ELECTRICAL Safety Measures

"Elimination is the first priority! Ensure a risk assessment is completed before energized work tasks are completed."

Working With Capacitors

By Terry Becker, P.Eng., CESCP, IEEE Senior Member

Electrical safety related knowledge is still growing. We have used capacitors in electrical circuits for over 200 years. Historical records identify the first "capacitor" as the Leyden Jar, from research performed by Dutch physicist Pieter van Musschenbroek at the University of Leiden. Impressed by the power of the shock he received, Musschenbroek was quoted as writing *"I would not take a second shock for the kingdom of France."* This quote, as it pertains to this article, is an interesting testament related to the electric shock hazard from a capacitor when compared to other ac or dc electrical equipment.

Unfortunately it is only until recently that more formal research[1] into the electrical hazards related to capacitors has been formally completed and is published in the 2021 Edition of NFPA 70E Standard for Electrical Safety in the Workplace and will most likely be published in the pending 2024 Edition of the CSA Z462 Workplace electrical safety Standard, scheduled to be published in March 2024.

The definition and explanation of a capacitor as taken from Wikipedia:

A capacitor is an electronic device that stores electrical energy in an electric field by accumulating electric charges on two closely spaced surfaces that are insulated from each other. It is a passive electronic component with

two terminals.

The effect of a capacitor is known as capacitance. While some capacitance exists between any two electrical conductors in proximity in a circuit, a capacitor is a component designed to add capacitance to a circuit.

The physical form and construction of practical capacitors vary widely, and many types of capacitors are in common use.

Some of the new information with respect to electrical hazard classification for a capacitor that was not previously available is included in Table 1 Electrical Hazard Classification, Capacitors in this article. This information is extracted from NFPA 70E Standard for Electrical Safety in the Workplace, Chapter 3, Article 360 Safety-Related Requirements for Capacitors, NFPA 70E Annex R Working With Capacitors and USA Department of Energy published IEEE papers and tutorials.

This new information needs to be considered related to work tasks performed on capacitors by Qualified Persons and their work task-based Shock Risk Assessment and Arc Flash Risk Assessment. In the past, an electric shock hazard would be the primary focus. With the new information available, it is apparent that Dutch physicist Pieter van Musschenbroek's quote was correct – an electric shock from a capacitor is unique compared to an electric shock received from other ac and dc electrical equipment. There are electrical hazards classified related to an abnormal arcing fault and arc flash occurring specific to capacitors.

Table 1 – Electrical Hazard Classification, Capacitors[1, 2]

Electrical Hazard Classification Voltage or Electrical Equipment	Potential Severity of Injury or Damage to Health
Capacitors: Hazard Thresholds (NFPA 70E, Article 360.3): • <100V and >100J stored energy. • ≥100V and >1.0 J of stored energy. • ≥400V and >0.25 J of stored energy.	Abnormal Arcing Fault: • >120kJ, >1.2 cal/cm². • Thermal hazard if >100J of stored energy. • Acoustical shock wave, hearing protection boundary >100J of stored energy. • Lung protection boundary, >122kJ. Electric Shock Effects: • Function of energy, risetime, pulse length and body impedance. • Impulse shock. • ≥100V threshold. • Energy delivered, 1 to 10ms: • Slight sensation, 0.05 to 1mJ. • Disagreeable, 5 to 100mJ. • Painful, 0.1 to 0.5J. • Injury likely, 1 to 50J. • Fibrillation likely, 50 to 1000J. Other: • Fire hazard, dielectric fluids. Toxic vapours.

When working with capacitors the following electrical hazards need to be considered[2]:

1. Electric shock and subsequent current flow into the human body. *"The capacitor electric shock hazard to a person is an impulse electric shock with an exponential decay curve. The severity of the electric shock is related to the amount of energy (joules) delivered and the time in which the energy is delivered. Injuries from capacitor electric shock include severe reflex action, internal and external burns, and heart fibrillation."*
2. Arcing fault and arc flash burn injuries. *"At approximately 120kJ, there exists sufficient stored energy to create an arc flash hazard (greater than 1.2 cal/cm²) at a working distance of 18 inches. This*

is a conservative lower bound that assumes all of the stored energy has been converted to radiant heat."

3. Arc blast pressure wave, physical trauma. Hearing damage and lung damage. *"Capacitors can have a significant arc blast hazard due to the very high short-circuit current involved. The effects of the acoustic electric shock wave can rupture eardrums and collapse lungs. While hearing protection should be used above 100 joules to mitigate against hearing damage, there is no PPE for protection against lung collapse, which becomes a hazard above 122 kJ."*

In NFPA 70E Annex R two new "boundaries" specific to capacitors are identified and we need to ensure they are not applied to any other ac or dc electrical equipment. They are defined in NFPA 70E, Chapter 1, Article 105 Definitions as:

Boundary, Hearing Protection (Hearing Protection Boundary)*: Worker distance at which a 1 percent probability of ear damage exists from 20 kPa (3.0 psi) shock wave."*

Boundary, Lung Protection (Lung Protection Boundary)*: Worker distance at which a 1 percent probability of lung damage exists from a 70kPa (10 psi) shock wave.*

As illustrated in Table 2 Electrical Safety Related Boundaries For Capacitors, specific attention is required in order to differentiate capacitors from other ac and dc electrical equipment as noted. Formulas for calculating the Hearing Protection Boundary and Lung Protection Boundary are documented in NFPA 70E Annex R and pending CSA Z462 Annex W and have also been included in commercially available power system software.

Table 2 – Electrical Safety Related Boundaries For Capacitors

Low & High Voltage Electrical Equipment Arc Flash (work task-based interaction or abnormal arcing fault no direct interaction)	Low & High Voltage Electrical Equipment Including Capacitors Electric Shook Protection Approach Boundaries (exposed conductors and circuit parts)	Capacitors[1]	Comments Related to Capacitors[2]
Arc Flash Boundary	Limited Approach Boundary	Arc Flash Boundary	When an arc flash hazard exists, an approach limit from an arc source at which incident energy equals 1.2 cal/cm^2 (5 J/cm^2).
Arc Blast Pressure. Arc flash, arc blast pressure results when the abnormal arcing fault occurs, expanding air. Arc blast pressure is based on arcing fault current, NOT incident energy.	Restricted Approach Boundary	Arc Blast Hazard	A source of possible injury or damage to health from energy deposited into acoustical shock wave and high-velocity shrapnel (reference 70E, Article 360, Z462, Clause 6.7).
		Lung Protection Boundary[3]	Worker distance at which a 1 percent probability of lung damage exists from a 70kPa (10 psi) shock wave.
		Hearing Protection Boundary[3]	Working distance at which a 1 percent probability of ear damage exists from a 20kPa (3.0 psi) shock wave.

1. Reference NFPA 70E, Chapter 1, Article 100 Definitions and CSA Z462, 2024 Edition when published, Clause 3 Definitions (new definitions added). The definitions identify their applicability as noted.
2. An electric shock received from capacitors will be different than a normal ac or dc shock. Reference Annex R of NFPA 70E and Annex W of CSA Z462 2024 when published.
3. Reference NFPA 70E Annex R or CSA Z462 Annex W Working With Capacitors when published. Separate formulas are provided and will be included in available power system software.
4. Do not mix the capacitor boundaries with other low or how voltage ac or dc electrical equipment when completing a work task's arc flash risk assessment.

This article was intended to increase awareness of new information related to capacitors and electrical hazard classification and you are encouraged to review in detail the information included in NFPA 70E Standard for Electrical Safety in the Workplace, 2024 Edition and pending information that will be included in the CSA Z462 Workplace electrical safety Standard, 2024 Edition. This additional information should be included in an updated energized electrical work task based qualitative risk assessment procedure documented in an employer's Electrical Safety Program.

If you are interested in discussing the information presented in this article or would like a specific topic presented, contact me at 587.433.3777 or e-mail terry.becker@twbesc.ca.

[1] Scott, Mark, "Working Safely with Hazardous Capacitors: Establishing Practical Thresholds for Risks Associated With Stored Energy," IEEE Industry Applications Magazine, Vol. 25, Issue 3, 2019: 44-53.

[2] Electrical hazard classification information is referenced from USA Department of Energy Electrical Hazard Classification Tutorials, IEEE Electrical Safety Workshop papers and NFPA 70E Standard for Electrical Safety in the Workplace, 2024 Edition.

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