Danger – Electricity

Solar Energy Educational Material

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Consumers Energy Solar Garden Projects web site, https://www.consumersenergy.com/content.aspx?id=8271

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Danger – High Voltage

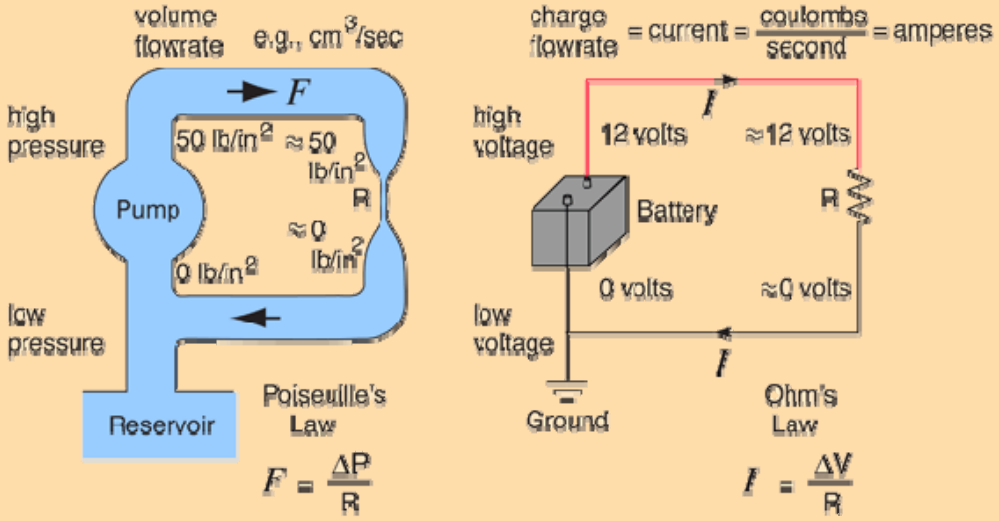
- Well, this is sort of correct
  - A “voltage potential” will cause a current to flow if a path of electrical conduction exists.
  - No path, No flow, No problem … but it might be dumb luck that a path doesn’t exist!
- Current flow causes problems …
  “disrupt your heart and muscles”
  - And, the amount of “power” can leave serious burns (power = voltage x current)

All About Circuits, online textbook, Vol. 1 – Direct Current (DC), Chap. 3: Electrical Safety,:
http://www.allaboutcircuits.com/textbook/direct-current/chpt-3/importance-electrical-safety/

Electricity & Fluid Flow

- Current provides a flow of “energy” when a voltage potential exists.
  - Similar to water flow when a difference in water pressure exists.
- Voltage defines the availability of energy to do some work.
  - Similar to a difference in water pressure.
- Power is the result (product) of voltage and current.

DC Circuit - Water Analogy



Hyperphysics, Carl R. Nave, Department of Physics and Astronomy, Georgia State University
http://hyperphysics.phy-astr.gsu.edu/hbase/electric/watcir.html#c5

Similar physical concepts and mathematics can be found in many areas of science and engineering.

Ohms Law

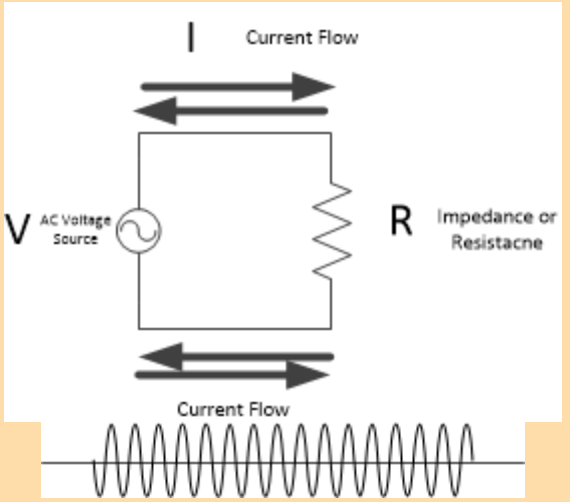
- Voltage (V) and Current (I) are related through Ohm's Law
  - For fluid flow: pressure and flow

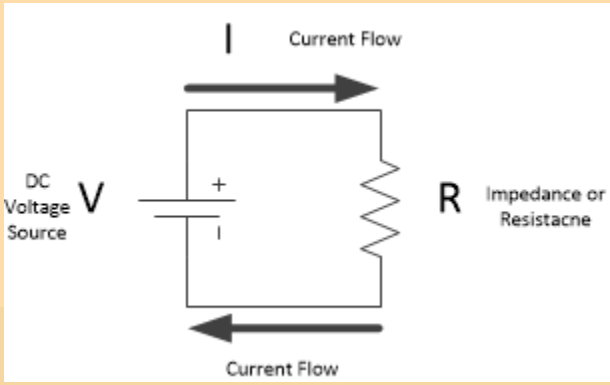
$$V = I \times R$$

- R refers to resistance/impedance (friction loss)
  - resistance impedes the flow of current (water)
  - the higher the resistance, the less the current
  - the smaller the hose or higher friction, the less water will flow.

AC versus DC

- Alternating current (AC)
  - Current varies sinusoidally
  - Typical home are 120 V @ 60 Hz
  - Single Phase line-neutral
    - may include “earth” in a 3-prong plug
  - Three Phase A, B, C
    - may include “neutral” each phase has a 120 degree offset
- Direct Current (DC)
  - Batteries or constant voltage systems
  - Electric cars
  - Current flow always in same direction!





AC versus DC Detection

- Firefighter Hot Sticks
  - **They Do Not Detect DC voltage or current!**
  - The full name is an AC Hot Stick for a reason … AC Field Detection.

Hotstick USA,
http://hotstickusa.com/achotstick

- There are "clamp-on" current meters that can measure DC
  - Clamp on only one wire, not a wire pair! Close contact/access.
  - Hall-effect or magnetic field strength sensors.

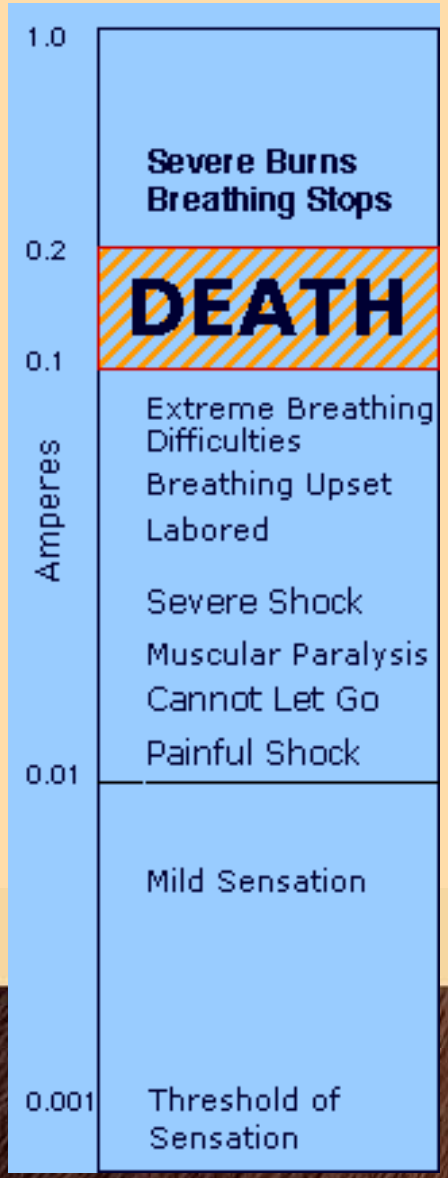
Fluke Application Note, Proper use of clamp meters in commercial and residential settings.
http://media.fluke.com/documents/1989065_6003_ENG_C_W.PDF

Effects of Current on People

Current in milliamperes (mA)	Effects
1 mA or less	No sensation; probably not noticed
1 to 3 mA	Mild sensation not painful
3 to 10 mA	Painful shock.
10 to 30 mA	Muscular control could be lost or muscle clamping
30 to 75 mA	Respiratory paralysis
75 mA to 4 amps	Ventricular Fibrillation
Over 4 amps	Tissue begins to burns. Heart muscles clamp and heart stops beating

Study Guide: Electrical Safety Hazards Awareness, Los Alamaos National Laboratory, Center of Excellenece for Electrical Safety, https://www.lanl.gov/safety/electrical/docs/elec_hazard_awareness_study_guide.pdf

Simplified Est. of Effects



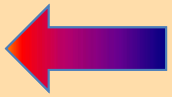
- 100 mA and above can kill
- 10 mA and above can cause pain and other problems

The Ohio State University, Physics Dept. Lab Safety Information, https://www.physics.ohio-state.edu/~p616/safety/fatal_current.html

Body Effect Voltages

TYPE OF RESISTANCE	RESISTANCE VALUES
Dry skin	100,000 to 600,000 Ohms
Wet skin	1,000 Ohms
Hand to Foot	400 to 600 Ohms
Ear to Ear	100 Ohms

Figure 2 Resistance Values



- For 500 ohms at 10 mA
  - voltages *above 5 Volts are significant*.
- For 500 ohms at 100 mA
  - voltages *above 50 Volts may be deadly*.

Study Guide: Electrical Safety Hazards Awareness, Los Alamaos National Laboratory, Center of Excellenece for Electrical Safety, https://www.lanl.gov/safety/electrical/docs/elec_hazard_awareness_study_guide.pdf

Voltage Levels of Concern

Table 1. Summary of Published Contact Voltage Levels of Concern for Humans

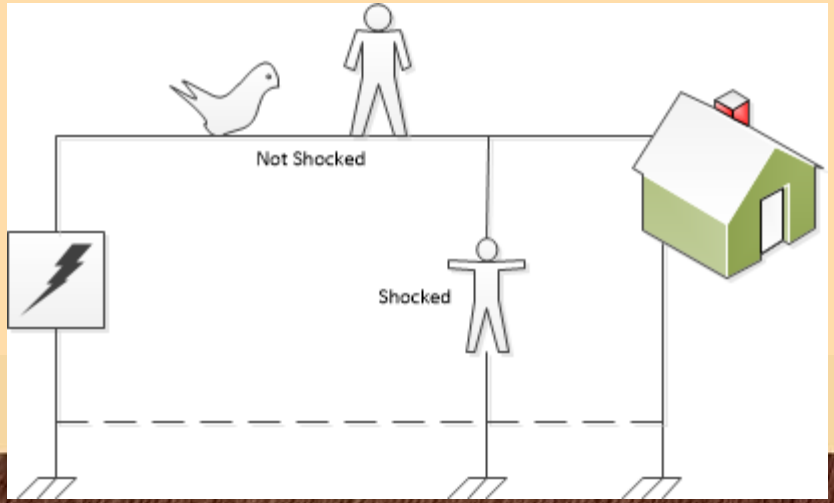
Reference Document	Published Level	Concern Category
UL-101 [4]	0.75 milliamps reaction current 2,000-ohm human body impedance.	Reaction Current
UL-60950-1 [8]	42.4 Vac and 60 Vdc is the stated limit under dry conditions and human hand path.	Shock Hazard
IEC 479-1 [9]	25 Vac clearly safe, 50 Vac marginally safe (duration dependent). 1000 ohm body impedance cited	Shock Hazard
OSHA Rule (29 CFR Part 1910) [10]	Circuits operating above 50 Vac or 50 Vdc.	Shock Hazard
NFPA 70E [11]	30 Vrms or 60 Vdc. 500-ohm wet human body resistance.	Shock Hazard
IEEE Yellow Book – Std. 902-1998 [5]	Currents as low as (10) milliamps and voltages above 50 V can cause fibrillation. 500-ohm minimum body resistance for wet conditions or cuts. 100-500 ohms for immersion (Table 7-2)	Heart Fibrillation
NACE [12]	15 volts.	Shock Hazard
NESC [13]	51 volts.	Shock Hazard
NEC® [14]	Circuits operating above 50 Vac or 50 Vdc or 15 V for wet areas.	Shock Hazard
IEEE Std 80 [2]	60 Vac for 4 sec. 1000 ohm human body impedance	Shock Hazard

- OSHA:
  - 50 Vdc or 50 Vac
  - 500 ohm wet body model
- IEEE Std. 80
  - 60 Vac for 4 sec.
  - 1000 ohm body model

D. Dorr, "Determining voltage levels of concern for human and animal response to AC current," 2009 IEEE Power & Energy Society General Meeting, Calgary, AB, 2009, pp. 1-6.

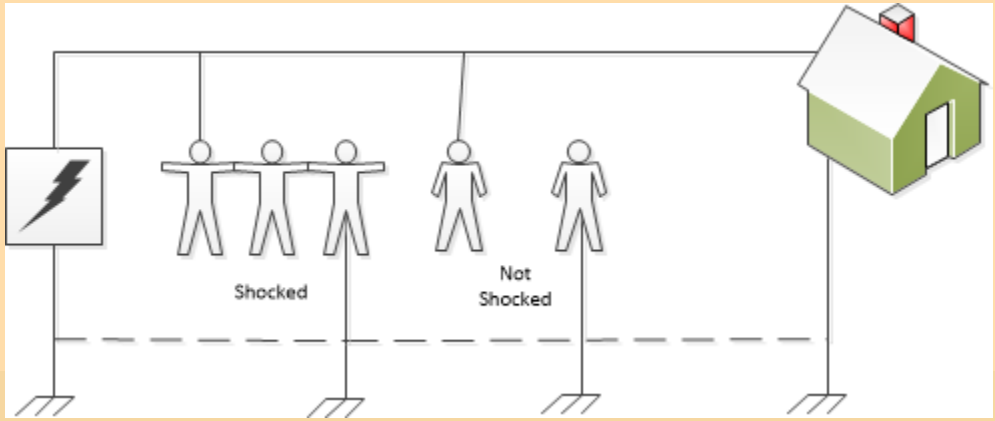
Birds, Squirrels, and Humans

- Why do birds sitting on a power wire or squirrels running across the wire survive while people touching power lines get electrocuted.
  - completing a circuit (path for current) with enough voltage potential to allow damaging current to flow.



Current Paths

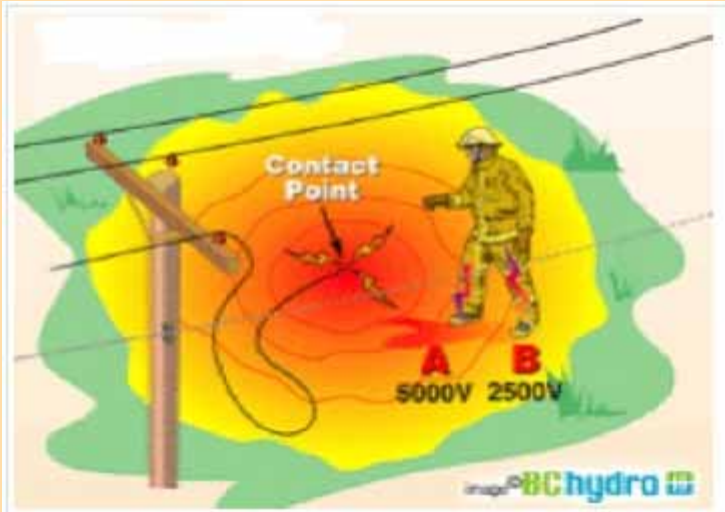
- The contact that completes a path may not be obvious.
  - Another person, a stream of water†, standing in a puddle, etc.
  - An electrical arc or downed power lines
    - Step and touch potential dangers related to power distribution lines or downed power lines involves “paths to earth” you may never think about!



† R. Rackstrom and D.A. Dini, Firefighter Safety and Photovoltaic Installations Research Project, Underwriters Laboratories Inc., Nov. 29, 2011.
http://www.ul.com/global/documents/offerings/industries/buildingmaterials/fireservice/PV-FF_SafetyFinalReport.pdf

Dealing with High Voltage

- Don’t become a conductor!
  - Power distribution lines should be avoided, stay 10 feet or more away!



STEP POTENTIAL

Study Guide: Electrical Safety Hazards Awareness, Los Alamaos National Laboratory, Center of Excellenece for Electrical Safety, https://www.lanl.gov/safety/electrical/docs/elec_hazard_awareness_study_guide.pdf

Ranges of Impedances (ohms)

Protective clothing, gloves, and footwear (boots) can save your life.

- Impedance varies widely based on materials, moisture and “paths” taken.

- Hand or foot contact, insulated with rubber: 20 M ohm typical. ($M=10^6$)
  - Current @ 120 Vac: 0.006 mA No sensation
- Foot contact through leather shoe sole (dry): 100 k to 500 k ohms ($k = 10^3$)
  - Current @ 120 Vac: 0.24 to 1.2 mA Threshold of perception
- Foot contact through leather shoe sole (wet): 5 k to 20 k ohms
  - Current @ 120 Vac: 6.0 to 24 mA Potential severe pain and breathing problems

All About Circuits, online textbook, Vol. 1 – Direct Current (DC),
http://www.allaboutcircuits.com/textbook/direct-current/chpt-3/importance-electrical-safety/

Medical Consequences

- Physiological responses to the current
  - Muscular control could be lost
  - Muscle clamping on or tetanus
  - Respiratory paralysis
  - Ventricular Fibrillation
- Electrical Burns
  - Electro-thermal burns through tissue
  - Contact burns at entry and exit points

Physiological Conditions

- Tetanus is the condition where muscles involuntarily contract due to the passage of external electric current through the body. When involuntary contraction of muscles controlling the fingers causes a victim to be unable to let go of an energized conductor, the victim is said to be “froze on the circuit.”

- “AC’s alternating nature has a greater tendency to throw the heart’s pacemaker neurons into a condition of fibrillation, whereas DC tends to just make the heart stand still.
  - Once the shock current is halted, a “frozen” heart has a better chance of regaining a normal beat pattern than a fibrillating heart. This is why “defibrillating” equipment used by emergency medics works: the jolt of current supplied by the defibrillator unit is DC, which halts fibrillation and gives the heart a chance to recover.”

All About Circuits, online textbook, Vol. 1 – Direct Current (DC), Chap. 3 Electrical Safety, http://www.allaboutcircuits.com/textbook/direct-current/chpt-3/importance-electrical-safety/

Medscape on-line

Electrical Injuries in Emergency Medicine

- Author: Tracy A Cushing, MD, MPH, FACEP, FAWM; Chief Editor: Joe Alcock, MD, MS more...

Updated: Mar 08, 2016

Epidemiology

US frequency

Electrical injuries are estimated to cause approximately 500-1000 deaths per year in the United States.[3, 4] They are responsible for 3-5% of all burn unit admissions and cause 2-3% of emergency department burn visits in the pediatric population.

Some evidence exists that the incidence of low-voltage injuries among children is declining, perhaps because of widespread use of ground fault circuit interrupters (GFCIs), but rates of high-voltage injuries, usually involving power lines or rail sources, has remained steady.[6] Due to the nature of occupational hazards with electricity, electrical injuries represent the fourth leading cause of work-related traumatic death (5-6% of all workers' deaths).[7]

Electrical Injuries in Emergency Medicine
http://emedicine.medscape.com/article/770179-overview#a5

Electrical Injuries: Epidemiology

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[3] Spies C, Trohman RG. Narrative review: Electrocution and life-threatening electrical injuries. Ann Intern Med. 2006 Oct 3. 145(7):531-7. [Medline].

[4] Koumbourlis AC. Electrical injuries. Crit Care Med. 2002 Nov. 30(11 Suppl):S424-30. [Medline].

[7] Casini V. Worker Deaths by Electrocution: A summary of NIOSH Surveillance and Investigative Findings. Department of Health and Human Services (NIOSH). May 1998.

Medscape web site, Electrical Injuries in Emergency Medicine
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Prognosis

For those without prolonged unconsciousness or cardiac arrest, the prognosis for recovery is excellent. Burns and traumatic injuries continue to cause the majority of the morbidity and mortality from electrical injuries.

Morbidity and mortality are largely affected by the particular type of electrical contact involved in each exposure. Overall mortality is estimated to be 3-15%.[1, 8] Flash burns have a better prognosis than arc or conductive burns.[5]

Persons who experience low-voltage injuries without immediate cardiac or respiratory arrest have low mortality, but there may be significant morbidity from oral trauma in children who bite electrical cords[15] or adults who suffer burns to the hand.

Persons who experience low-voltage injuries with cardiac or respiratory arrest may recover completely with immediate CPR on scene; however, prolonged CPR and transport time may result in permanent brain damage.

High-voltage injuries often produce severe burns and blunt trauma. Patients are at high risk of myoglobinuria and renal failure. Burns are often ultimately much worse than they initially appear in the ED.

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Electrical Injuries: Prognosis

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[1] Lee RC. Injury by electrical forces: pathophysiology, manifestations, and therapy. Curr Probl Surg. 1997 Sep. 34(9):677-764. [Medline].

[8] Luz DP, Millan LS, Alessi MS, et al. Electrical burns: a retrospective analysis across a 5-year period. Burns. 2009 Nov. 35(7):1015-9. [Medline].

Electrical Injuries in Emergency Medicine
http://emedicine.medscape.com/article/770179-overview#a5

Best Practices

- Don't touch anything that could be energized!
  - This includes ladders, tools, anything conductive or even victims.
  - Do not go near downed power lines. Do not be the path to ground!
- If possible, Turn it off and Let it discharge
  - Eliminate the risk – find all AC and DC disconnects and switch off
  - Until tested, assume voltage may still exist (particularly DC).
- Increase Resistance - wear proper boots and gloves if possible.
  - Rubber or wood handled tools are good too.
  - No jewelry, rings or watches please.
- Only use one hand. Keep feet together.
  - Two hands can complete a circuit
  - Hand to foot touch hazards may still exist.
  - Avoid foot to foot step hazards near downed power lines.

ADDITIONAL INFORMATION

References

- Consumers Energy Solar Garden Projects web site, https://www.consumersenergy.com/content.aspx?id=8271
- All About Circuits, online textbook, Vol. 1 – Direct Current (DC), Chap. 3: Electrical Safety,: http://www.allaboutcircuits.com/textbook/direct-current/chpt-3/importance-electrical-safety/
- Study Guide: Electrical Safety Hazards Awareness, Los Alamaos National Laboratory, Center of Excellenece for Electrical Safety, https://www.lanl.gov/safety/electrical/docs/elec_hazard_awareness_study_guide.pdf
- https://www.physics.ohio-state.edu/~p616/safety/fatal_current.html
- The Ohio State University, Physics Dept. Lab Safety Information, https://www.physics.ohio-state.edu/~p616/safety/fatal_current.html
- Weineng Wang, Zhiqiang Wang, Xiao Peng, *Effects of the Earth Current Frequency and Distortion on Residual Current Devices*, Scientific Journal of Control Engineering, Dec 2013, Vol 3 Issue 6 pp 417-422
- R. Rackstrom and D.A. Dini, Firefighter Safety and Photovoltaic Installations Research Project, Underwriters Laboratories Inc., Nov. 29, 2011. http://www.ul.com/global/documents/offerings/industries/buildingmaterials/fireservice/PV-FF_SafetyFinalReport.pdf
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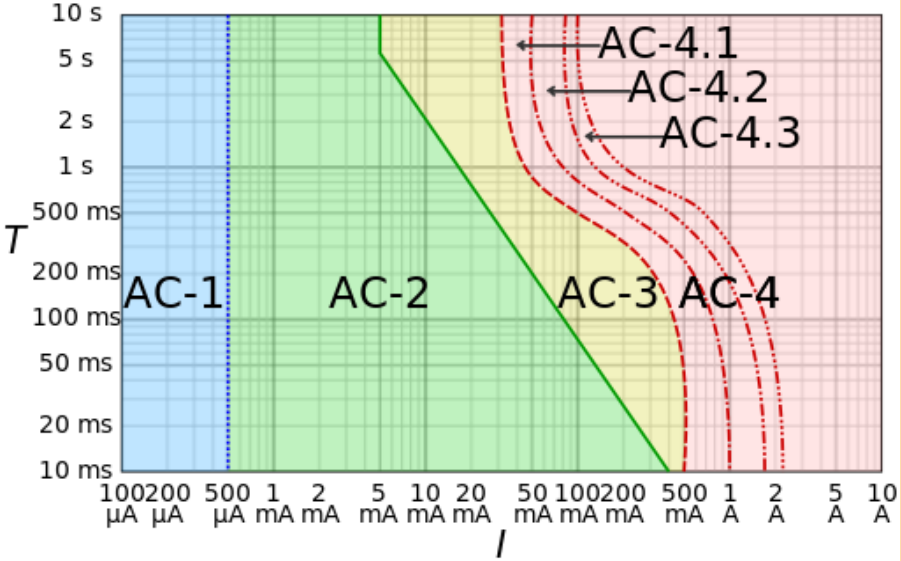
Estimated Body Effects: (Detail)

BODILY EFFECT	DIRECT CURRENT (DC)	60 Hz AC	10 kHz AC
Slight sensation felt at hand(s)	Men = 1.0 mA Women = 0.6 mA	0.4 mA 0.3 mA	7 mA 5 mA
Threshold of perception	Men = 5.2 mA Women = 3.5 mA	1.1 mA 0.7 mA	12 mA 8 mA
Painful, but voluntary muscle control maintained	Men = 62 mA Women = 41 mA	9 mA 6 mA	55 mA 37 mA
Painful, unable to let go of wires	Men = 76 mA Women = 51 mA	16 mA 10.5 mA	75 mA 50 mA
Severe pain, difficulty breathing	Men = 90 mA Women = 60 mA	23 mA 15 mA	94 mA 63 mA
Possible heart fibrillation after 3 seconds	Men = 500 mA Women = 500 mA	100 mA 100 mA	

All About Circuits, online textbook, Vol. 1 – Direct Current (DC), p. 87.
http://www.allaboutcircuits.com/textbook/direct-current/chpt-3/importance-electrical-safety/

Current Contact Time: (More Detail)



Log-log graph of the effect of alternating current I of duration T passing from left hand to feet as defined in IEC publication 60479-1.

- AC-1: imperceptible
- AC-2: perceptible but no muscle reaction
- AC-3: muscle contraction with reversible effects
- AC-4: possible irreversible effects
- AC-4.1: up to 5% probability of ventricular fibrillation
- AC-4.2: 5-50% probability of fibrillation
- AC-4.3: over 50% probability of fibrillation

Weineng Wang, Zhiqiang Wang, Xiao Peng, *Effects of the Earth Current Frequency and Distortion on Residual Current Devices*, Scientific Journal of Control Engineering, Dec 2013, Vol 3 Issue 6 pp 417-422