History of Paper Insulated Power Cables

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Early Cable Insulations

- Unvulcanized natural rubber -- 1811
- Glass tubes – 1816
- Gutta-percha – 1841 (Morse, NYC)
- Vulcanized Natural Rubber – Goodyear patent –1844 (telelgraph cable in 1860)
- Parafined Jute & Vulcanized Bitumen – 1879
- Natural rubber for power cables – 1880

Underground Ordinances

- In 1884, New York City:
- All overhead lines had to be removed and placed underground

- By 1900, many cities had same requirement

Paper Insulation

- Earliest paper cable – 1872
  - Bell wire
- Paper cable patent – 1884
  - “Spirally wound vegetable fiber”
- Oil impregnation – 1885
  - Vacuum drying & impregnation

Lead Press

- Invented in 1879 by Borel
- First used for 2 kV cable in 1885
- Flexible cable became possible

First Flexible PILC Cable

- 1885 to 1887, McCracken invented helical paper taping machine
- Electric lighting & telegraph cable
  - Lead sheath extruded over helically applied paper tapes
  - Impregnated by immersing in paraffin wax and then hot resin-oil

Lighting Progress in London

- 2.4 kV 1/Φ overhead cables in 1885
- Transformers on roofs
- Cable hung from messenger
- Sparks ignited the cables
- 400 customers by 1888
- New power station at Deptford

Ferranti in 1886

- 11 kV single phase cables
- Rigid 20 foot lengths
- Single sheets of wound brown paper
- Saturated with “Ozokerite” (a byproduct of candle making)
- 27 miles installed in iron pipes
- Some still in service in 1933

Flexible PILC Power Cable in North America

- Practical PILC in 1895
- National Conduit & Cable 13 kV in 1897
  - Installed in Minneapolis/St Paul
- 1898 Struggle: Paper vs Rubber
  - Use evenly divided between them
  - Higher voltages were with paper because of losses but many skeptics

Insulation Thickness
2 kV Paper Cable

- 1896: 500 mils
- 1900: 290 mils

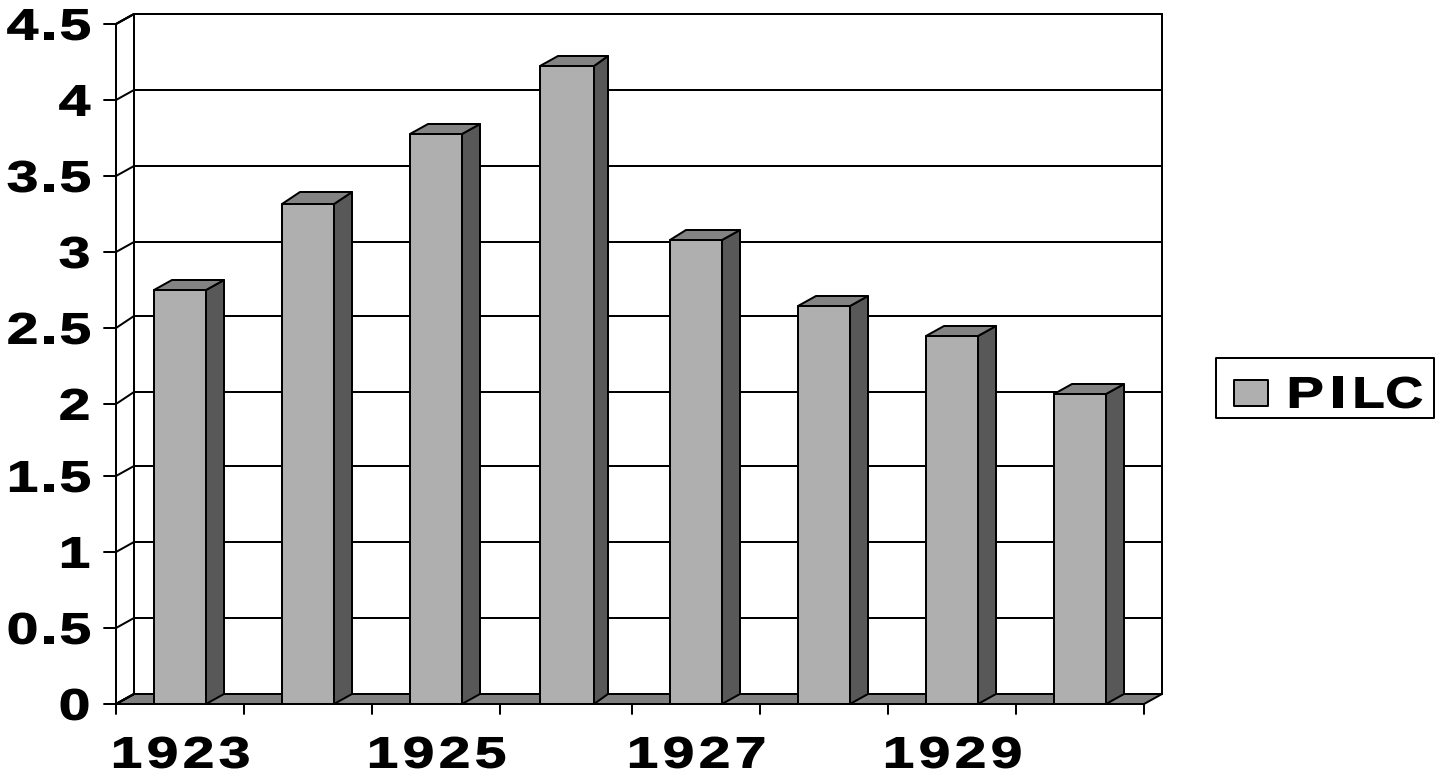
“Fully Established” PILC

- 1900 to 1945
- Few changes made in design EXCEPT shielded 3/c cables – Hochstadter, 1914
- Insulation of choice for medium voltage up to 25,000 volts

Early Impregnating Fluids

- First paper cables made with rosin-oil
- After 1918, petrolatum and pine rosin
- Mid 1920s, viscous paraffin-mineral oil
  - With and without rosin or polybutylene
- By 1940, Sun XX mineral oil
- Polybutene introduced in 1966, 138 kV

PILC Cable Failure Rate Per 100 Miles



Increasing Demand

- End of First WW saw rapid load growth
- Higher voltages needed for T & D
- Prices had been set by U S Government
- Enough business for all four major paper cable companies in US
- Money available for development

Milestones

- 1897: 3/c 5 kV belted in Chicago
- 1910: Sector conductors
- 1920: Shielded 3/c (Type H)
- 1927: SCFF at 132 kV in Chicago
- 1938: LPGF, 3/c, 35 kV
- 1941: HPGF 120 kV in Detroit

Improvements after 1950

- Fully shielded 3/c cables now standard at 15 kV and higher
- Improved fluid impregnation
  - Higher vacuum to dry tapes better
  - Degasification for better impregnation
  - Synthetic fluids
- Lower losses = greater ampacity
- Jackets: Neoprene to polyethylene

Higher Voltages: 69 to 220 kV

- Oil filled cables by Emanueli – 1917
  - Hollow core
  - Low viscosity fluid
  - Oil reservoirs to supply fluid during load cycles
- Pressurized systems – 1927
  - Fisher and Atkinson
  - First used in 1932 at 200 psi

1930: Pipe Type Cables

- Charles Bennett
- Welded gas & oil pipe lines experience
- Eliminated permanent lead sheath
- Rugged protection & pressure vessel
- 200 psi avoided ionization problems

Pipe Type Cable Milestones

- Short length near Philadelphia, 1932
- Installed in 1935 in Baltimore, MD
  - 17,000 circuit feet at 132 kV
  - 675 mils of paper
  - 200 psi using lower viscosity oil than for PILC
- By 1954, more pipe type than self-contained oil-filled in U. S.

Declining Years of PILC

- Need for skilled splicers
- Failures at risers
- Transition joints
- Environmental issues:
  - Lead
  - Oil
  - PCB concerns