HISTORICAL OVERVIEW OF MEDIUM & HIGH VOLTAGE CABLES

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Objective

"To present the evolution of cables in time to understand the lessons from the past: the legacy problems and their solution"

Outline

- Timeline
- Cable components
- Legacy problems - Cables
- Current challenges

Timeline

Cable History

Historical perspective is important, it tells us:

- What works
- What does not
- What is still out there
- What challenges it presents
- How large the problems may be or become
- How to avoid mistakes

AWARENESS

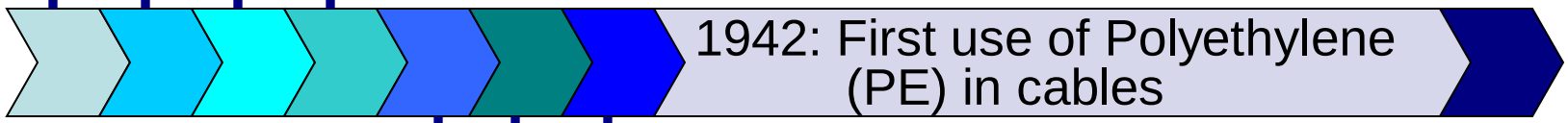
Timeline 1812-1942

1812: First cables used to detonate ores in a mine in Russia

1870: Cables insulated with natural rubber

1880: DC cables insulated with jute in “Street Pipes” – Thomas Edison

1890: Ferranti develops the concentric construction for cables



1937: Polyethylene (PE) developed

1925: The first pressurized paper cables

1917: First screened cables

Timeline 1963-1990

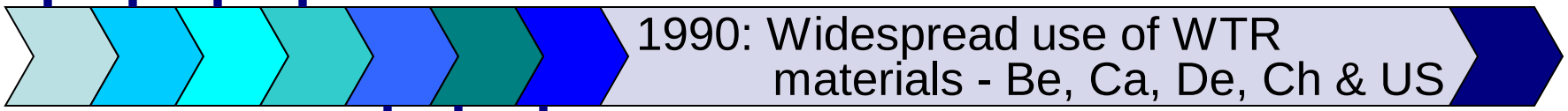
1963: Invention of crosslinked polyethylene – XLPE

1967: HMWPE insulation on UG cables in the US (Unjacketed tape shields)

1968: First use of XLPE cables for MV (mostly unjacketed, tape shields)

1972: Problems associated with water trees (MV) and contaminants (HV)

Introduction of extruded semicon screens



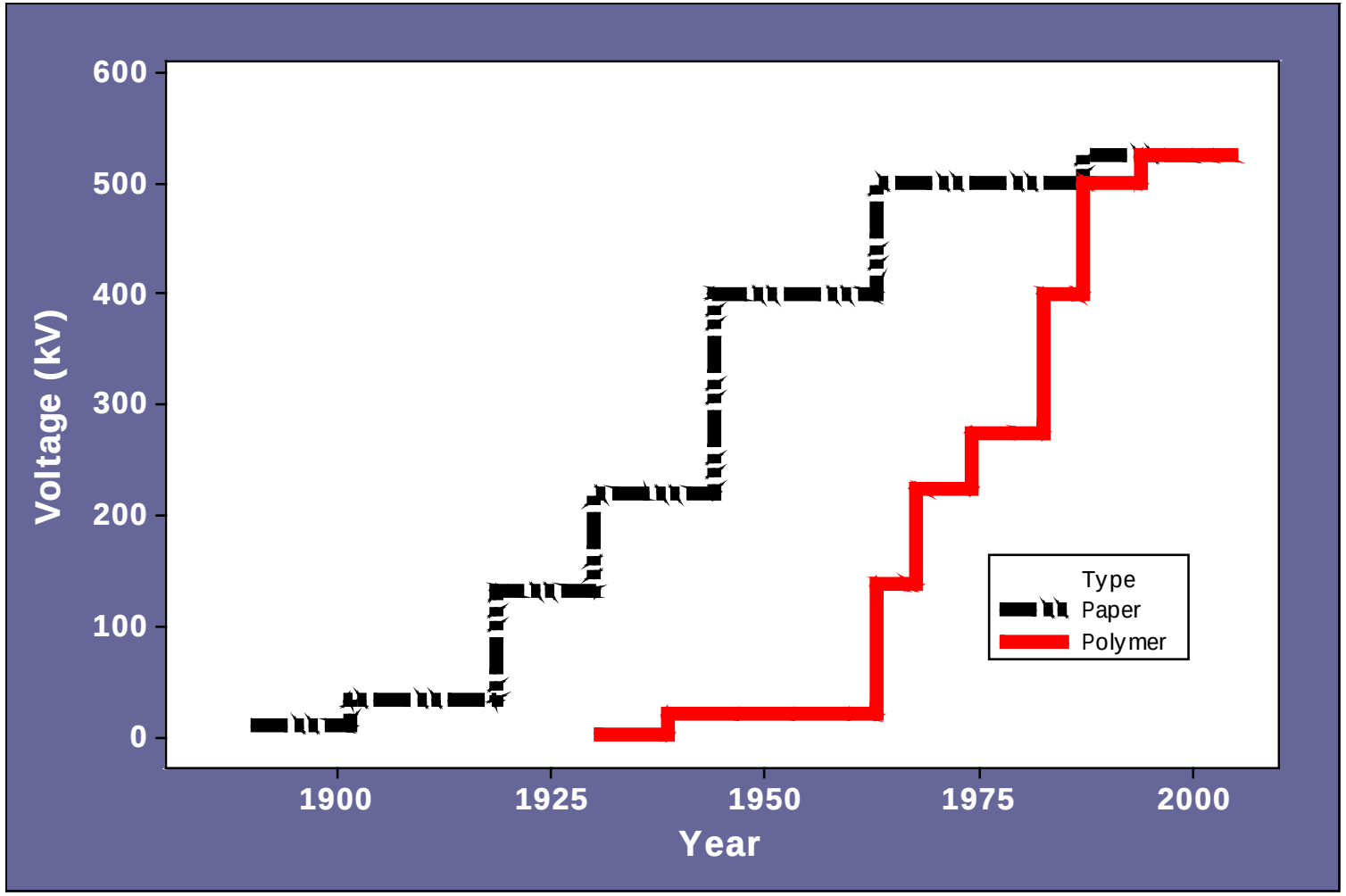
1989: Supersmooth conductor shields for MV cable in North America

1982: WTR materials for MV in USA & Germany

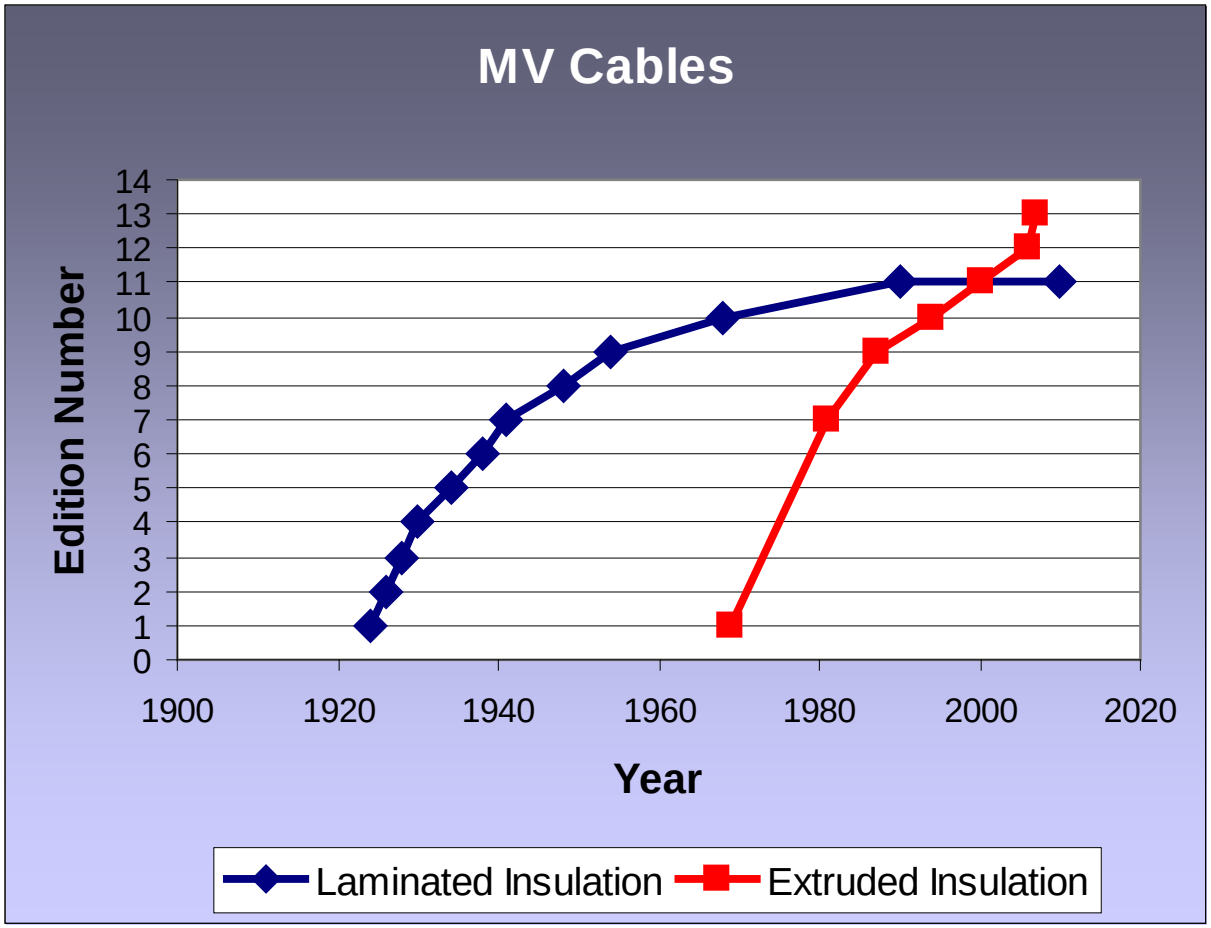
1978: Widespread use of polymeric jackets in US & Ca

Insulation History - Global

Ref [11]



AEIC Standards Development - MV



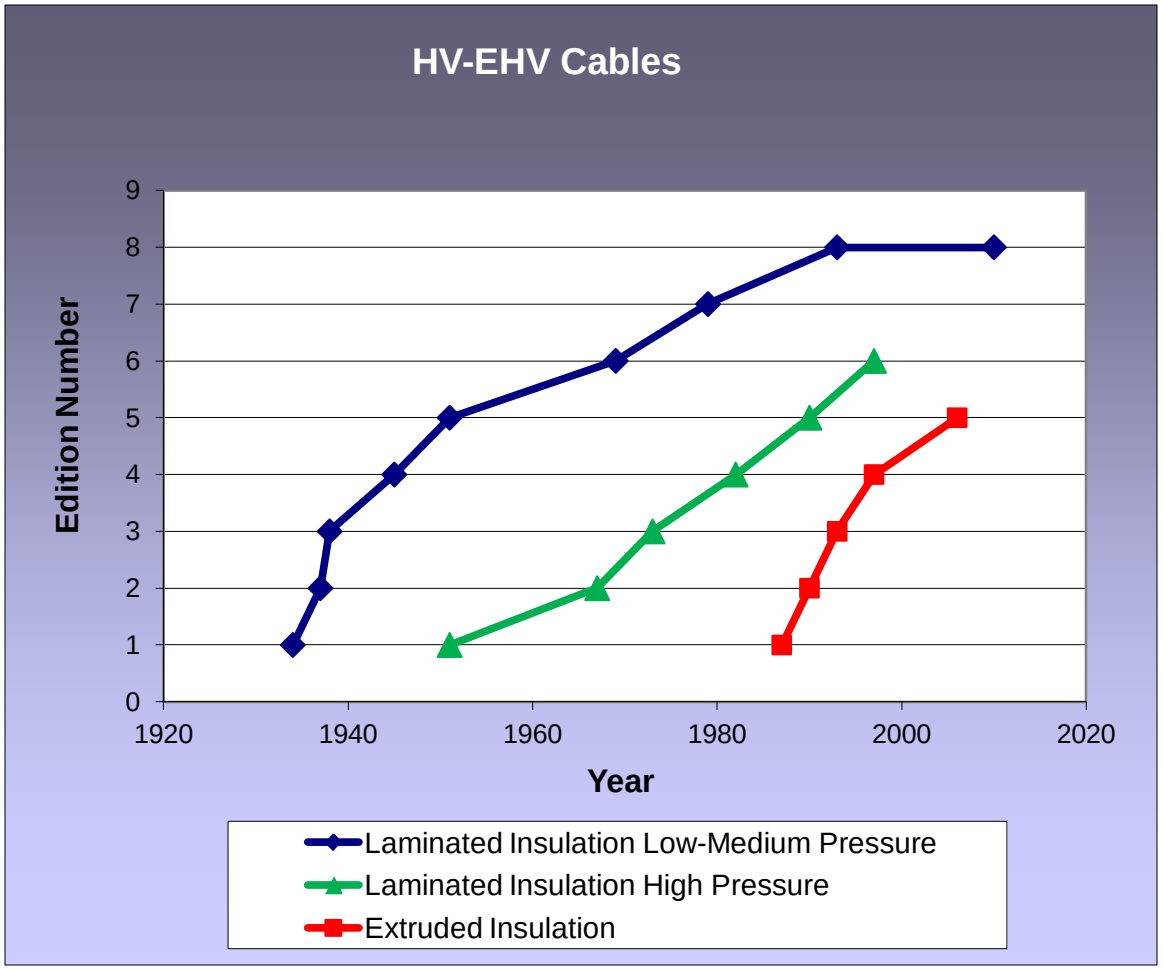
Laminated Insulation:

AEIC CS1

Extruded Insulation:

AEIC CS8 (previous CS5 and CS6)

AEIC Standards Development – HV / EHV



Laminated Insulation:

AEIC CS4 (Low-Medium Pressure)

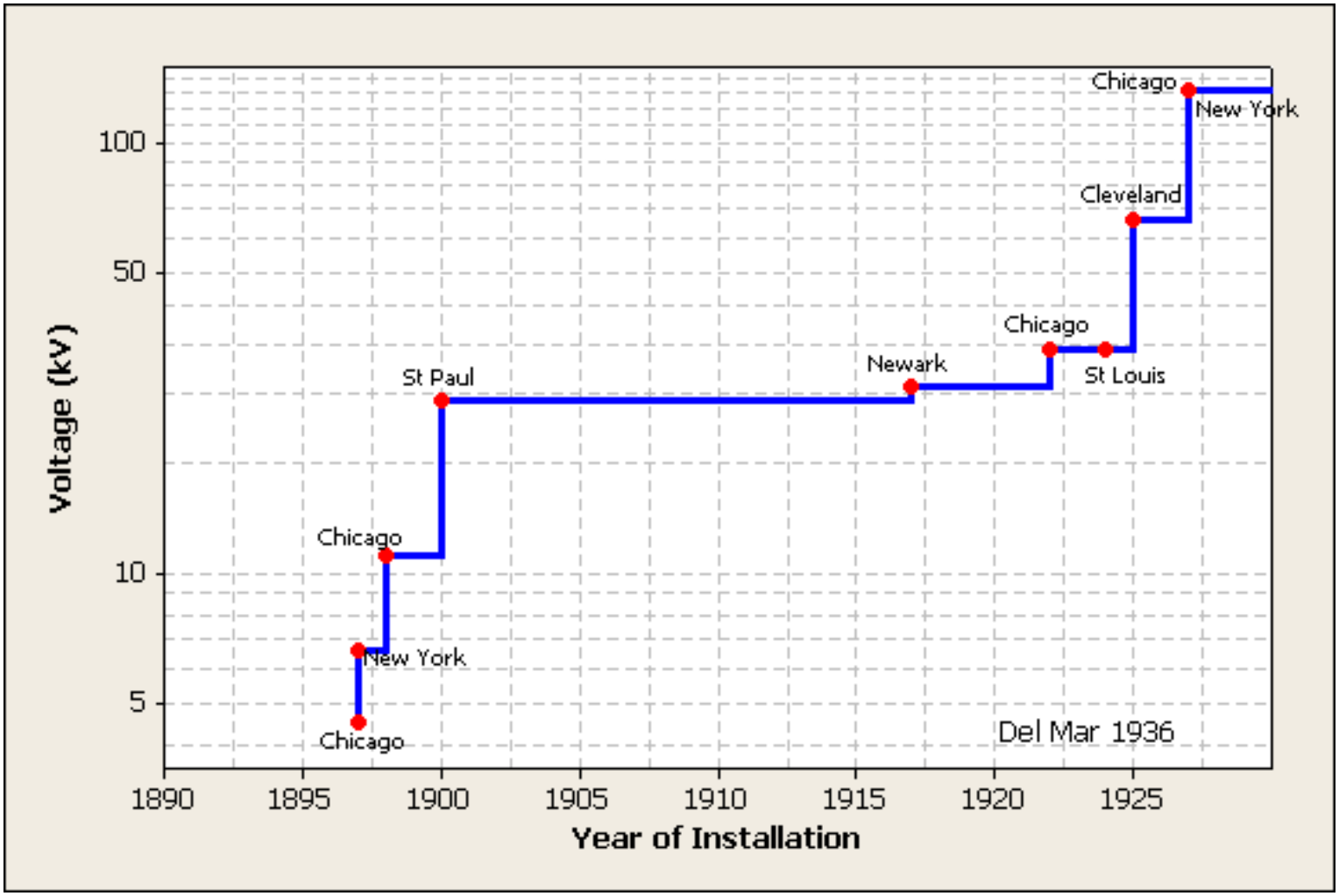
AEIC CS2 (High Pressure)

Extruded Insulation:

AEIC CS7, CS9 and CG4

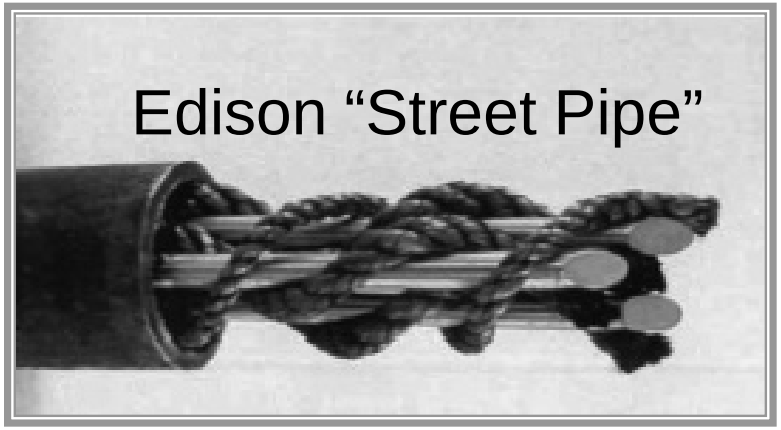
Initial American Installations

Ref [7]

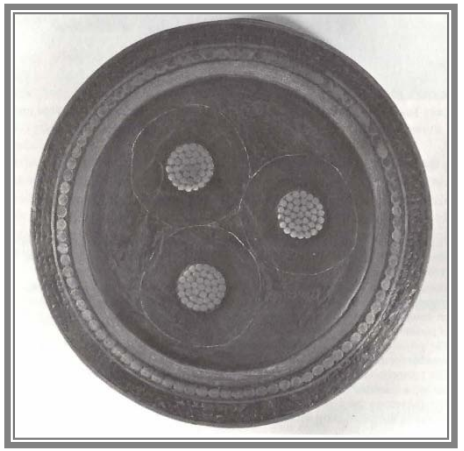


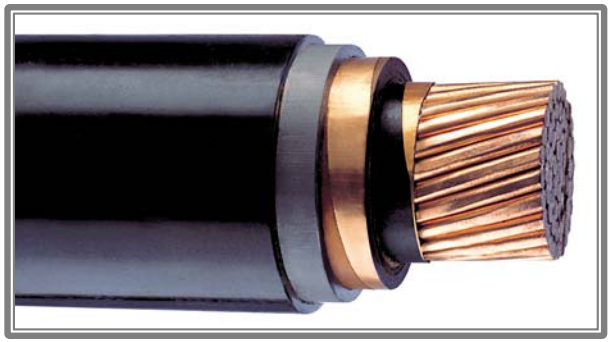
From Edison's to Today's Cable

Picture: Brian Besconnal



Picture: Black, 1983





Pictures: Prysmian

Picture: Southwire

Cable Components

1. Conductor
2. Conductor Shield or Screen
3. Insulation
4. Insulation Shield or Screen
5. Metallic Shield
6. Jacket (Recommended)

Picture: Southwire

1. Conductor

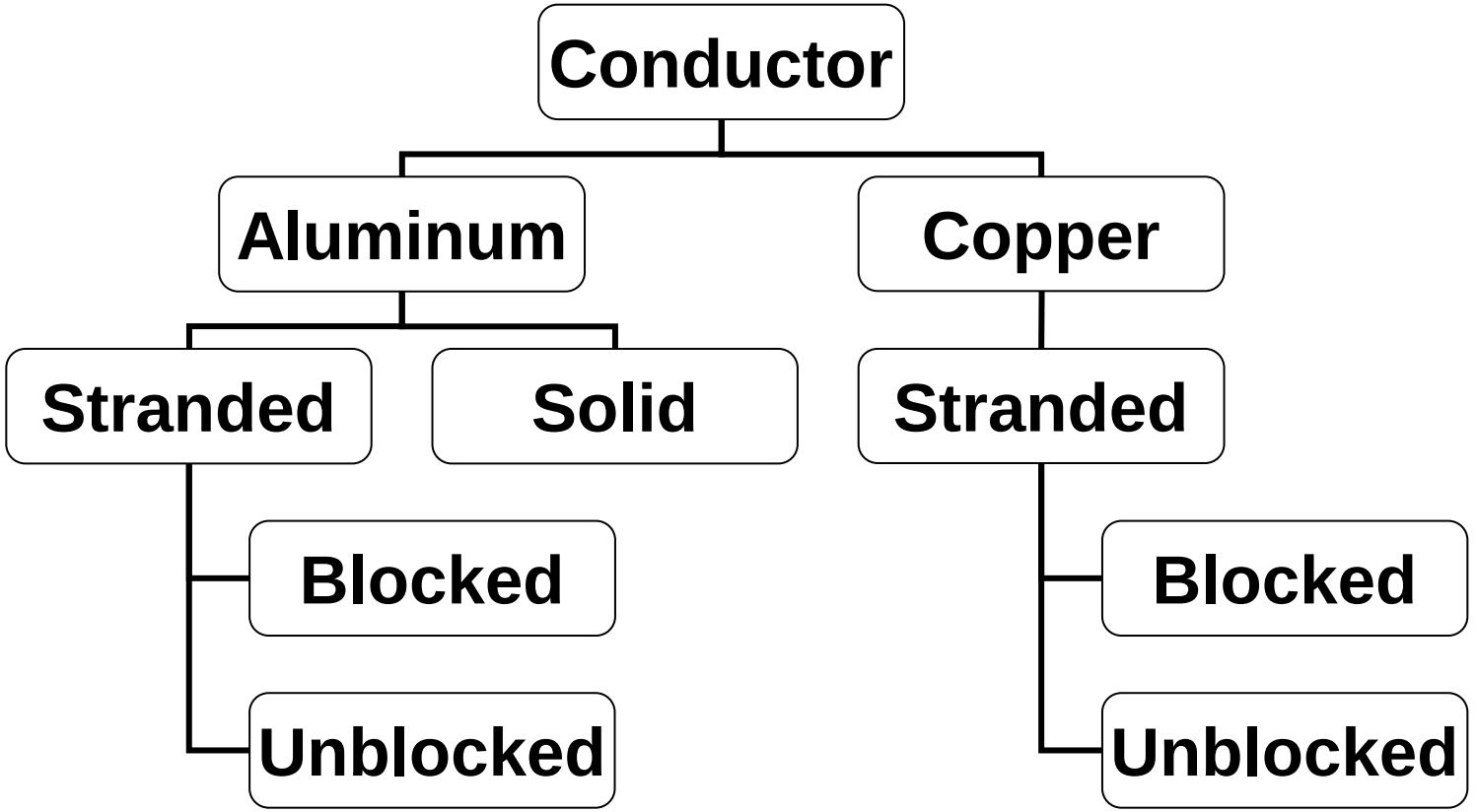
"Carries the current"

- Resistance should be small to reduce power losses:

$$P = R \times I^2$$

- Flexibility, weight and susceptibility to corrosion are concerns together with economical issues such as cost, availability, and salvage value

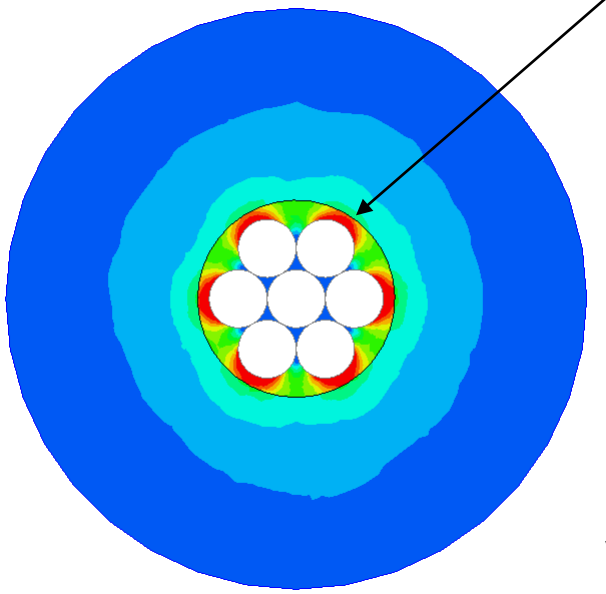
Conductor Characteristics



2. Conductor Shield

"Provides for a smooth interface between the conductor and the insulation"

With no conductor shield, electric field lines are concentrated, creating high stress points at the conductor/insulation interface.

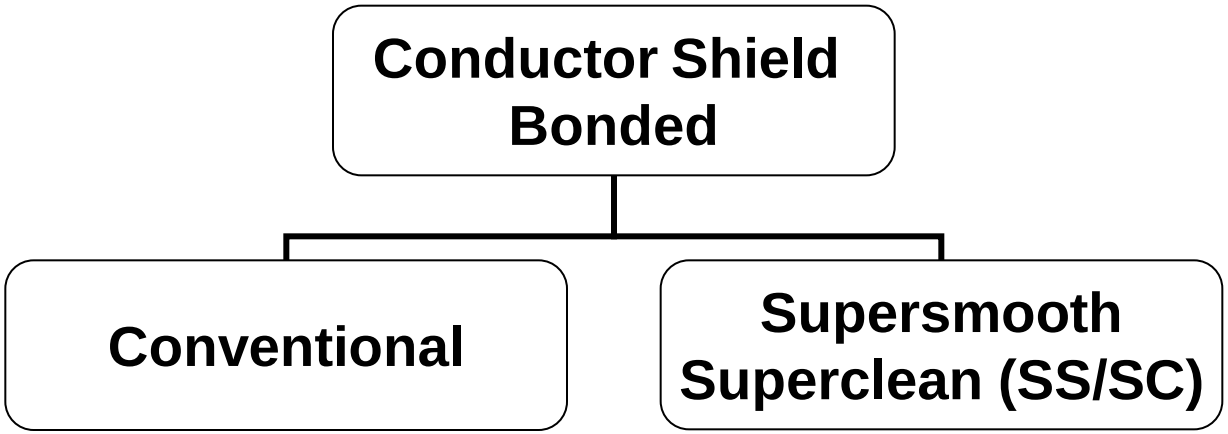


Finite Element Simulation

Conductor Shield Characteristics

Conductor shields are semiconductive, so they are neither an insulator nor a conductor. Semiconducting materials are based on carbon black (manufactured by controlled combustion of hydrocarbons) that is dispersed within a polymer matrix

On larger conductor sizes, tape shields are often used to prevent material “fall-in” between the strands during manufacture

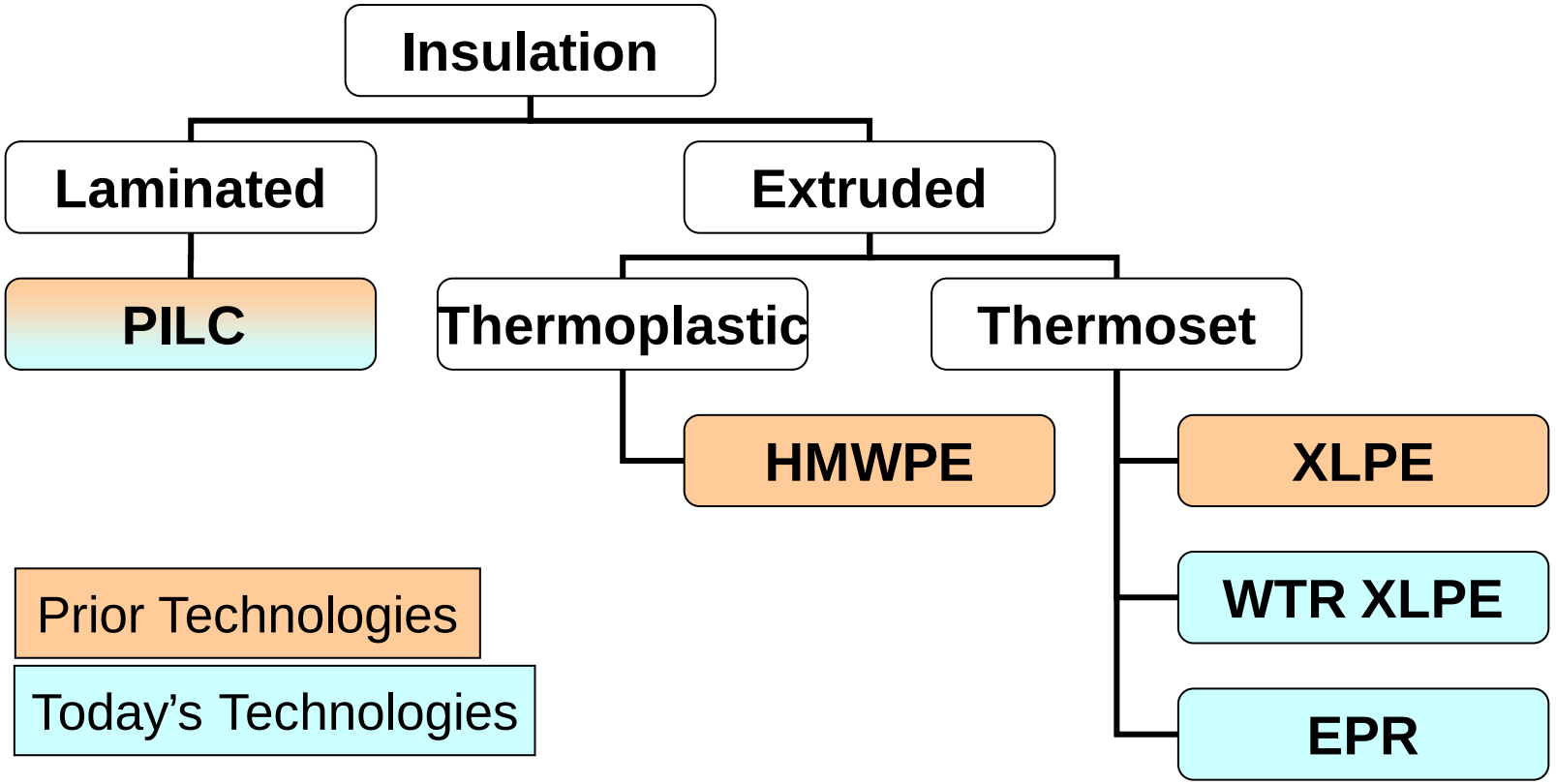


3. Insulation

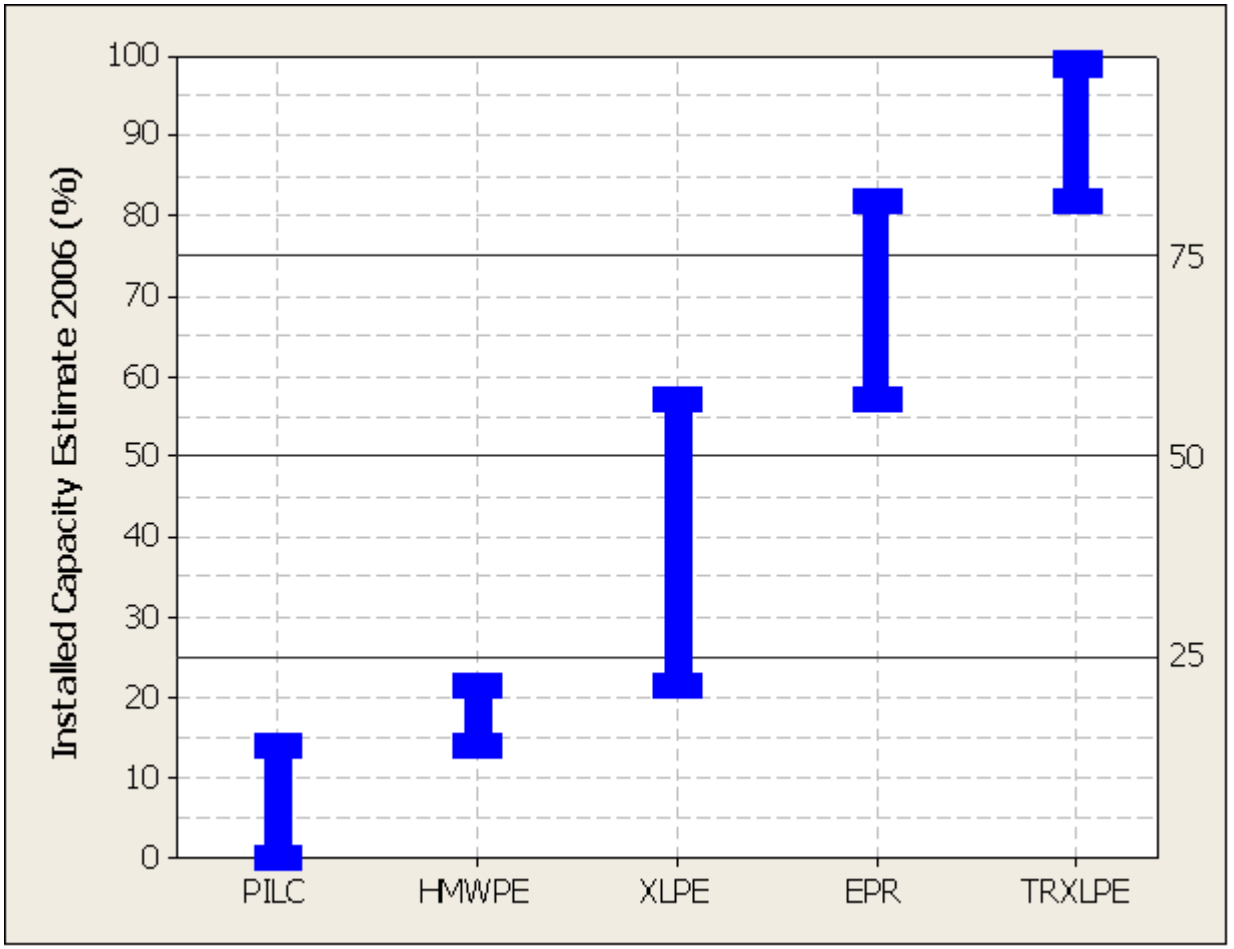
"Contains voltage between the conductor and ground"

- Must be clean
- Must have smooth interfaces with the conductor and insulation shields
- Must be able to operate at the desired:
  - Electrical Stress
  - Temperatures

Insulation - MV



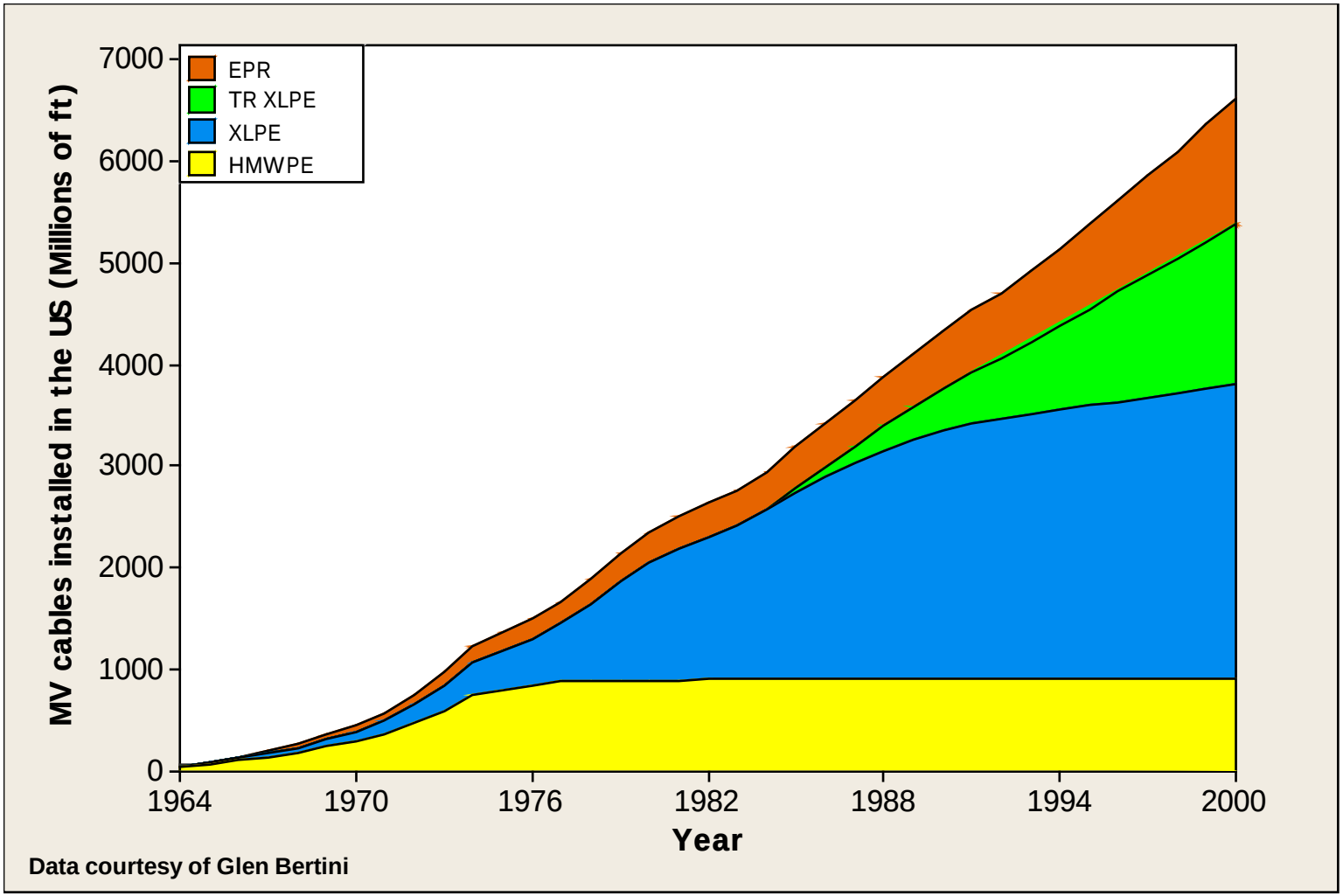
MV Cable "Installed Capacity" In USA



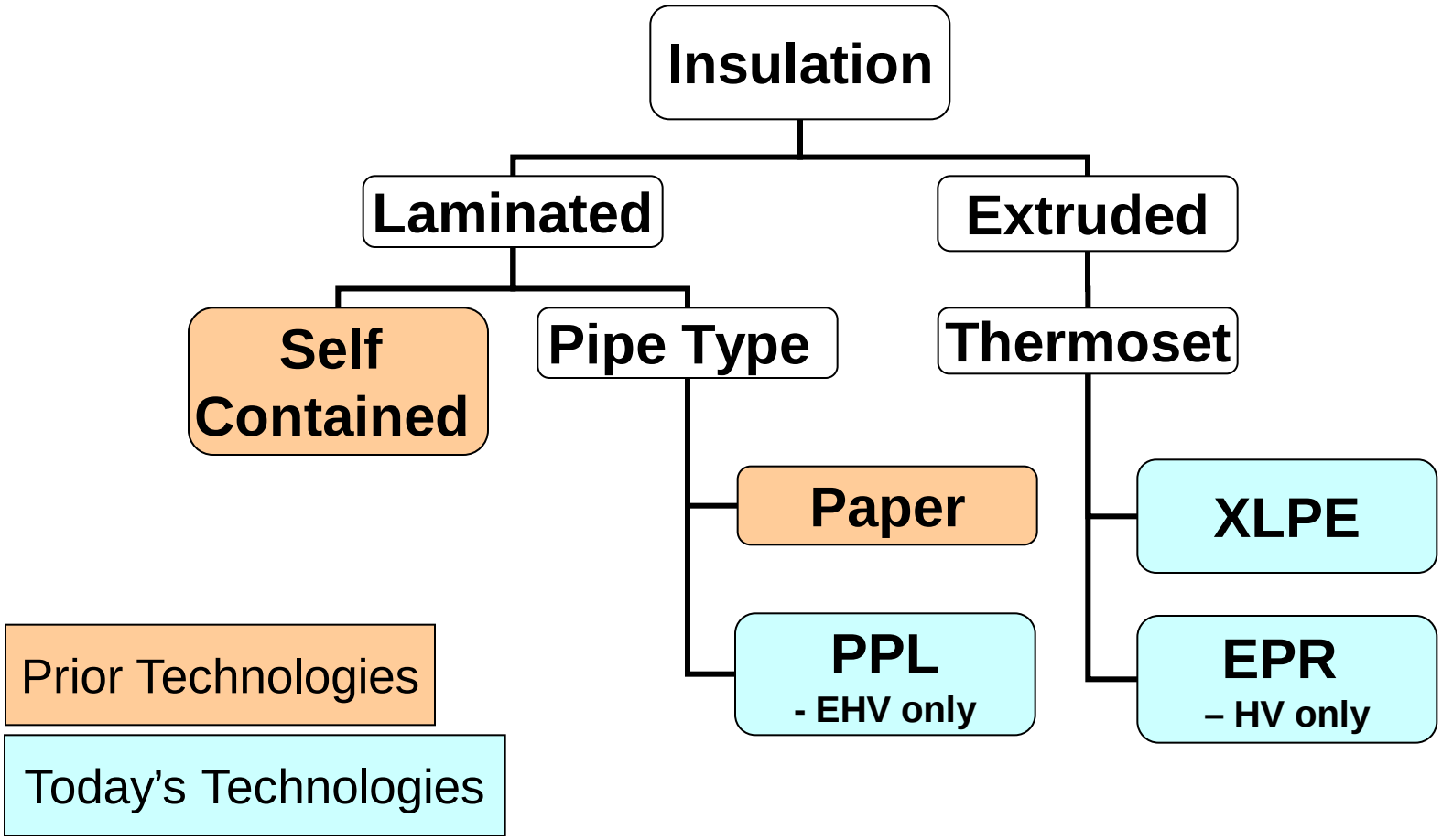
Ref [18]

MV Extruded Cable Installed in USA

Ref [18]



Insulation – HV / EHV

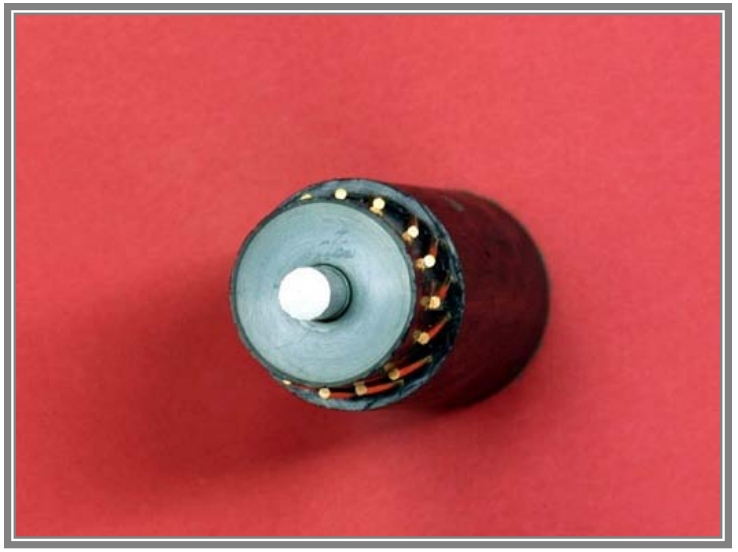


Examples of Laminar Insulation Cables

Picture: Southwire

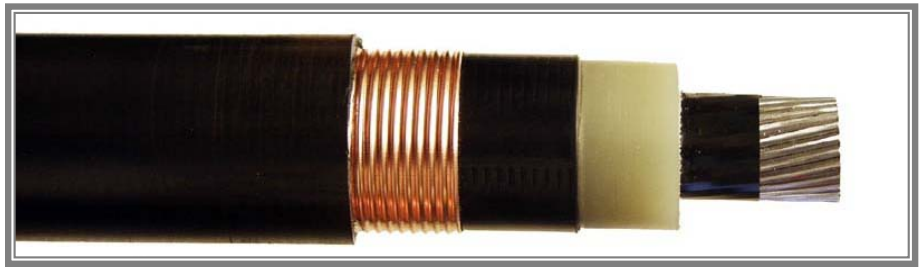
Pictures: Prysmian

Examples of Extruded Insulation Cables



Pictures:

Prysmian

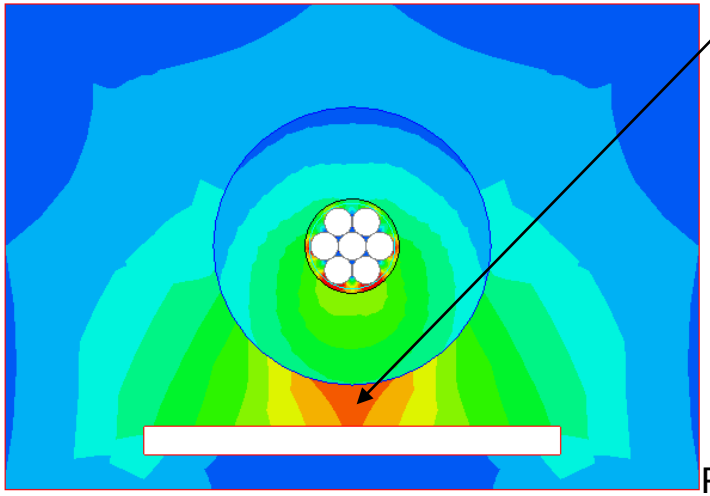


Pictures: Southwire

4. Insulation Shield

"Keeps the voltage and stress within the insulation"

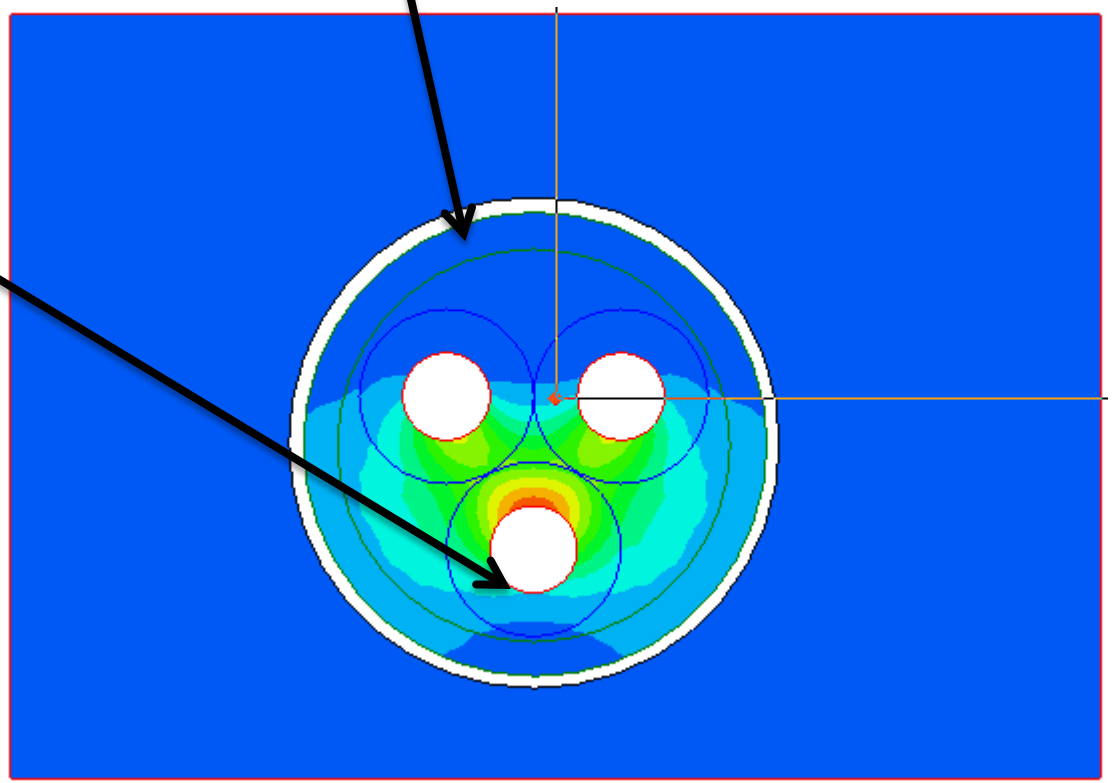
With no insulation shield, electric field lines are concentrated, creating high stress points on the outside surface of the insulation.



Finite Element Simulation

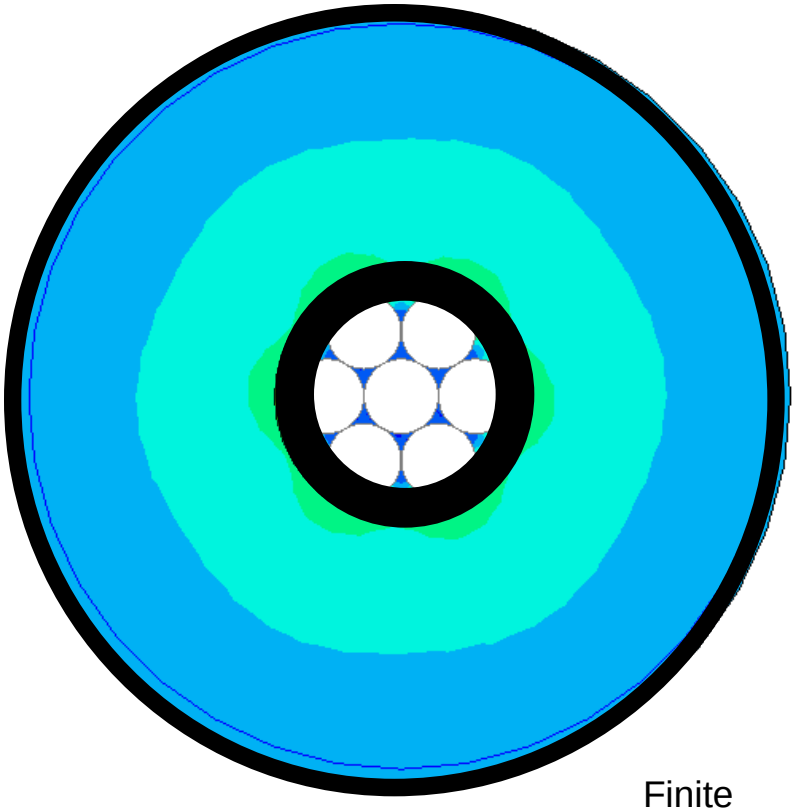
Belted Cables

- Early laminated cables had a “belt” of insulation over the core insulation.
- This led to tangential stresses that were a cause of a lot of early failures



Finite Element Simulation

Conductor and Insulation Shield (CS & IS) Effect



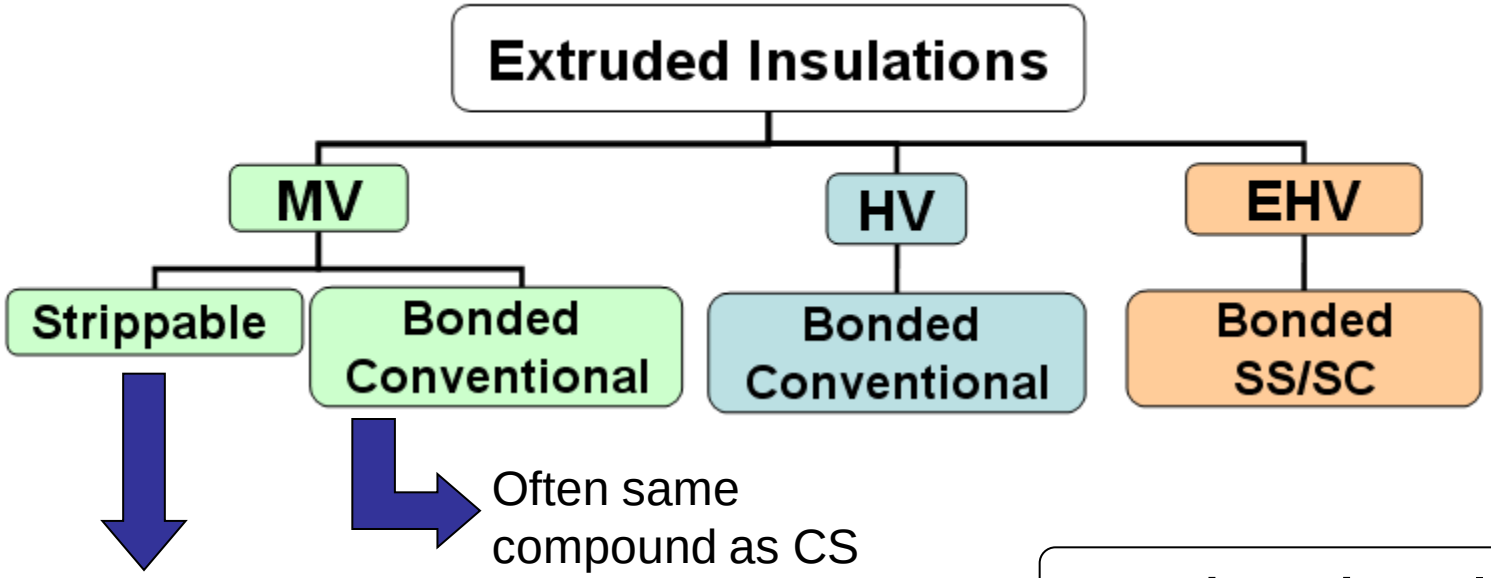
Finite Element Simulation

When both shields are:

- smooth
- intact

Then, electric field lines are uniform, with a controlled electrical stress distribution.

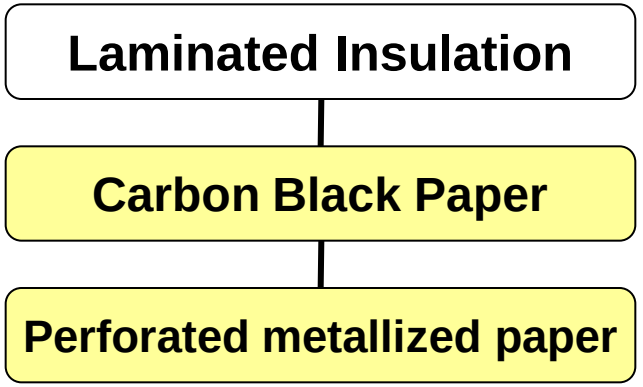
Insulation Shield – MV, HV, and EHV



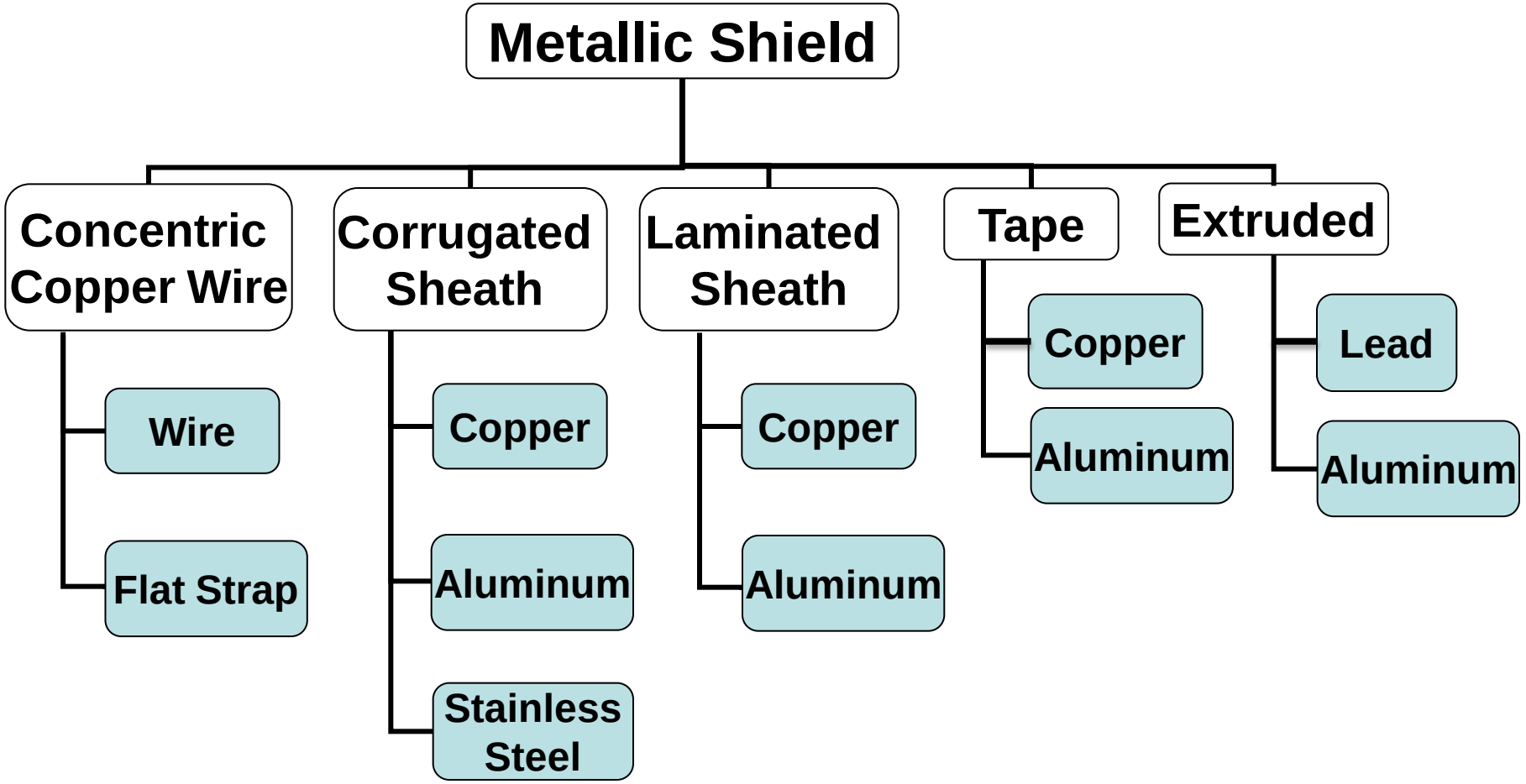
Often same compound as CS

Preferred in North America, Asia & parts of Europe.

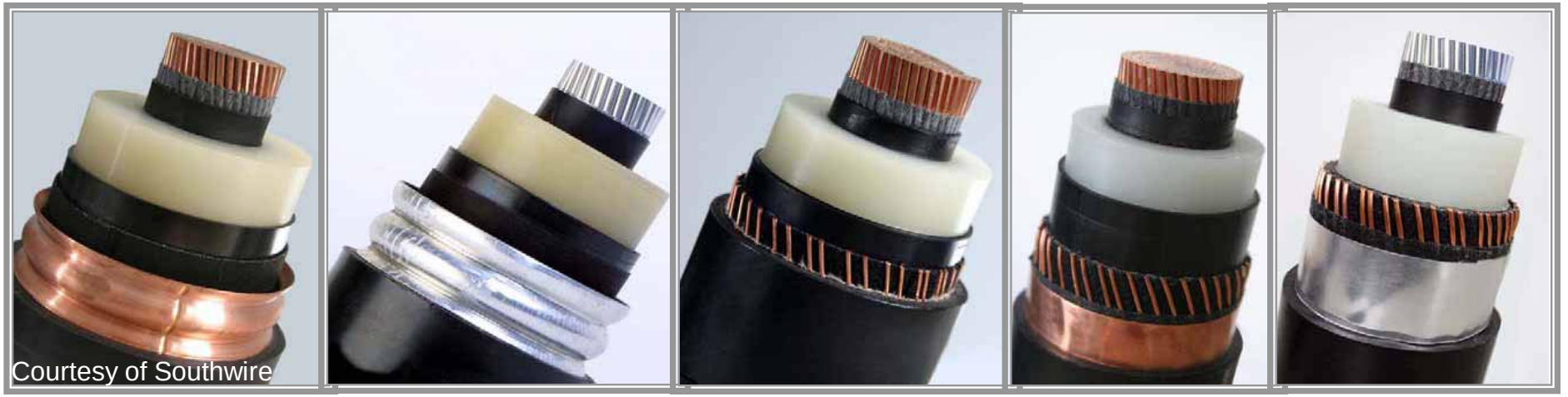
Thought to permit easier termination & splicing of cables <u>but</u> service performance is very dependent upon the workmanship / training of the installer, which is often variable



Types of Metallic Shields



Examples of Metallic Shields



A B C D E

A – Welded Copper Corrugated Sheath

B – Welded Aluminum Corrugated Sheath

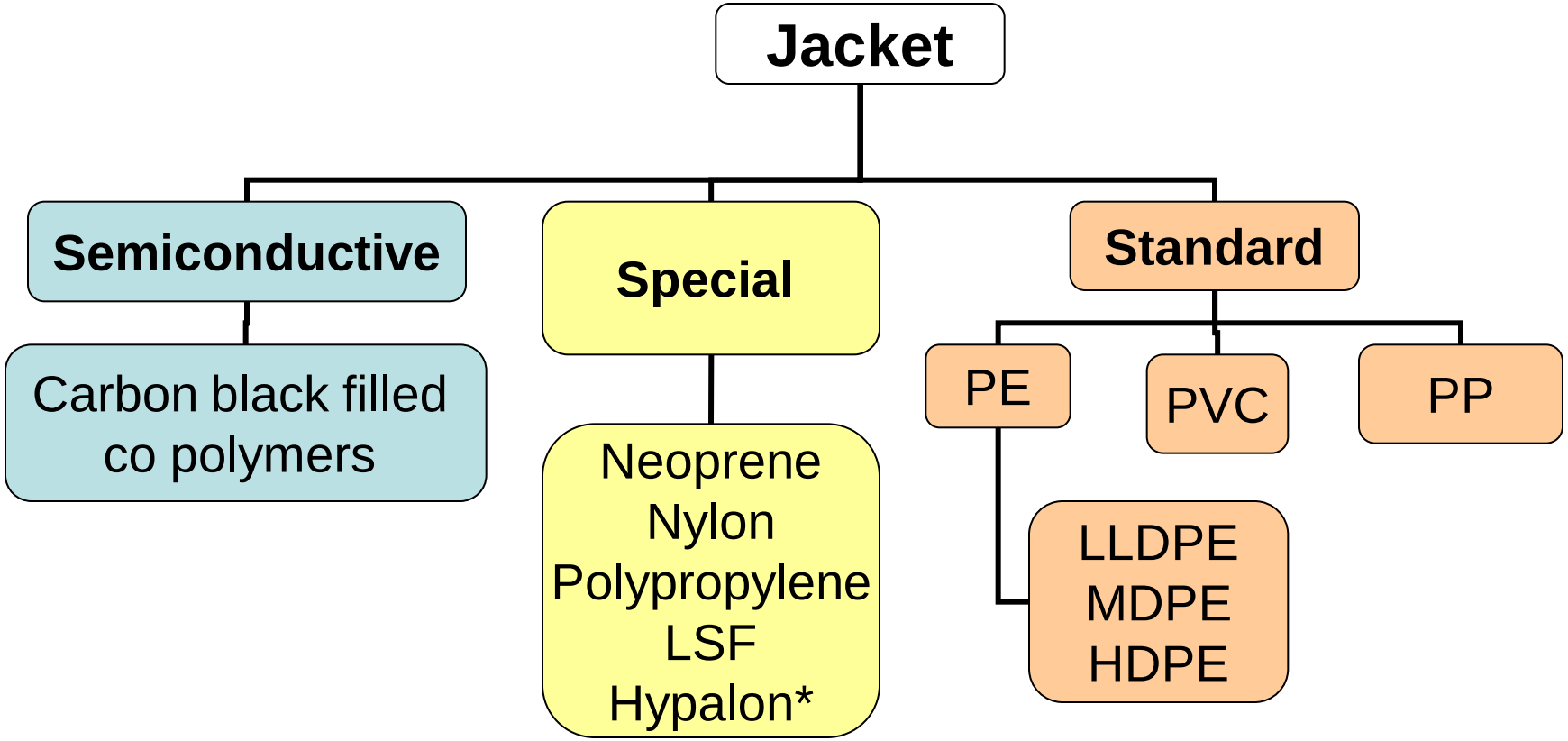
C – Concentric Copper Neutrals

D – Copper Neutrals with Copper Composite Laminate Sheath

E – Copper Neutrals with Aluminum Composite Laminate Sheath

Pictures: Southwire

Types of Jackets Materials



* No longer available

Enhanced Grounding

Chemical / Thermal Resistance

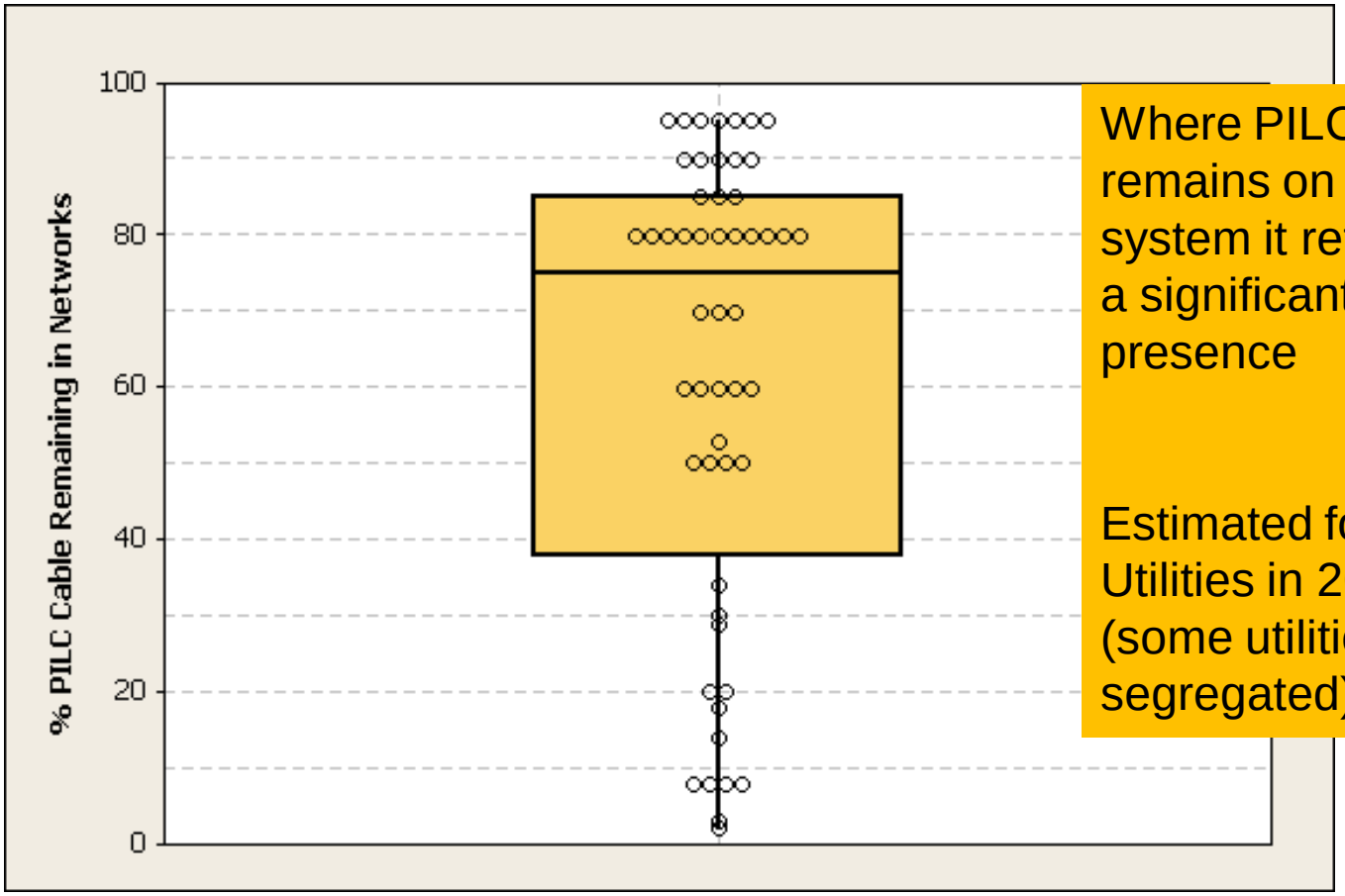
Legacy Issues
Cables

PILC Cables

- Differing designs
  - Belted vs. shielded
  - Jacketed vs. unjacketed
- Lead corrosion (PILC)
- Temperature performance and stability of impregnants
- Draining of compounds
  - Dry insulations
  - Collapsed Joints
- Overheating due to high dielectric losses
- Moisture ingress leading to overheating
- Loss of impregnant due to lead sheath leaks
- Combinations of the above

Remaining PILC in US Networks

Ref [15]

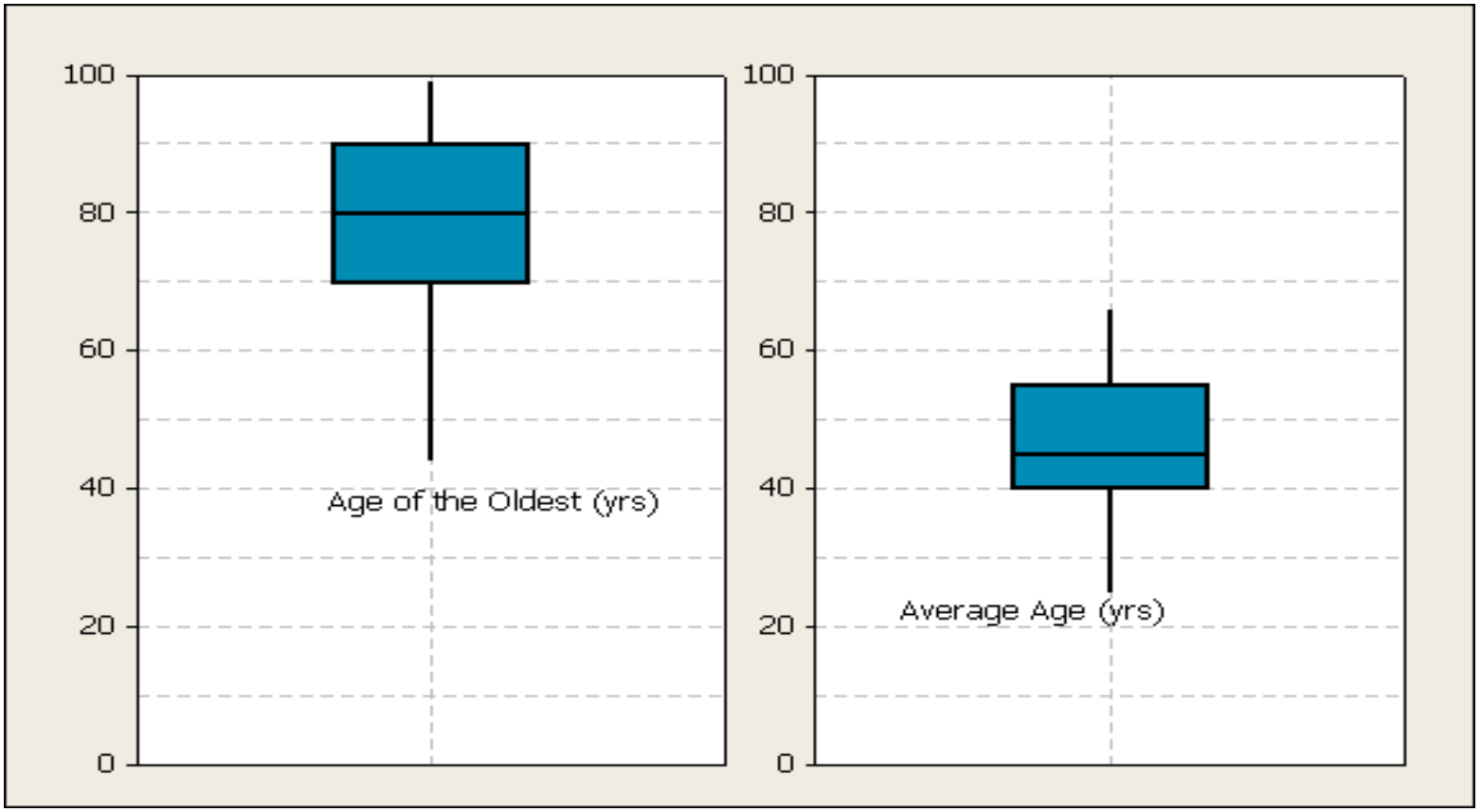


Where PILC remains on the system it retains a significant presence

Estimated for US Utilities in 2010 (some utilities segregated)

The PILC experience teaches us that today's decisions will be with engineers for a very long time

Ref [15]



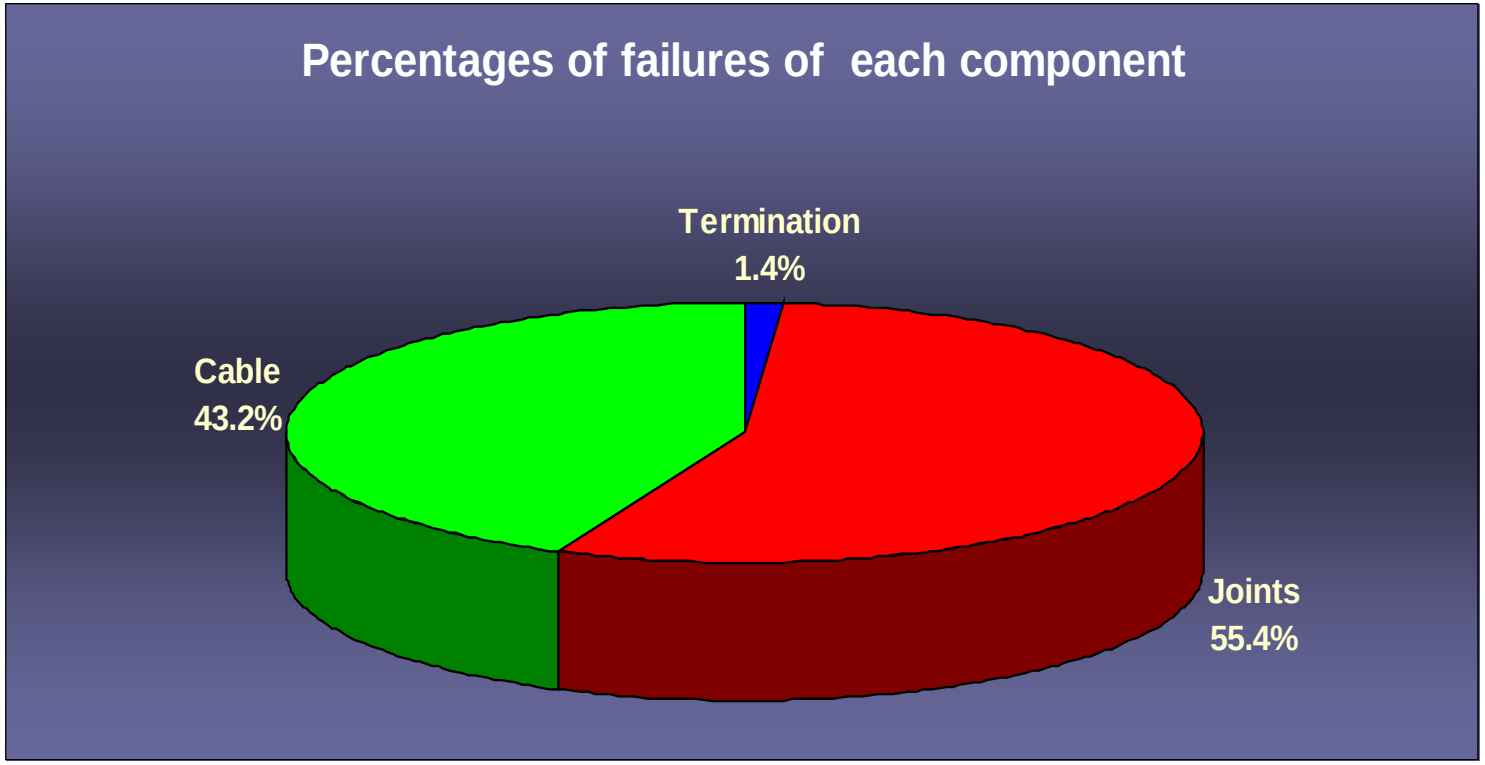
Extruded Cables

- Differing designs
  - Jacketed vs unjacketed
  - Extruded shields vs graphite shields
- Dirty insulation compounds (PE, early XLPE)
- Insulations that were susceptible to water treeing (PE , early XLPE)
- Poor manufacturing processes
  - Open compound handling procedures
  - Changing Formulations (EPR)
- Inadequate cable designs
  - Unblocked conductors
  - Unjacketed cables
  - Cables with inadequate neutral designs
- Combinations of the above

Current Challenges

Percentage of Failures per each Component

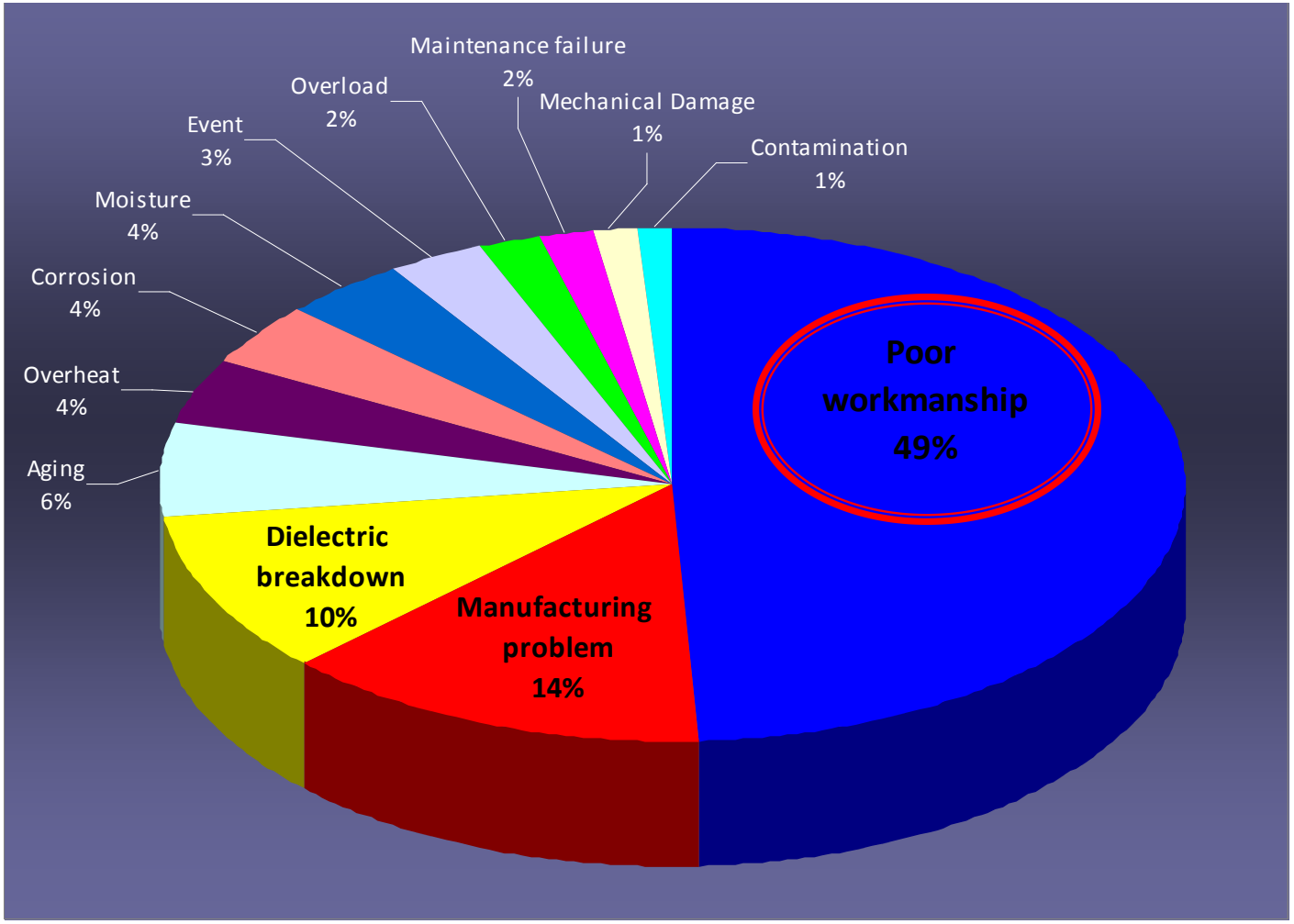
Ref [17]



Accessories: Joints or splices, and Terminations

Failure Modes

Ref [17]



Building a Reliable Cable System