Electric Safety

Text: Chapter 9.1

ECEGR 3500

Electrical Energy Systems

Professor Henry Louie

Overview

- Statistics
- Electric Shock
- Effects of Voltage and Current
- Body Resistance
- Shock Duration

Electrical Safety Statistics

- >30,000 non-fatal shock accidents each year
- >400 fatalities per year in the U.S.
- Deadliest consumer products
  - Small appliance
  - Power tools
  - Lighting equipment
- Electricity causes over 51,000 household fires each year causing $1.3 billion in property damage

Source: Electrical Safety Foundation International

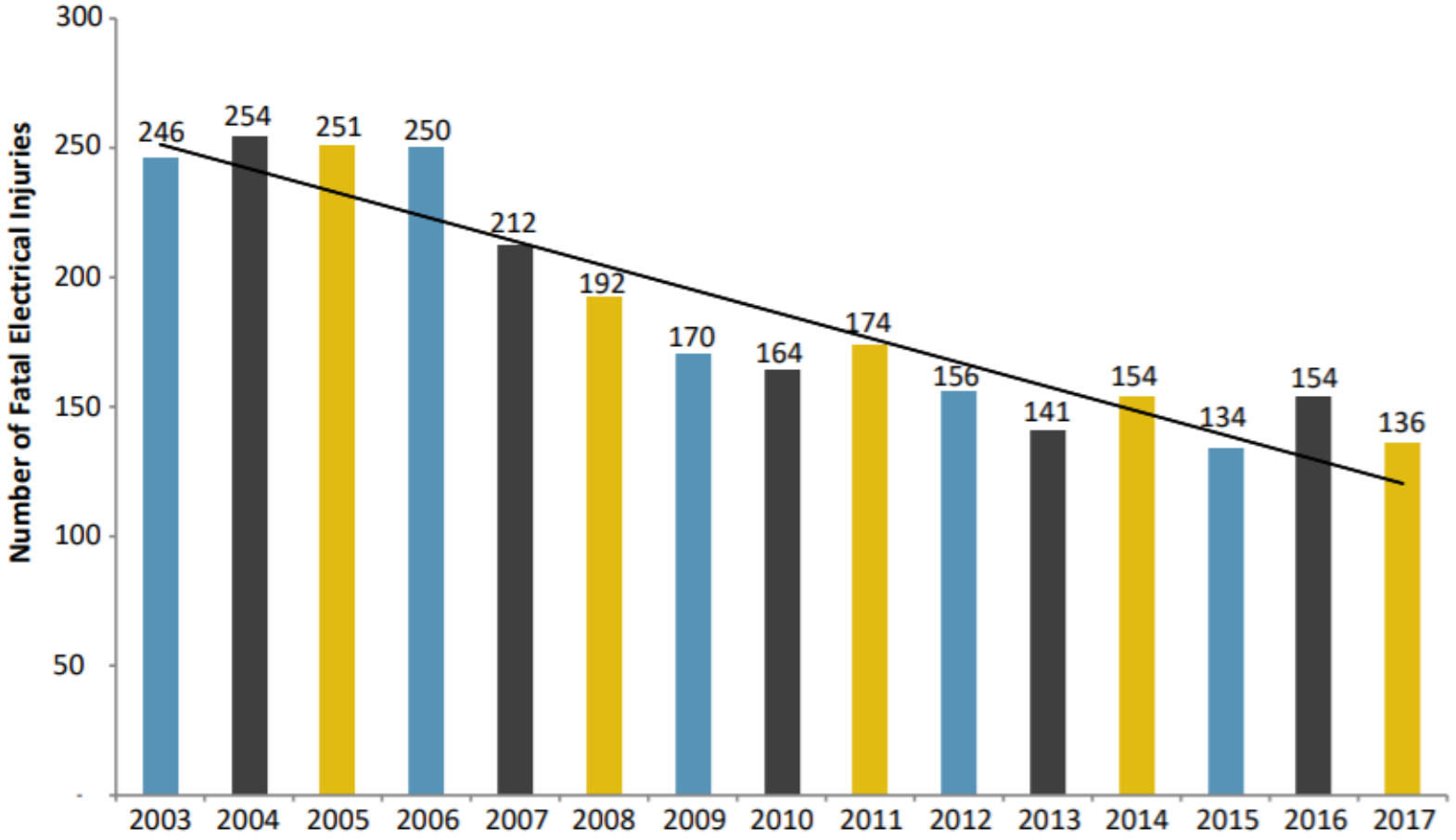
Safety Statistics: construction worker fatalities in the U.S. (2018)

- Falls: 338 (33.5%)
- Struck by object: 112 (11.1%)
- Electrocutions : 86 (8.5%) "Electrocution" implies a fatality.
- Caught in between (crushed, caught in, compressed, collapsed): 55 (5.5%)

Electrocutions are part of the "Fatal Four" of construction fatalities

Source: https://www.osha.gov/oshstats/commonstats.html

Electrical Fatalities



Electrical Fatalities 2003 -2017

54% of fatal electrical injuries occured in the construction industry

11% drop in fatal electrical injuries between 2017 and 2016

6th Contact with / exposure to electricity is the 6th most common cause of workplace fatalty

5% of electrical injuries in 2017 were fatal

Source: https://www.esfi.org

Workplace Injuries

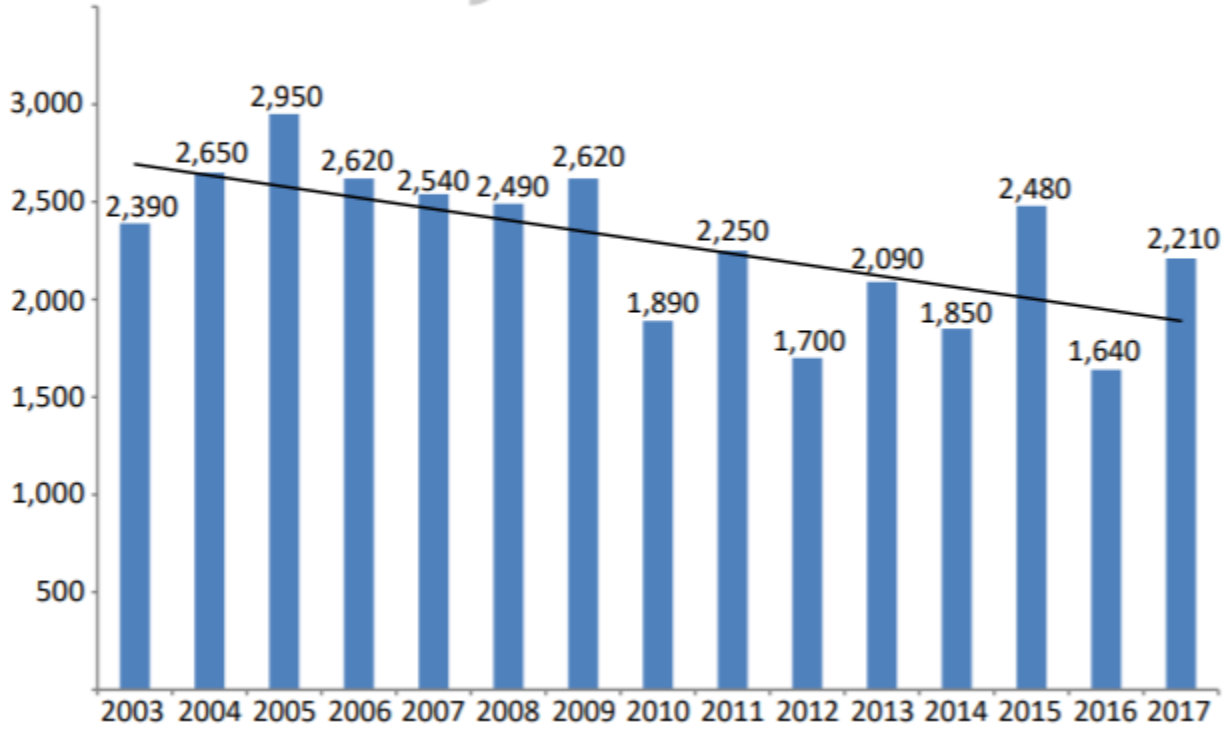
Electrical Injuries

Electrical Injuries 2003 -2017

360 electrical injuries occured in the construction industry

35% increase in electrical injuries between 2016 and 2017

10 the median number of days away from work due to electrical injury



Source: https://www.esfi.org

Electric Shock

- Current traveling through a body can cause pain and damage
  - Cells can overheat, causing internal burns
  - Nerves can be damaged
  - Organs can be damaged, primarily lungs, brain and heart (if within conduction path)
- Just how much current is needed to cause pain or death?

Electric Shock

- Difficult to conduct experiments on the human responses to electric shock (would you volunteer?)
- Charles Dalziel conducted research in the 1970's which is the basis for our understanding today

Source: Electric Energy: An Introduction, M. El-Sharkawi

Electric Shock

- Rules of Thumb
  - Women are more sensitive to shock than men
  - Uncomfortable sensation begins around 1.2 mA for women and 1.8 mA for men
  - Muscles can still be controlled if the current is less than 6mA for women and 9 mA for men
  - People tend to be more sensitive to ac rather than dc

Electric Shock

	Current (mA)			
	dc		ac	
Reaction	Men	Women	Men	Women
No sensation on hand	1.0	0.6	0.4	0.3
Tingling (threshold of perception)	5.2	3.5	1.1	0.7
Shock: Uncomfortable, muscular control not lost	9.0	6.0	1.8	1.2
Painful shock, muscular control is not lost	62.0	41.0	9.0	6.0

Source: IEEE Standard 524a, 1993.

This simple table overlooks several other factors, including the wide range of variability in humans.

Exercise

Other than current magnitude and type (ac/dc), what other factors influence how severe a response to electric shock is?

Exercise

Other than current magnitude and type (ac/dc), what other factors influence how severe a response to electric shock is?

Answer. Many factors, especially voltage level, duration and conduction path, and even the frequency of the ac.

Electric Shock

	Current in mA			
	0.5% of Population		50% of Population	
Threshold	Men	Women	Men	Women
Let-go: Worker cannot release wire	9	6	16	10.5
Respiratory tetanus			23	15
Ventricular fibrillation	100	67		

Source: IEEE Standard 1048, 1990.

Effects of Voltage & Current

Effect of Voltage

- Most electric shocks are of lower voltage (100-400V), but still can be dangerous and fatal
- Current can cause muscles to contract, making release of the energized object difficult or impossible (also possibly tearing the muscle and breaking bones)—longer duration means more electrical energy dissipated in the person's body
- Shocks of >1000V can cause severe current to flow, and may cause the person to be thrown from the energized object (perhaps causing loss of limb or additional injury due to a fall)

An internet search for "electrical burn" images will test your stomach.

Effect of Current

- Current, not voltage causes death (but voltage governs the current level)
- Concerned with current affecting the beating of the heart (fibrillation) and the energy dissipated into a person's tissue
  - As little as 10 microA can cause cardiac arrest

Effect of Current

- Thermal energy dissipated by the current is:

$$E = i^2Rt$$

where

- E: energy (joules)
- i: current, RMS or dc (Amps)
- R: resistance (Ohms)
- t: time (s)

Recall that energy is power x time (if power is constant)

The longer the time connected to the circuit, the greater the chance of serious harm and death.

Body Resistance

Effect of Resistance

- Current through the body must obey Ohm's Law, like any other circuit
- Therefore, the current through the body depends on the resistance of the body, and the circuit connected to the body

Body Resistance

- Your body has resistance (impedance in general)
- Body resistance depends on the where it is measured, body composition and the conditions of the skin
  - sweat/water reduces resistance
  - fat, bone, tendon have higher resistances than muscle, nerves and arteries
- Wide range of variability
- Always use the lower value of the resistance range when designing for safety

Body Resistance

TABLE 9.3 Body Resistance in Ohms

	Hand-to-Hand		Hand-to-Feet
Resistance	**Dry Condition**	**Wet Condition**	**Wet Condition**
Maximum	13,500	1,260	1,950
Minimum	1,500	610	820
Average	4,838	865	1221
Source: IEEE Standard 1048, 1990.			

Body Part	Resistance (Ω)
Each hand plus arm	500
Each leg	500
Torso	100

Exercise

Is it safe to grab the terminals of a 12V battery with your bare hands?

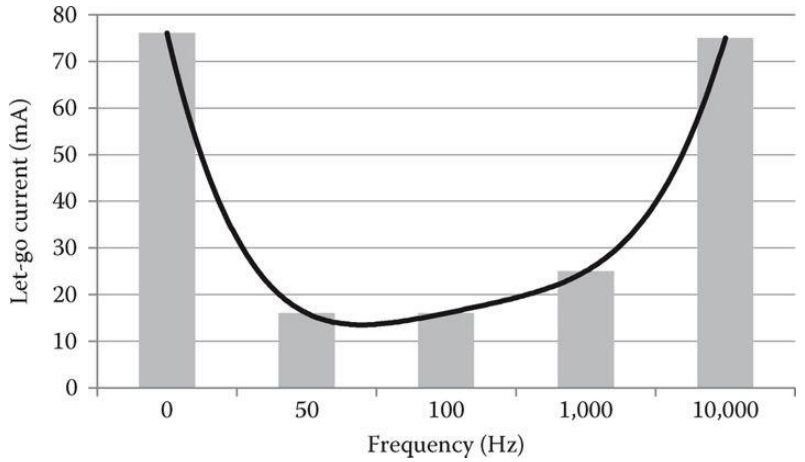
Exercise

Is it safe to grab the terminals of a 12V battery with your bare hands?

Answer. Assuming the resistance of both arms and hands is 1000 Ohms, then the current is 12mA. This should be perceptible, but in general your resistance is much greater than 1000 Ohms. However, always be careful when working around voltage sources.

Effect of Frequency

- ac is more dangerous than dc
- 50/60 Hz is more likely to cause ventricular defibrillation than dc
- Ability to let go of the energized circuit is also frequency dependent



Shock Duration

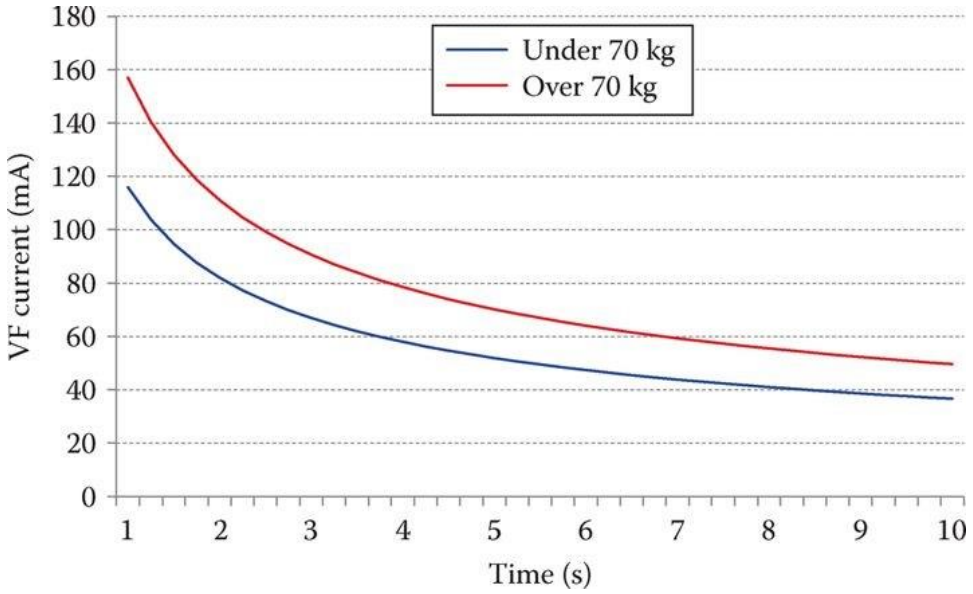
Shock Duration

- The longer the duration of the shock, the more likely death will occur
- An empirical formula developed by Dalziel

$$i = \frac{K}{\sqrt{t}}$$

where

- i: current (in mA)
- K: constant dependent on the weight of the victim (K = 116 for weight less than 70 kg, K = 157 for weight greater than 70 kg)



Exercise

An adult male weighing 95kg is shocked by 100mA. How long until ventricular fibrillation is induced according to Dalziel's formula?

Exercise

An adult male weighing 95kg is shocked by 100mA. How long until ventricular fibrillation is induced according to Dalziel's formula?

Answer. $i = \frac{K}{\sqrt{t}}$

$$t = \frac{K^2}{i^2} = \frac{157^2}{100^2} = 2.46s$$

Electrical Safety Videos

Watch these videos

- https://www.esfi.org/resource/overhead-power-line-car-crash-736
- https://www.esfi.org/resource/electrical-safety-outside-the-home-overhead-power-lines-737
- https://www.esfi.org/resource/gfci-virtual-demonstration-481
- https://www.esfi.org/resource/extension-cord-safety-virtual-demonstration-214