INSULATION MATERIAL DEVELOPMENT FOR ELECTRIC POWER EQUIPMENT - A DECADE OF PROGRESS

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BACKGROUND

FACTORS DRIVING NEW INSULATION DEVELOPMENT:

- MORE ENVIRONMENT-FRIENDLY EQUIPMENT
- IMPROVED THERMAL PERFORMANCE
- MORE ROBUST INSULATION LEADS TO MORE COMPACT DESIGN --> POTENTIAL FOR LOWER PRODUCT COST

HINDRANCE :

- UTILITY CUSTOMERS ARE VERY CONSERVATIVE IN ACCEPTING NEW INSULATION MATERIALS;
- NEW MATERIALS ARE USUALLY MORE EXPENSIVE.

TODAY'S DISCUSSION LIMITED TO:

- ELECTRICAL INSULATION FOR TRANSMISSION AND DISTRIBUTION EQUIPMENT
- INSULATION DEVELOPMENT WITHIN THE LAST 10 YEARS

OVERVIEW - TRADITIONAL INSULATION MATERIALS

EQUIPMENT	CONDUCTOR INSULATION	FILM INSULATION	DIELECTRIC MEDIUM
Fluid-filled transformers (power, distribution, instrument)	• Kraft paper • polyvinyl formal (Formvar) • polyester w/ PAI topcoat • epoxy powder coating	• Kraft paper • Thermoplastic polyester (Mylar)	• Mineral oil • Silicone fluid • High-temp. hydrocarbon fluids • SF_6
Dry-type transformers (distribution, instrument)	• Aramid paper (Nomex) • polyvinyl formal (Formvar) • polyester w/ PAI topcoat	• Nomex • Mylar • Glass mat saturated w/ casting resin	• Bis-phenol A epoxy • Cycloaliphatic epoxy • Polyurethane • Polyester or silicone varnishes + air

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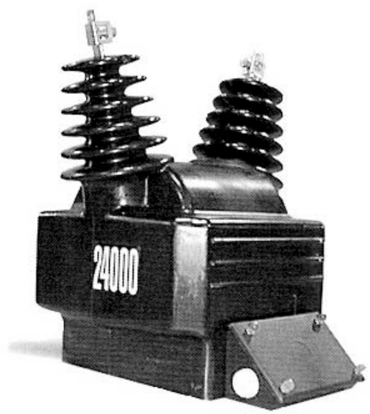
OVERVIEW - TRADITIONAL INSULATION MATERIALS (CONT'D)

DT winding cross-section

Instrument transformer



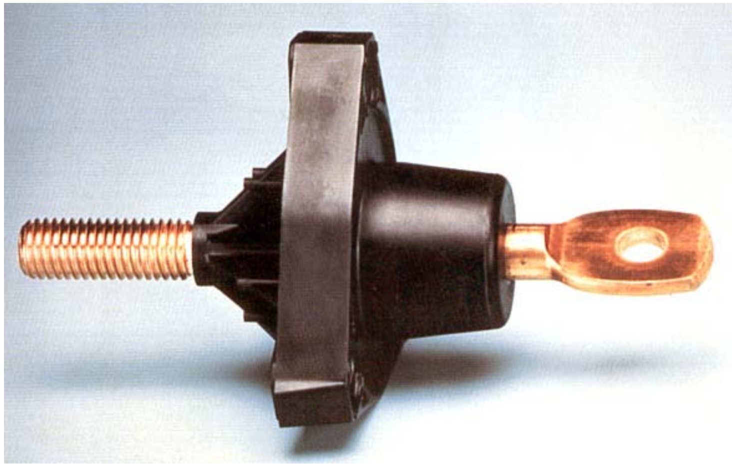
Resin cast distribution transformer

OVERVIEW - TRADITIONAL INSULATION MATERIALS (CONT'D)

EQUIPMENT	FILM INSULATION	DIELECTRIC MEDIUM	OUTDOOR INSULATION
HV bushing - oil-filled	• Kraft paper	• mineral oil	• Porcelain
- dry type	• paper	• epoxy resin	• Silicone rubber • porcelain
LV bushing –	None	• Epoxy molding compound • Porcelain • Polymer concrete	None
HV Capacitors	• Polypropylene • Paper/polypropylene	• Isopropyl biphenyls • Phenyl xylyl ethane	Porcelain

OVERVIEW - TRADITIONAL INSULATION MATERIALS (CONT'D)

HV distribution bushing

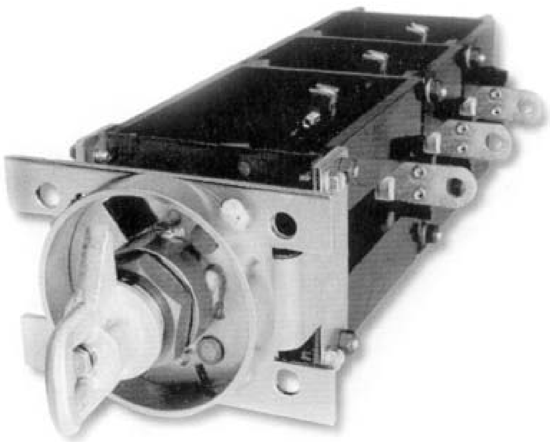


LV distribution bushing

OVERVIEW - TRADITIONAL INSULATION MATERIALS (CONT'D)

EQUIPMENT	OTHER INSULATION	DIELECTRIC MEDIUM	OUTDOOR INSULATION
Power circuit breakers	• Glass reinforced polyester	SF_6	• None
Switchgears	• Epoxy powder coating on bus bars • Glass reinforced polyester	• Air • Vacuum	
Switches (air, oil type)	• Molded glass reinforced polyester parts • Filament wound epoxy housing	• Air • Mineral oil	• porcelain
Fuse cutouts	• polyacetal arc chute • filament wound epoxy tube	•	
Reclosers		• vacuum • air • mineral oil	• Porcelain

OVERVIEW - TRADITIONAL INSULATION MATERIALS (CONT'D)



Loadbreak oil switch

Recloser with resin cast bushings

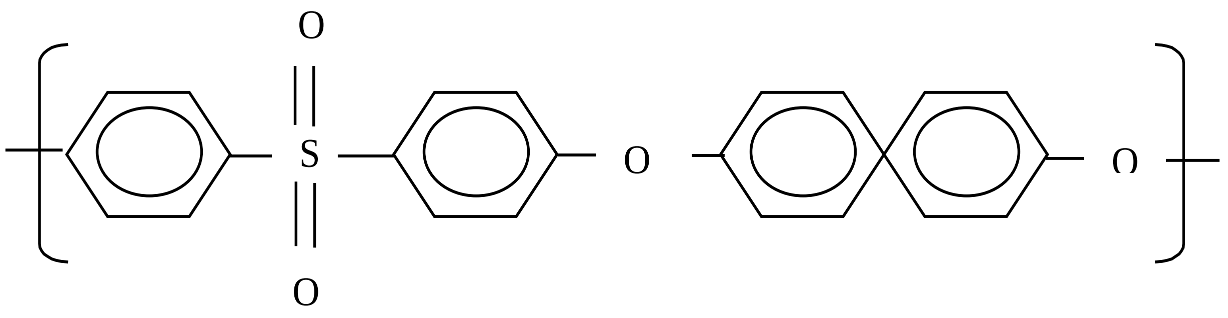
I. New Conductor Insulation

1. Melt extruded thermoplastic coatings

Advantages: solventless, one pass vs. multiple pass for enamel, improved concentricity.

1.1 Polyphenyl sulfone (Amoco Radel R) coated rectangular wire

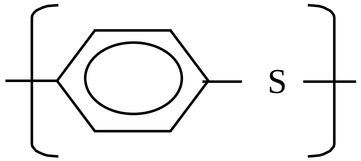
- Jointly developed by ABB & HMC
- Class H (180°C) insulation
- Used in oil-filled distribution transformers (OFDT) since 1993.



I. New Conductor Insulation

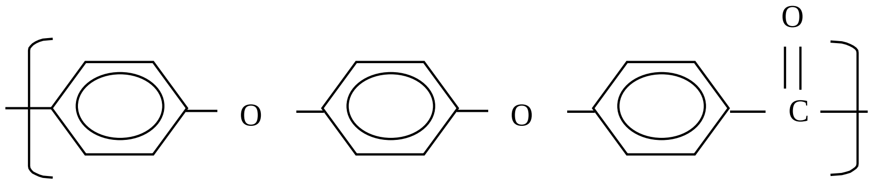
1.2 Polyphenylene sulfide (PPS) coated wire

- Being jointly developed by Hoescht-Celanese & Southwire
- Promising 180°C material.
- Ability to extrude thin film consistently is main issue.



1.3 Polyetherether ketone (PEEK) coated round wire

- Developed by Phelps Dodge.
- Estimated 250°C rating
- High cost is a deterrent.



I. New Conductor Insulation (cont'd)

2. Film tapes

2.1 Lower cost, very thin Nomex® (aramid) film (1.5 -mil thick)

- Introduced by DuPont in early 1990's
- Strong thin film with improved oil impregnability
- Used in new and refurbished OF transformers

2.2 Microporous polyester composite film Quintek 163

- Jointly developed by MagneTek & Quin-T
- Thermal and electrical properties and cost between Kraft paper and aramid paper.
- Long term hydrolysis is main concern.

2.3 Polyester film tape coated with B-staged epoxy adhesive

- Developed by Bharat Heavy Electricals (India)
- Windings made with conductor wrapped with this film have improved short circuit resistance over Kraft paper taped winding
- Implementation plan hasn't been disclosed

I. New Conductor Insulation (cont'd)

3. Wire enamels

3.1 Heat curable enamels

- Focus is on on improving the thermal and corona resistance of the insulation for motors
- Polyester-based insulation may be applicable for dry type transformers

3.2 Ultraviolet (UV) radiation cured coatings

- ABB has been conducting prestudy on this new insulation technology for sheet conductor and bus bars. Some advantages:
  - very fast curing mechanism
  - can be designed as a dual cured (UV + heat) material
  - good electrical, thermal and chemical resistance

II. New Film (Layer) Insulation

1. **Polyethylene naphthalate (PEN)**
   - Thermoplastic polyester developed by ICI and Dupont.
   - Similar to PET Mylar® with higher Tg and improved hydrolytic resistance.
   - 180°C thermal rating.
   - Possible conductor insulation for gas insulated transformer

2. **Improved strength Kraft paper** Thinflex® at low thickness (3-mill or 75 microns)
   - Developed by EHV-Weidmann as interleaving insulation for sheet conductor in OFDT's
   - Strong thin paper allows reduction of insulation thickness --> improved space factor in winding of OFDT's --> reduced cost. All other properties similar to regular Kraft paper.

3. **Paper-Mylar-paper laminate ET 1721**
   - Recently introduced by Bedford Materials
   - Intended for same application as the EHV Thinflex paper above
   - Better dielectric and mechanical properties at same thickness

III. Molding Compounds

1. Reinforced thermoplastic polyesters (PET and PBT)

Replacing traditional thermosets (epoxy, polyesters) in transformer component applications such as:

- LV bushings for OFDT's ;
- Load tap changer in OFDT's
- Load break oil switch housing, etc.

Advantages are lower component cost from improved manufacturing efficiency, and less scrap.

IV. Resins - Impregnating and Casting

1. Impregnating resins. Main thrusts of the development effort are:

(a) To reduce impact of solvent emission into the environment - water based, high-solid and solventless systems;

(b) To increase thermal rating of the insulation (up to 200°C)

New impregnating systems are mostly designed for motors and small transformers.

2. Casting resins. Emphasis on higher temperature rating and/or improved toughness.

2.1 155°C rated (class F) novolac epoxy

- Developed by Bharat Heavy Electricals (India) for insulators
- Less expensive with comparable performance than bis-phenol A epoxies.

2.2 200°C rated Araldite CW229 epoxy

- Developed by Ciba Specialty Chemicals
- Good mechanical and electrical properties
- Suitable for dry type transformers, post insulators, switchgear components.

IV. Resins - Impregnating and Casting (cont'd)

2. Casting resins (cont'd)

2.3 Crack-resistant epoxy resin developed by Ciba.

- Withstood thermal cycling from 150°C to -50°C without cracking
- Toughening achieved through addition of rubber particles Core/Shell
- Suitable for all casting applications that are subjected to drastic temperature swings.

2.4 180°C (class H) Polyether Amide Resin (PEAR),

- Being commercialized by PEAR Development Corp. (Canada)
- A lower cost alternative resin to premium high temperature epoxies
- Outstanding mechanical strength,
- Good resistance to thermal cycling from -80°C to 200°C
- Suitable for HV insulators and dry type transformers.

2.5 Castor-oil based polyurethanes

- Very good toughness, highly crack resistant.
- Lower cost alternative to epoxies
- Already used in instrument transformers. Suitable for recloser.

V. New Dielectric Fluids

1. Biodegradable vegetable-based oils:

1.1 Biotemp® developed by ABB
- Used in oil-filled transformers
- 97% biodegradable, higher fire point than mineral oil
- Improved electrical performance
- Its use in other liquid filled power equipment is being investigated.

1.2 Envirotemp® FR3 by Cooper Power
- Used in oil-filled transformers
- High biodegradability
- Improved electrical performance

1.3 Rape-seed based oil developed in India as a capacitor fluid.
- Claimed to be non-toxic, low flammability
- Its properties were comparable with standard capacitor fluids based on testing in a 21 kV, 20,000pF power capacitor
- Commercialization plan is not known.

V. New Dielectric Fluids (cont'd)

2. Biodegradable synthetic oils

2.1 Synthetic hydrocarbon blend Edisol TR by Cooper Power

- degrades faster and more completely than mineral oil
- superior dielectric properties
- higher fire point

2.2 Dielectric Systems (WI) has developed several synthetic hydrocarbon based fluids (Alpha, Beta and ECO series) with varying degree of biodegradability.Compared to mineral oil:

- ECO fluids have the highest biodegradability (90%)
- lower viscosity
- equivalent or better electrical performance

3. Environmentally safer fluids

3.1 Perfluorinated ether Galden HT 135 commercialized by Ausimont (Italy)

- complete non-flammability
- does not biodegrade, does bio-accumulate
- adequate but not excellent electrical properties

CONCLUSION

- There are very few new insulation materials developed specifically for electric power equipment. Mostly, improvements were made with existing materials already in use elsewhere. The exception may be in the dielectric fluid area.

- In the short term, deregulation of the electric utility industry will impede new insulation development. Utilities are not willing to pay more for equipment due to difficulty in passing on the extra cost to their customers.

- The next significant breakthrough in insulation material for electric power equipment will most likely be the conductor insulation as driven by motor and aerospace applications. The high temperature coating would be thinner yet tougher with high dielectric strength, and can be applied on conductor in an environmentally safer process. Example: radiation-curable coatings.