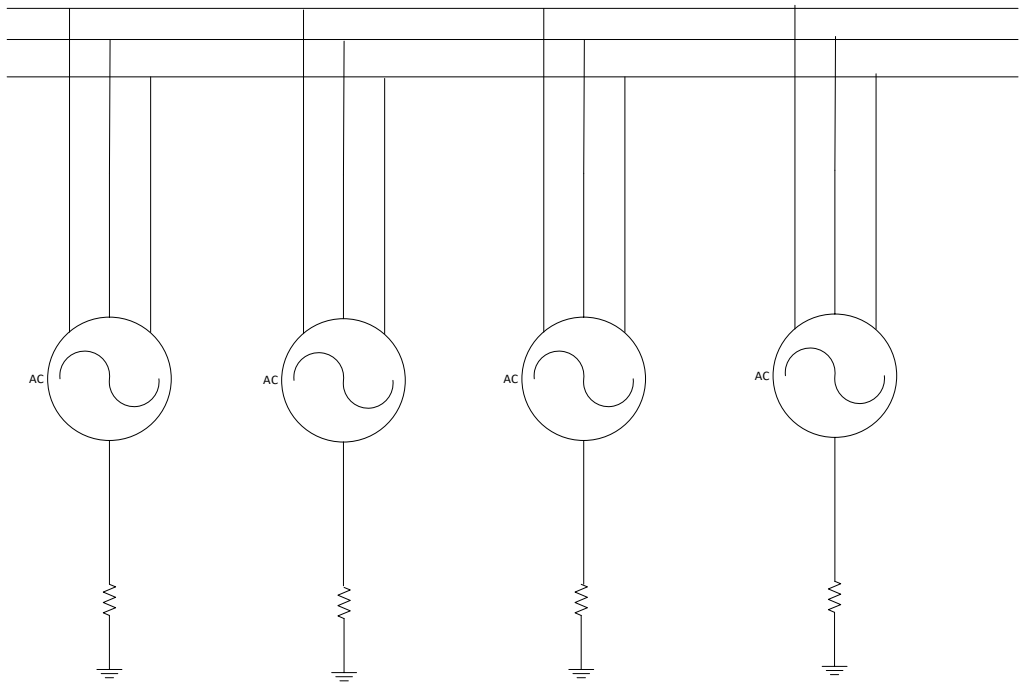
Parallel Sources



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Thank you

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