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Safety Analysis of Trailing Cables Used on High-Voltage Continuous Miners

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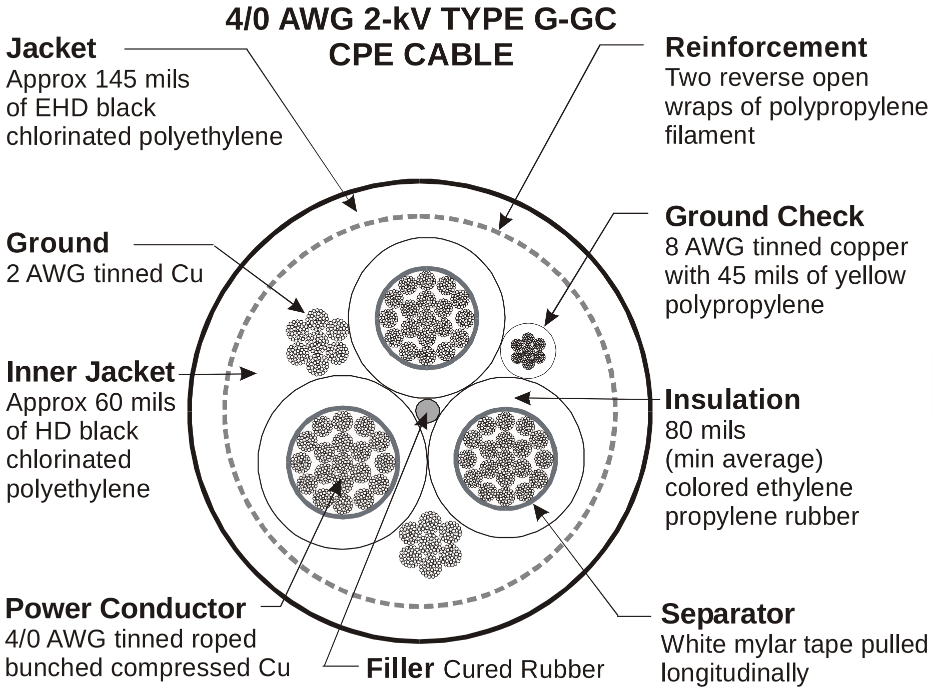
Introduction

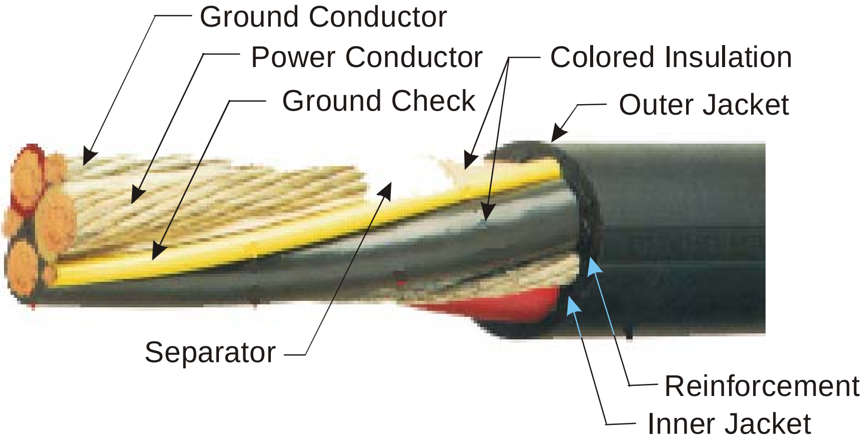
- MSHA's Proposed Rules for High-Voltage Continuous Miners require special precautions with respect to cable handling, as compared with low and medium-voltage trailing cables.
- The rigorous cable-handling requirements have lessened potential productivity gains to a point where mine operators are asking why high-voltage trailing cables cannot be treated the same as low and medium-voltage trailing cables.
- With the other proposed safety requirements in place, the following question arises, "Is there truly an increased safety hazard associated with a high-voltage system, as compared with existing low and medium-voltage systems?"

Study funded by Joy Mining Machinery to Answer the Following Questions:

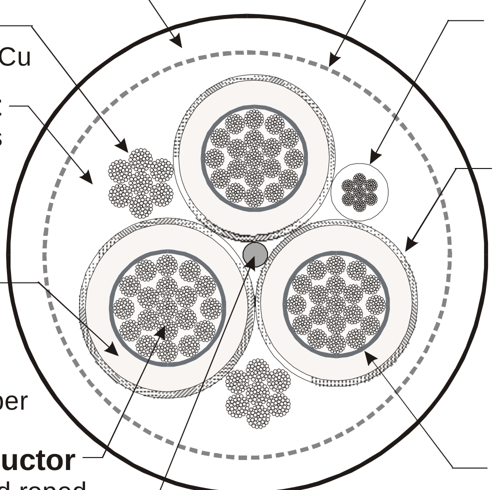
- Is a trailing cable on a high-voltage system more likely to be damaged and cause a shock hazard as compared with cables used on existing low and medium-voltage systems?
- If a direct-contact shock does occur on a high-voltage system, is it more dangerous than one from an existing low or medium-voltage system?

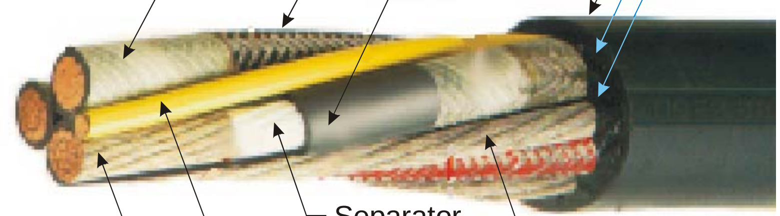
Typical trailing cable for a low-voltage (440 V or 550 V) continuous miner



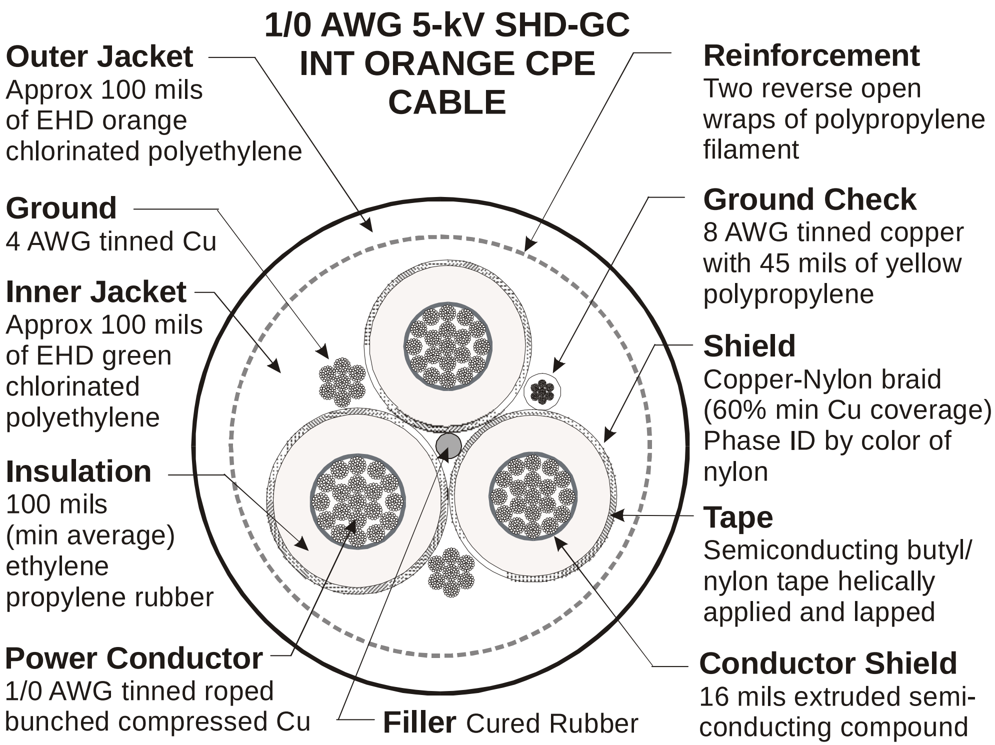


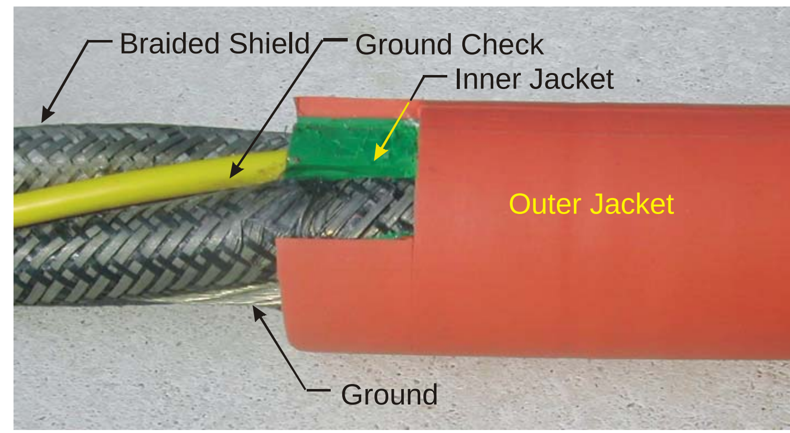
Typical trailing cable for a medium-voltage (950 V) continuous miner

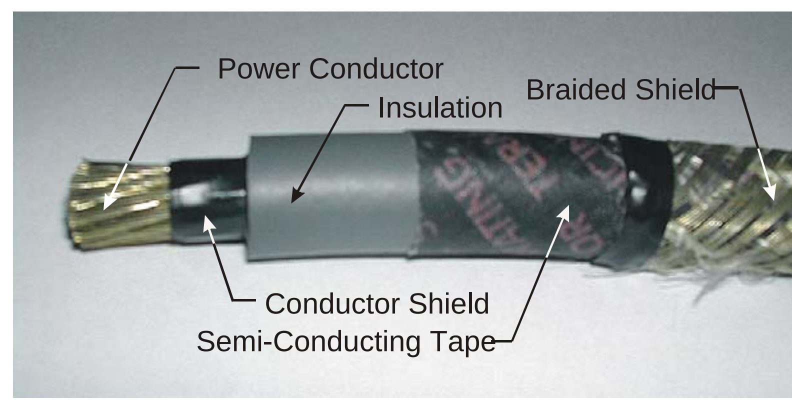




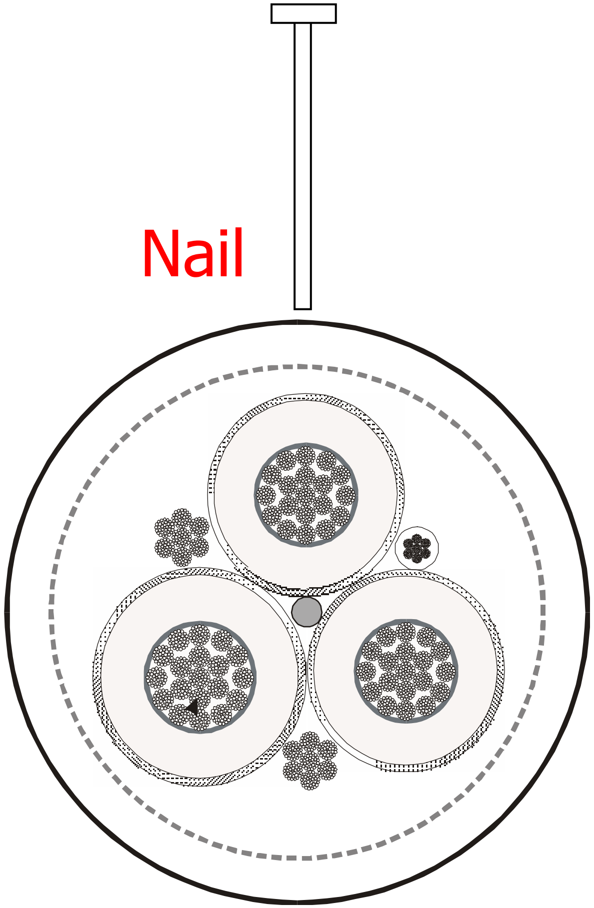
Typical Trailing Cable for a 2300-V or 4160-V Continuous miner







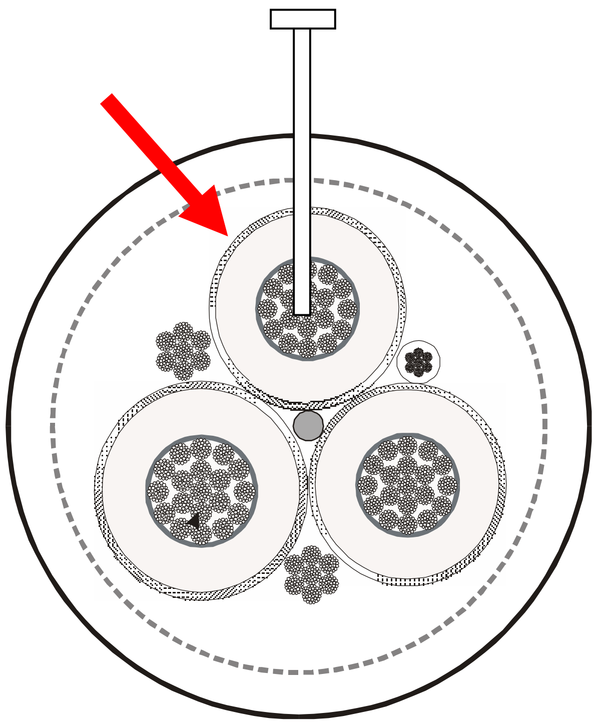
Shock Hazard – Scenario 1: Cable is Punctured by a Metallic Object



Low Voltage

- No shielding.
- The nail is elevated to line-to-ground voltage.
- The hazard could go undetected for an indefinite period of time.

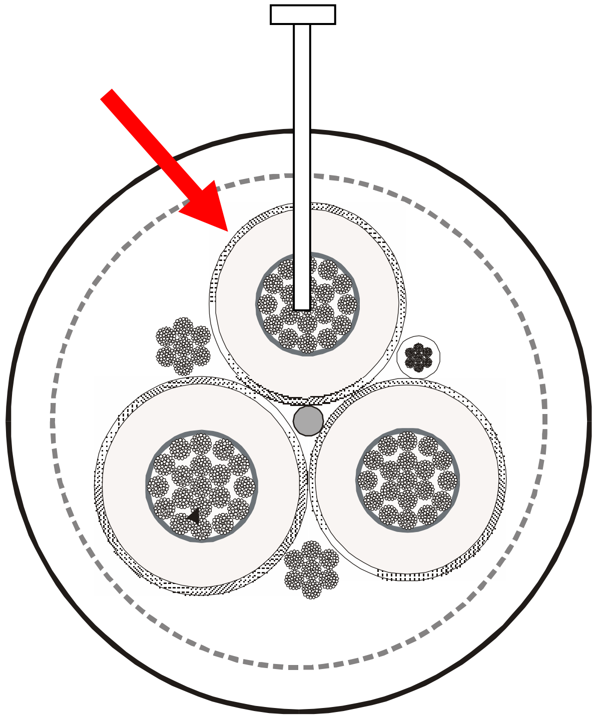
Shock Hazard – Scenario 1: Cable is Punctured by a Metallic Object



Medium Voltage

- Grounded shielding (60% coverage) reduces the possibility of this type of hazard.
- Provides a conductive path which causes tripping when the ground-fault current exceeds 6A.

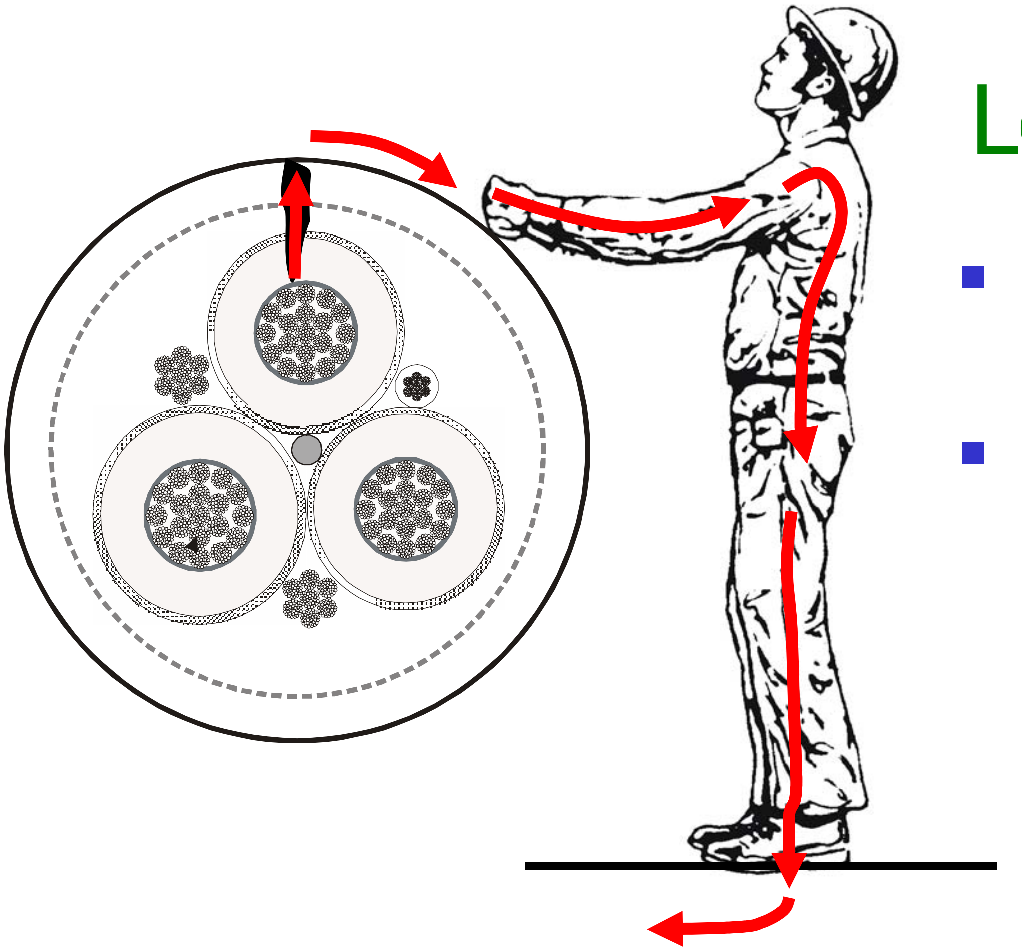
Shock Hazard – Scenario 1: Cable is Punctured by a Metallic Object



High Voltage

- Grounded shielding (60% coverage) plus semi-con tape (100 % coverage) virtually eliminates this hazard.
- Provides a conductive path which causes tripping when the ground-fault current exceeds 0.125 A.

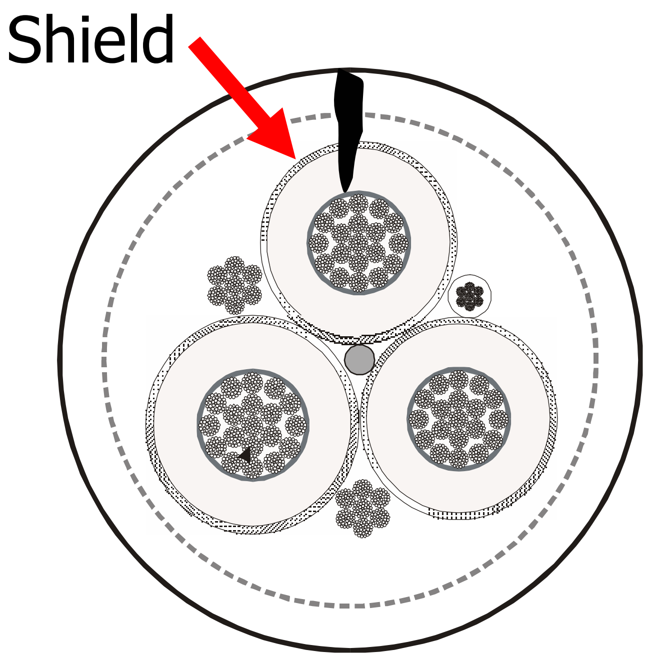
Shock Hazard – Scenario 2: Cable is Gouged and Allows Water and Dirt to Penetrate to a Power Conductor



Low Voltage

- Creates a leakage path to cable jacket.
- Can go unnoticed for an indefinite period.

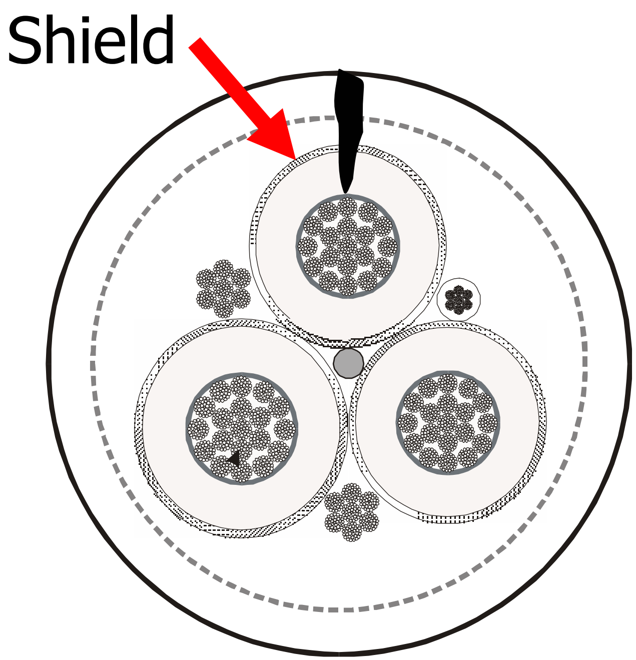
Shock Hazard – Scenario 2: Cable is Gouged and Allows Water and Dirt to Penetrate to a Power Conductor



Medium Voltage

- Braided shield helps reduce this hazard.
- But tripping will not occur unless the leakage resistance is less than 65.5 Ω.

Shock Hazard – Scenario 2: Cable is Gouged and Allows Water and Dirt to Penetrate to a Power Conductor



High Voltage

- Braided shield and very sensitive ground-fault protection (0.125 A trip) significantly reduce this hazard.
- Tripping will occur with a leakage resistance up to 8 kΩ.

Shock Hazard – Scenario 3: Cable is Damaged so that a Bare Energized Conductor is Exposed

Low Voltage

- A minimum of 205 mils of reinforced inner and outer jacketing,
- A minimum of 80 mils of insulation, and
- A layer of mylar tape.

Shock Hazard – Scenario 3: Cable is Damaged so that a Bare Energized Conductor is Exposed

Medium Voltage

- A minimum of 205 mils of reinforced inner and outer jacketing,
- A braided nylon/copper shield,
- A layer of rubber-backed-fabric tape (lapped),
- A minimum of 80 mils of insulation, and
- A layer of mylar tape.

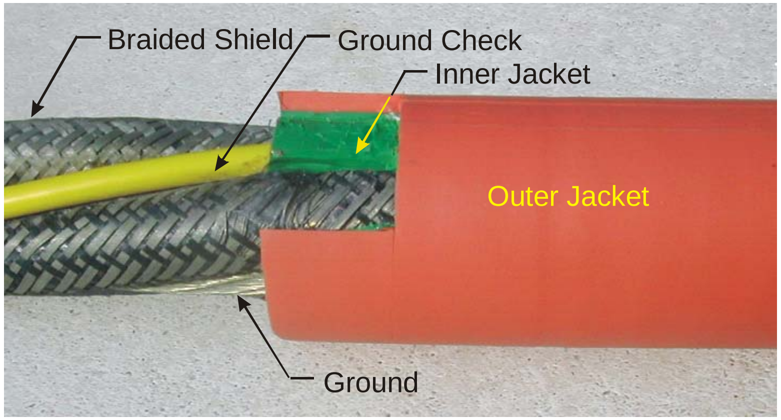
Shock Hazard – Scenario 3: Cable is Damaged so that a Bare Energized Conductor is Exposed

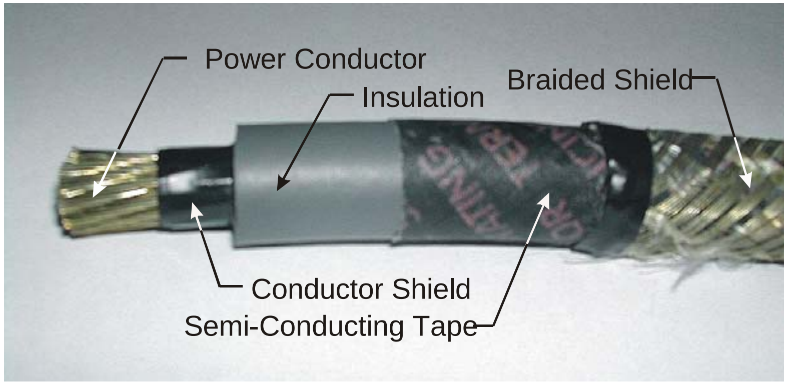
High Voltage

- A minimum of 220 mils of reinforced inner and outer jacketing,
- A braided nylon/copper shield,
- A layer of semi-conducting tape (lapped),
- A minimum of 110 mils of insulation, and
- 15 mils of extruded semi-conducting compound.

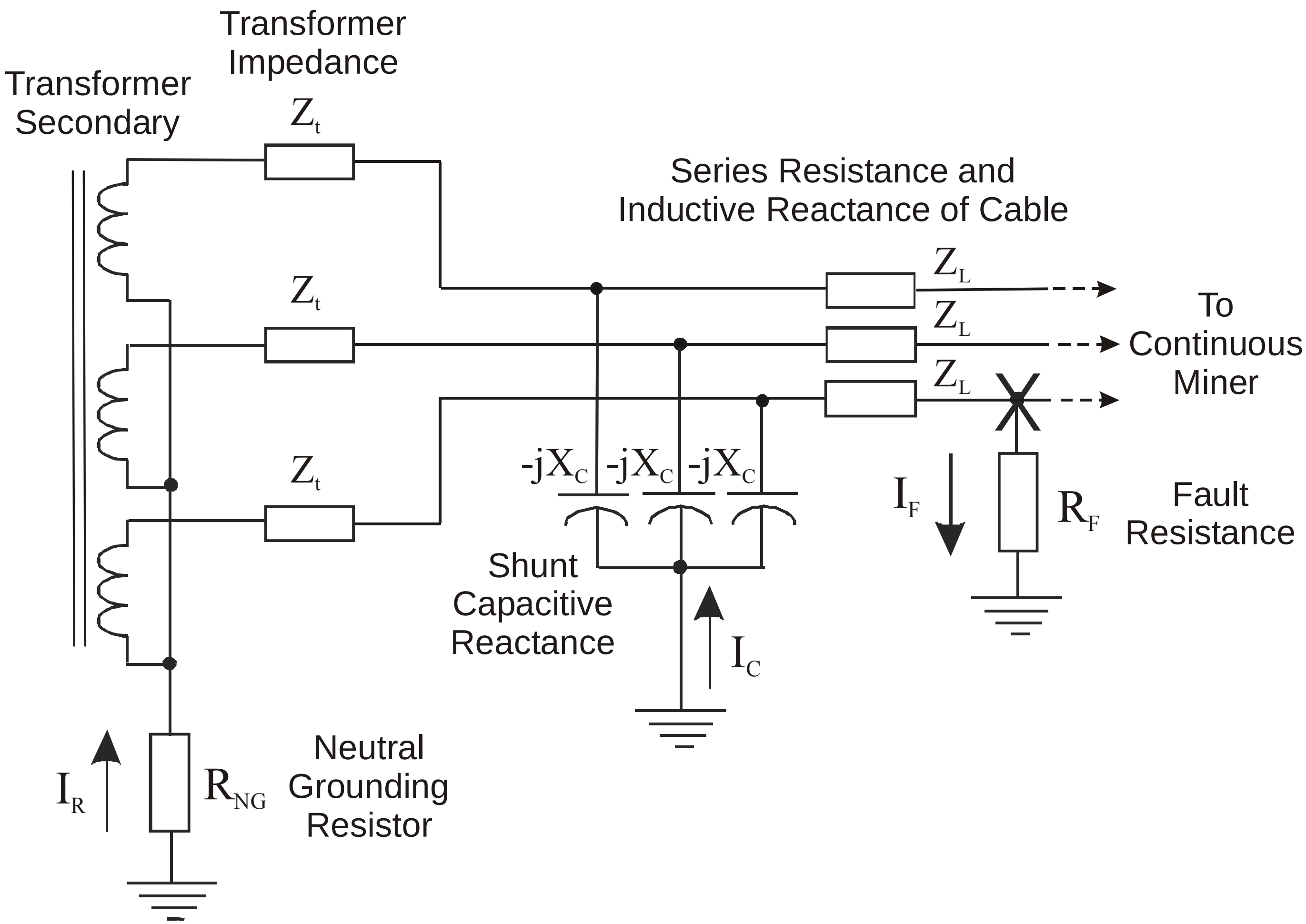
Advantages of the High-Voltage Cable

- The combined thickness of the inner and outer jackets is increased by 7.3%, and the insulation thickness is increased by 37.5%.
- The rubber-backed-fabric tape is replaced by a layer of semi-conducting tape.
- The mylar tape is replaced with 15 mils of extruded semi-conducting compound.
- The separate colors required for the inner (green) and outer jackets (orange) increase the possibility for visually detecting damaged jackets on the cable

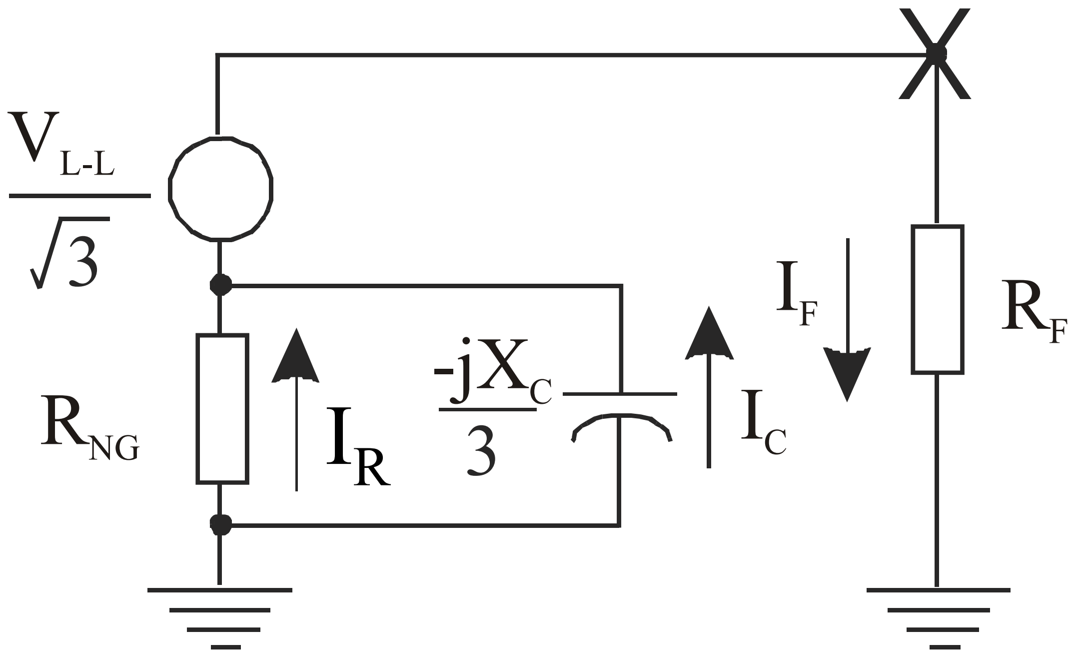




Three-Phase Generic Circuit for Modeling Electrical Hazards



Single-Phase Representation of the Previous Circuit



Values of Neutral-Grounding Resistors

Low Voltage

480-V System: $$R_{NG} = \frac{\frac{480}{\sqrt{3}}}{15} = 18.5\ \Omega,$$

600-V System: $$R_{NG} = \frac{\frac{600}{\sqrt{3}}}{15} = 23.1\ \Omega,$$

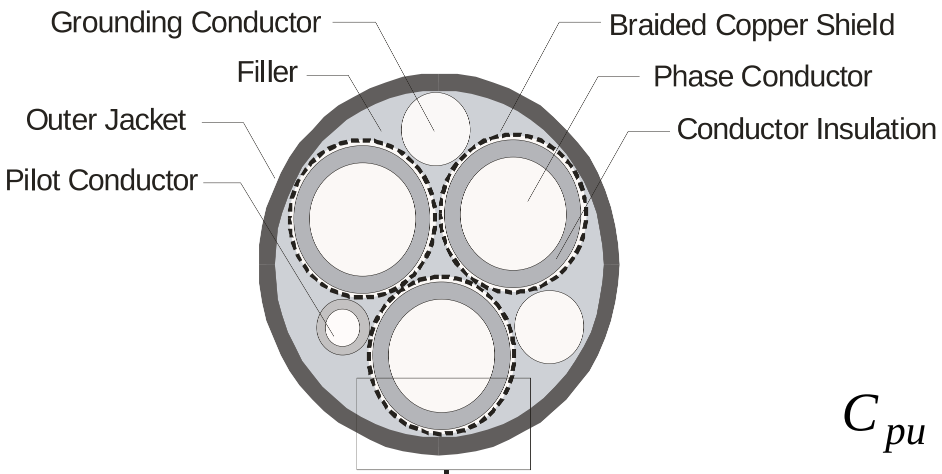
Medium Voltage

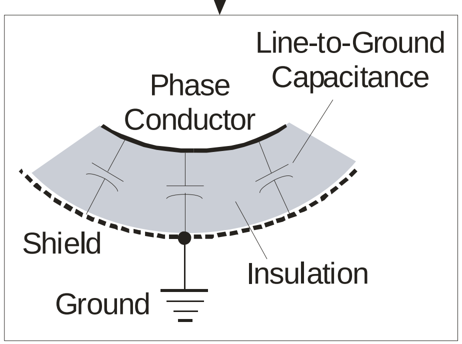
1040-V System: $$R_{NG} = \frac{\frac{1040}{\sqrt{3}}}{15} = 40.0\ \Omega.$$

High Voltage

2400-V System: $$R_{NG} = \frac{\frac{2400}{\sqrt{3}}}{0.5} = 2.77\ \text{k}\Omega$$

Cable Capacitance



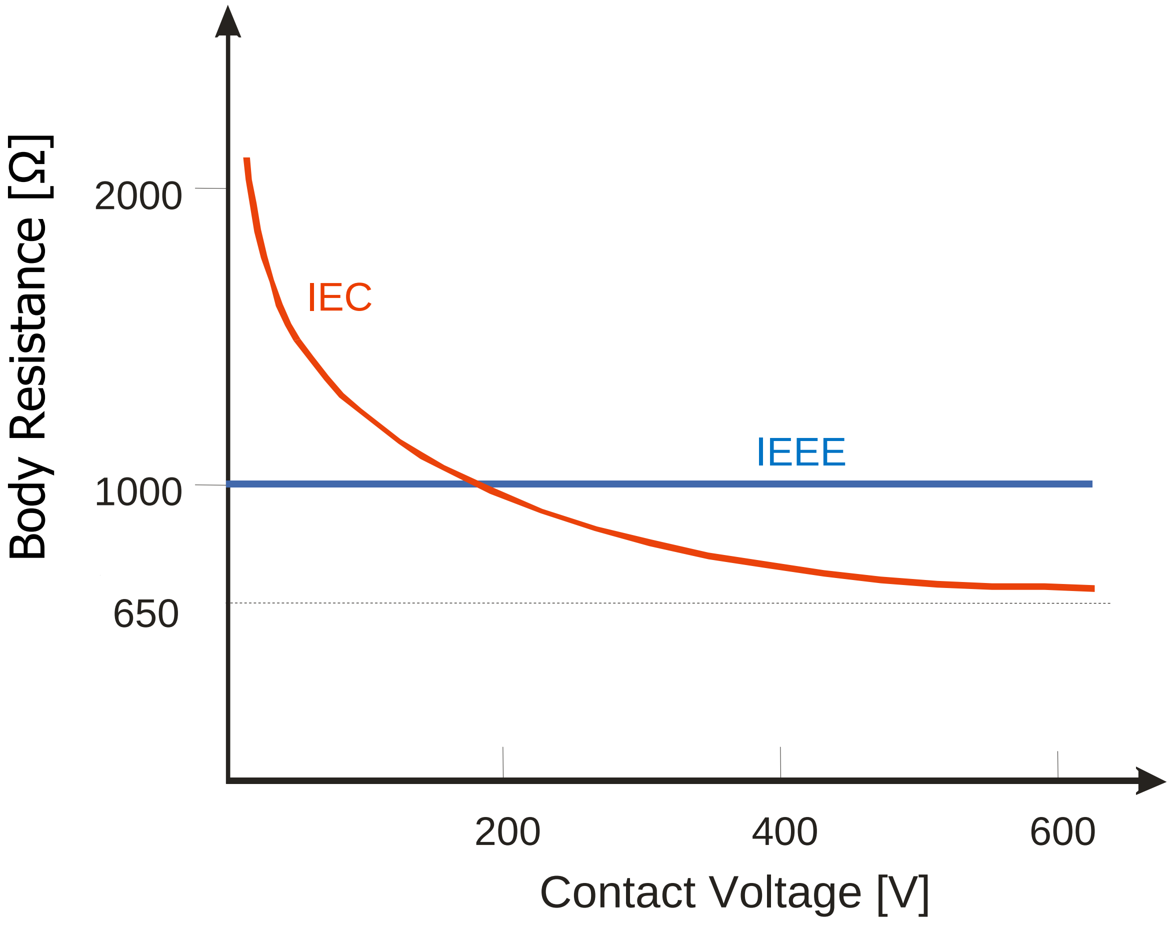


$$C_{pu} = \frac{7.354\xi}{\log_{10}\left(1 + \frac{2t}{d}\right)} \quad \text{[pF/ft]}$$

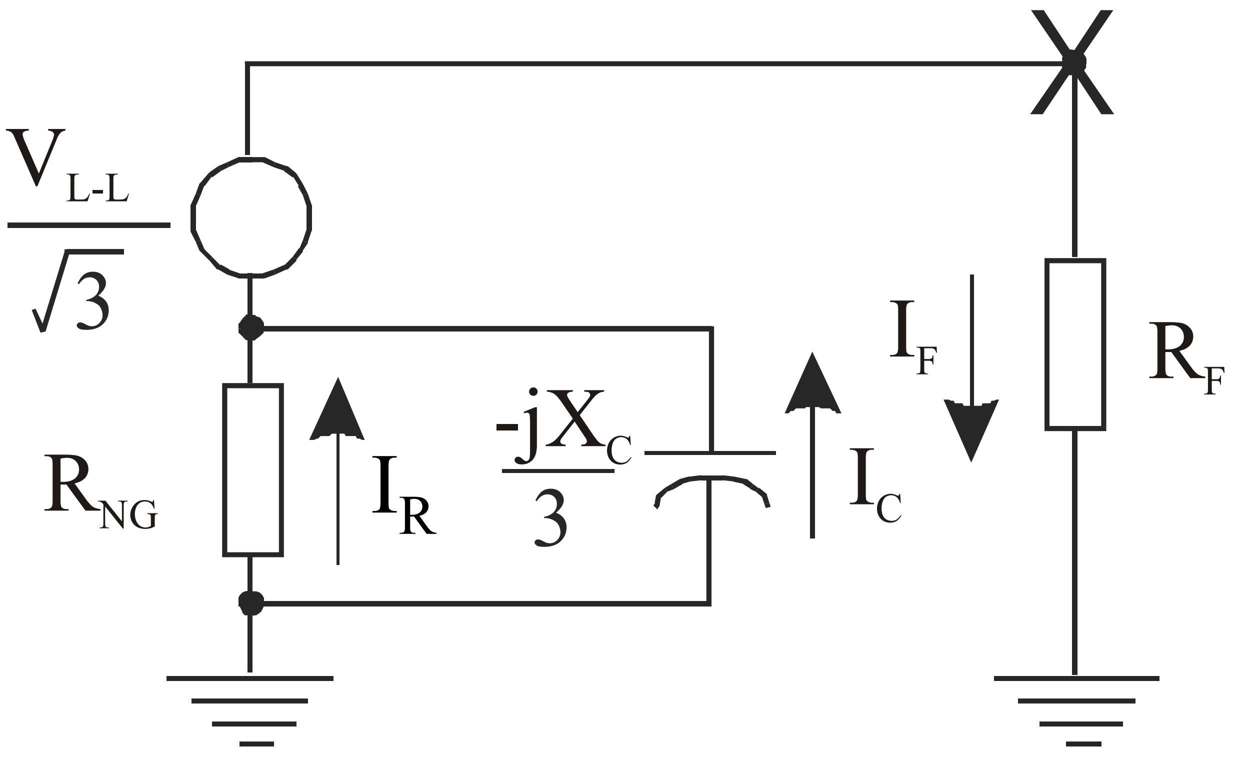
$$C_{pu} = \frac{7.354(3.2)}{\log_{10}\left(1 + \frac{2(0.110)}{0.414}\right)} = 127 \text{ pF/ft}$$

C = (800 ft) (127 x 10-12 pF/ft) = 0.102 μF

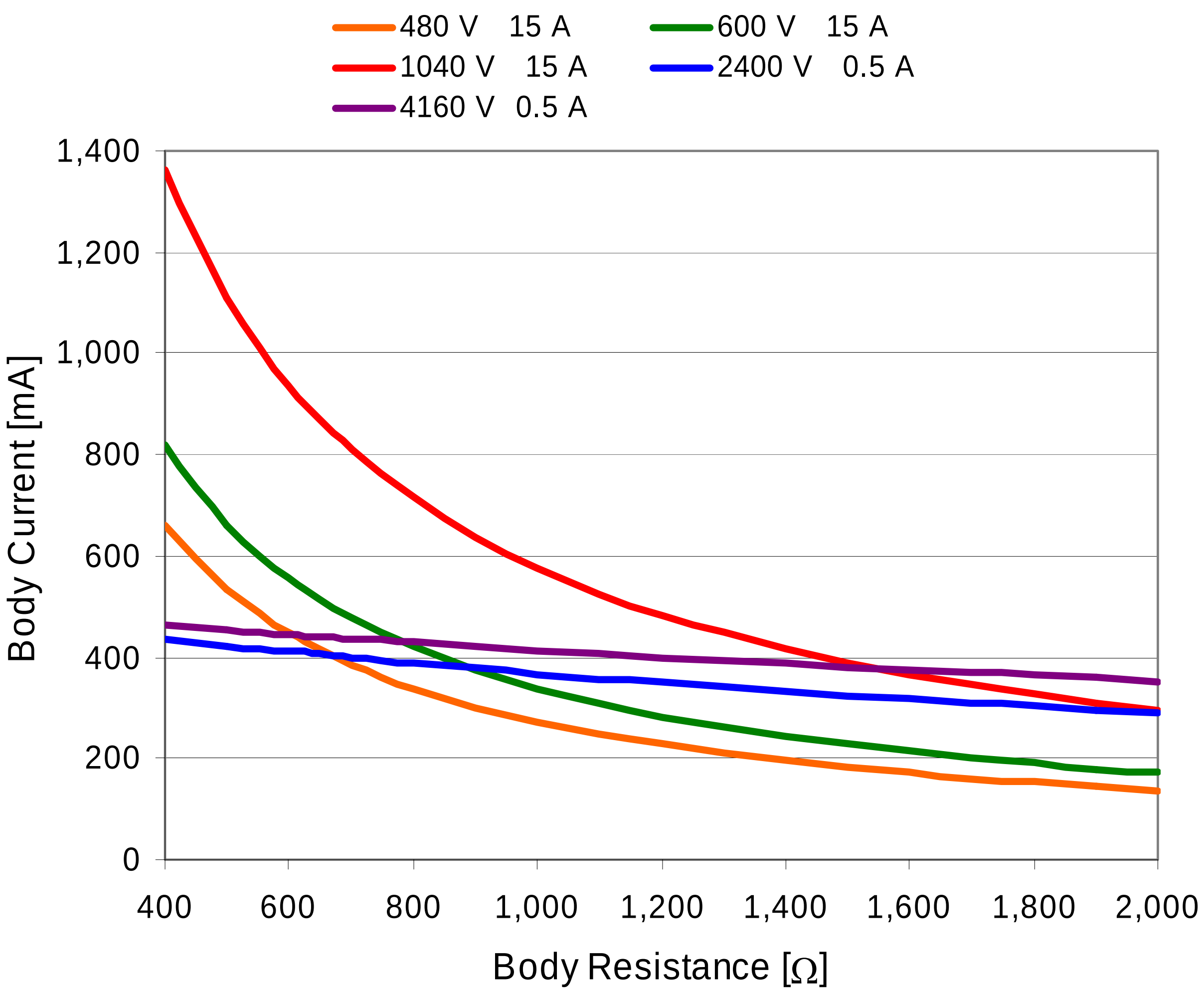
Body Resistance



Calculation of Body Current



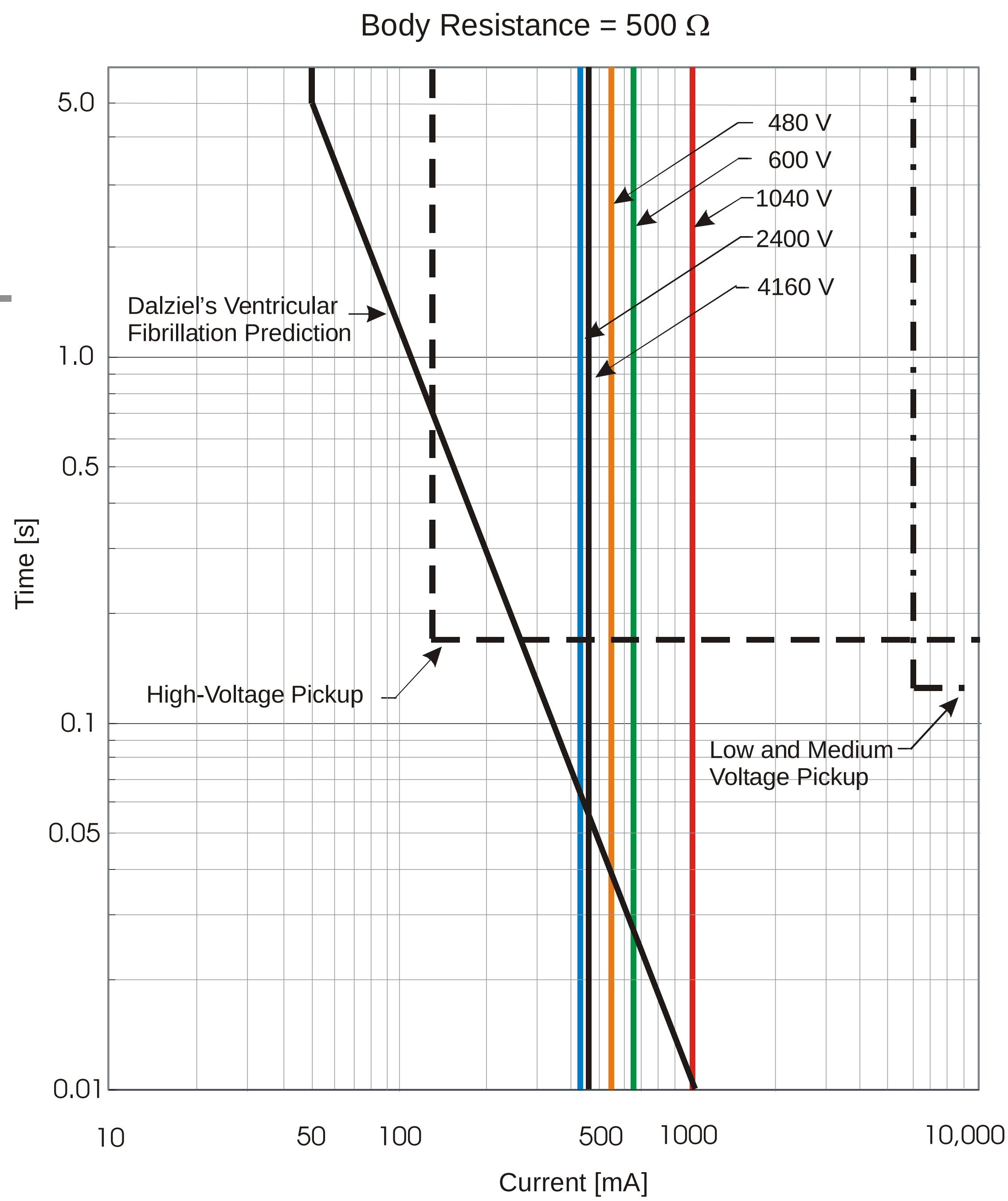
Body Currents at the Various Voltage Levels



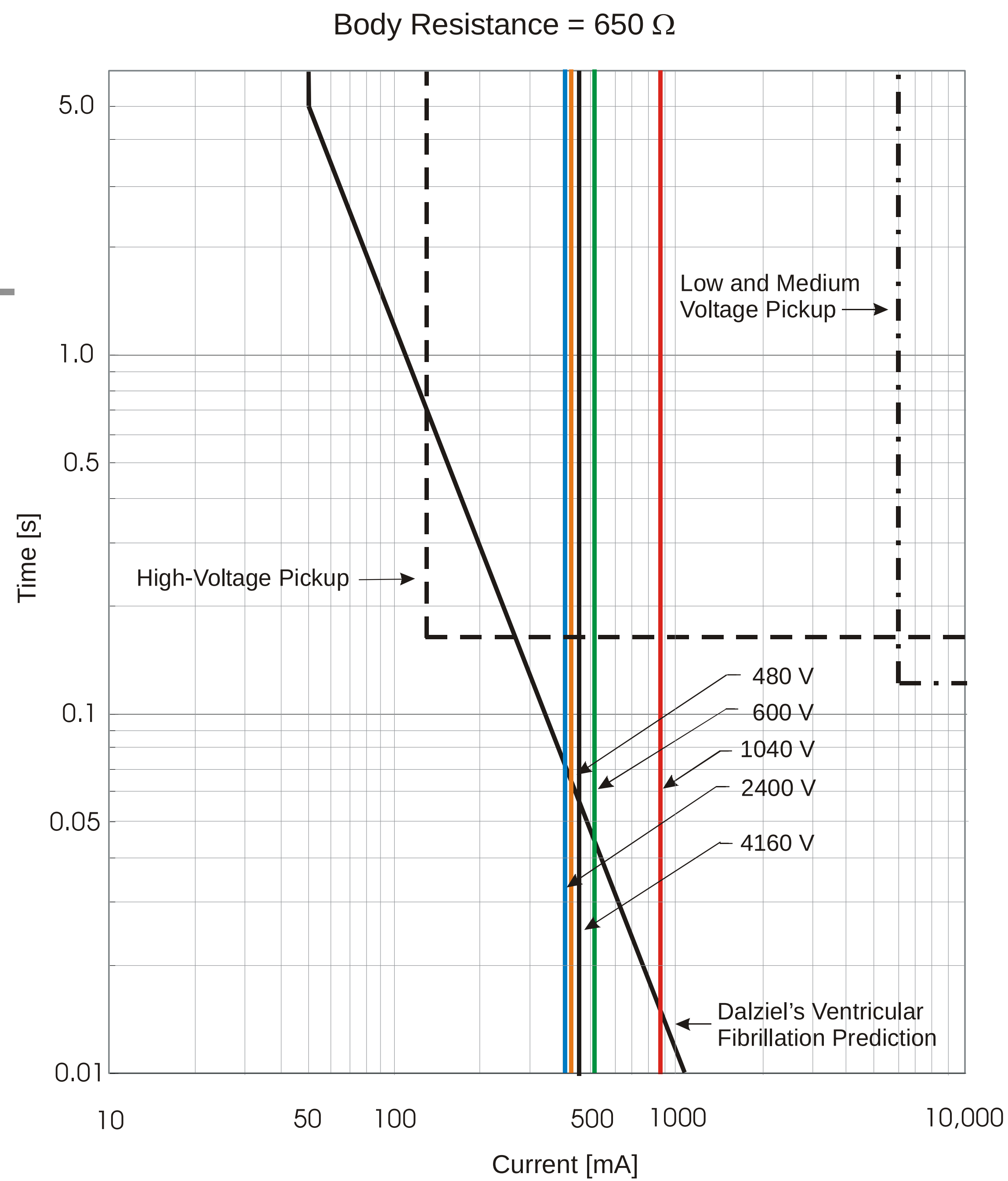
Summary of Body Currents

Voltage	Body Resistance = 500 Ω		Body Resistance = 650 Ω		Body Resistance = 1000 Ω	
	Body Current [mA]	GFR Tripped	Body Current [mA]	GFR Tripped	Body Current [mA]	GFR Tripped
480 V	534	NO	415	NO	272	NO
600 V	662	NO	515	NO	339	NO
1040 V	1,112	NO	870	NO	577	NO
2400 V	424	YES	405	YES	368	YES
4160 V	453	YES	440	YES	414	YES

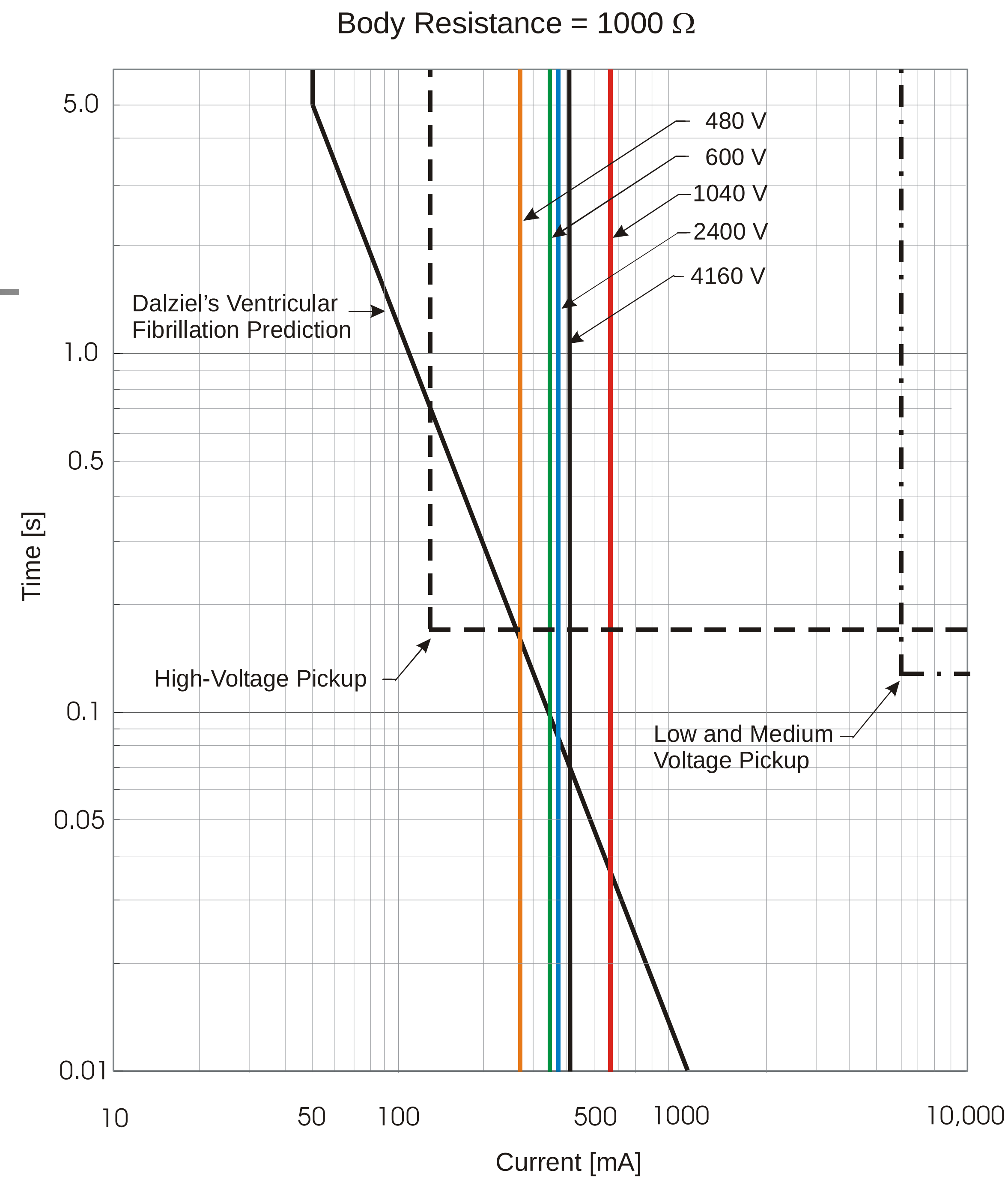
Body Currents for a Body Resistance of 500 Ω



Body Currents for a Body Resistance of 650 Ω



Body Currents for a Body Resistance of 1000 Ω



Thank You!