The correct jacket is required

The next step in outdoor instrument transformers

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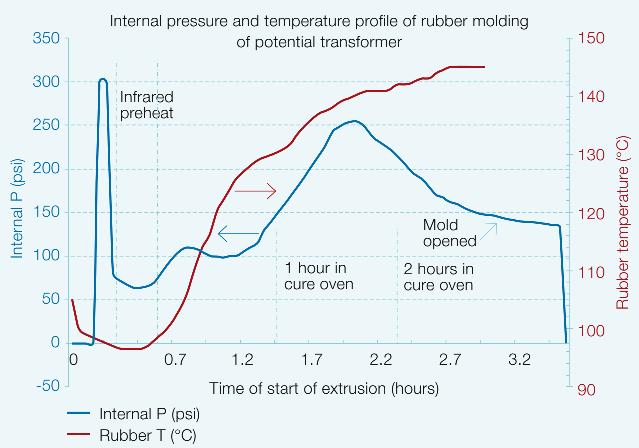
Instrument transformers convert voltage or current from high values, which are carried by the transmission and distribution networks, to lower values, which can be used by low-voltage devices. They are used for metering (energy billing and transaction purposes), protection (protective relays and system protection), control (system control functions) and load surveying (economic management of industrial loads). The design and construction of the instrument transformer can be quite different depending on the applications it is used for. Generally, metering instrument transformers require high accuracy in the range of normal operating voltage and current, while protection instrument transformers require linearity in a wide range of voltages and currents.

During disturbances, such as system faults or transient over-voltages (surges or spikes), the output of the instrument transformer can be used, via a protective relay, to initiate an appropriate response. This may be to open or close a breaker, or reconfigure the system so that the disturbance is mitigated and the rest of the system remains protected. Instrument transformers are the most common and economic means of detecting such disturbances. This they must do, even when subjected to a variety of outdoor environmental stresses such as ultraviolet radiation, pollutants, humidity, rain, temperature variations and salt fog. To perform well in these tough environments, ABB constantly reviews the materials used to protect its instrument transformers.

R & D focus

In the late 1960s, butyl rubber was the prevailing dry-type insulating medium for medium-voltage (up to about 40 kV) instrument transformers. Properly compounded outdoor-grade butyl rubber is a very good insulator and proprietary formulations of butyl rubber are still used by some instrument transformer manufacturers today. The high processing pressures (more than 15 times atmospheric pressure) required for rubber molding and curing are not, however, ideally suited to the preservation of exact dielectric clearances and geometries of the core-coil assembly that are required for the proper performance of the transformer[1] 1. This limitation has motivated continued investigations into alternative insulating materials for outdoor instrument transformers (OIT).

1 Typical temperatures and pressures associated with butyl rubber molding of instrument transformers.



Note that pressure (P) peaks briefly at 300 psi during the extrusion step and later at 250 psi during the curing (vulcanization) of the rubber. (Courtesy of Westinghouse Electric Corp.)

Liquid casting resins were evaluated and found to be excellent alternatives to butyl rubber dielectrics. Their starting ingredients can be pumped, metered, mixed and dispensed either under moderate vacuum pressures during vacuum casting, or under slightly elevated injection pressures (about twice atmospheric pressure) during automated pressure gelation (APG) processes. The curing step can be carried out at or slightly above atmospheric pressure (two to three times atmospheric pressure). These more forgiving processing conditions are better able to preserve the exact spacing and geometry of the core-coil assembly and to produce consistently high quality products.

One such resin, cycloaliphatic epoxy (CEP), was first used for outdoor insulators in the late 1970s. It has very good resistance to degradation and tracking erosion and can withstand exposure to humidity, ultraviolet (UV) radiation, outdoor pollutants and chemicals. Globally, CEP is the most popular outdoor insulation for medium-voltage equipment.

In the 1980s, outdoor-grade polyurethane (PUR) elastomers (elastic polymers) were found to be an alternative cost-effective insulator for medium-voltage electrical equipment. These resins were mainly processed by vacuum liquid casting. Among all liquid-casting resins, PUR has the least intrusive process, with lower molding temperatures and faster cycle times than alternative epoxy resin vacuum casting processes. Fully cured outdoor-grade PUR elastomers are easy to manufacture, have very good insulating properties and adequate outdoor performance.

2 Water beading on the vertical surface of the HCEP cast OVR after two years in Kitty Hawk, North Carolina (Courtesy of Dominion Virginia Power).

Advanced outdoor insulation

Silicone rubber is widely recognized today as the premier insulation material for outdoor equipment due to its light weight, high-voltage resistance and superior performance in heavily polluted environments. Its very good outdoor performance is due to its hydrophobicity (water repelling properties).

Hydrophilic (water attracting) insulating material, when wet, tends to form a continuous film on its surface that allows conductive airborne contaminants (eg, salts, inorganic and organic acids) to collect and dissolve, which leads to the formation of impervious conductive films. These electrolytic films lead directly to dry-band arcing[2]. If the insulation is polymeric in nature, the very high temperatures (> 1,000 °C) of the arc thermally degrade the polymer and cause erosion of the insulating surface, which leads to an increase in current leakage. With time, the dry bands propagate and subsequent elongation of the arc eventually leads to flashovers. The long-term performance of outdoor equipment is therefore severely affected by the choice of insulating material used for encapsulation.

Water beading occurs on the surface of hydrophobic insulating material so that conductive contaminants roll off the surface.

Hydrophobic insulating materials prevent water forming a surface film. Droplets of water form beads that roll

Footnotes

[1] Molding (or casting) refers to the process in which a liquid material is poured into a hollow and allowed to solidify. Curing refers to the toughening or hardening of a polymer by cross-linking polymer chains. In rubber, the curing process is called vulcanization. It involves the application of high temperatures and the addition of curatives like sulfur.

[2] Dry-band arcing: Environmental aging (moisture, heat, UV radiation, dust blasting, etc) degrades the polymer surface, causing it to become wettable by water and allows a electrolytic film of moisture and contaminants to form on its surface. This alters the designed electric field distribution and current leakage occurs. Ohmic heating raises the local surface temperature and evaporates the water film. Dry bands form, across which arcing occurs.

off such surfaces, taking with them any conductive contaminants. This self-cleaning characteristic of hydrophobic surfaces reduces the incidence of dry-band arcing, thereby extending the life of outdoor equipment. This is the main reason why silicone rubber is the preferred material for high-voltage outdoor insulators.

In the early 2000s, a more advanced hydrophobic version of CEP called hydrophobic cycloaliphatic epoxy (HCEP; trade name Hydrophobic Araldite®) was introduced to the electrical insulating resin market. The manufacturer of HCEP reported improved hydrophobic properties compared with CEP. HCEP maintained surface hydrophobicity after prolonged exposure to aggressive outdoor environments, while preserving its excellent electrical, chemical and thermal properties and resistance to erosion (properties inherent to CEP material). Based on these reports, HCEP was determined to be the best commercial outdoor insulation material available for the development of a new generation of outdoor vacuum recloser (OVR).

The new OVR, with HCEP-embedded poles and vacuum interrupters, resulted from the extensive development of HCEP advanced design tools and manufacturing processes 2. Such HCEP-embedded poles comply with the French railway's fire and smoke standards and can now be used in vacuum circuit breakers for railway power-supply applications.

Furthermore, the OVR has been certified by the South African utility Eskom after it passed a one-year outdoor exposure test at the Koeberg Insulator Pollution Test Station (KIPTS), near Cape Town, South Africa. The climatic conditions at this location are reported to be among the most severe in the world for damaging UV-radiation, for significant exposure to various industrial and marine pollutants, and for heavy precipitations.

Superior design and production

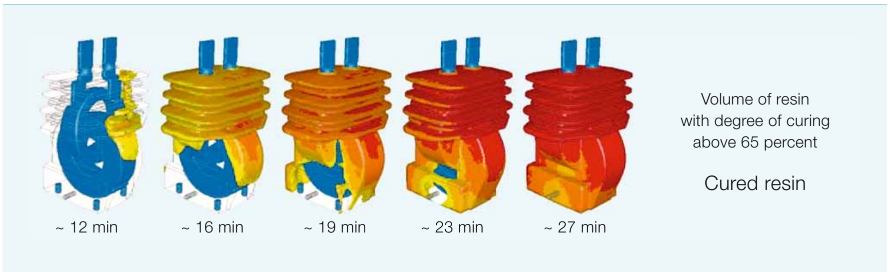
The successful development and introduction of the OVR with HCEP insulating material provided the impetus to use the same technological strategy to develop the next generation of OITs, combining advanced design tools with the best commercially available dielectric material. In late 2003, ABB initiated the development of a new generation of OITs with enhanced performance in severely polluted outdoor environments. This strategy took advantage of simulation software to optimize the OIT design so that the production of numerous expensive prototypes could be avoided.

Advanced simulation software is used to calculate the predicted electric field-stress distribution inside and on the surface of the cast electrical device. Different field-stress distributions can be simulated so that the geometry of the design can be optimized for the dielectric spacing of the insulation material.

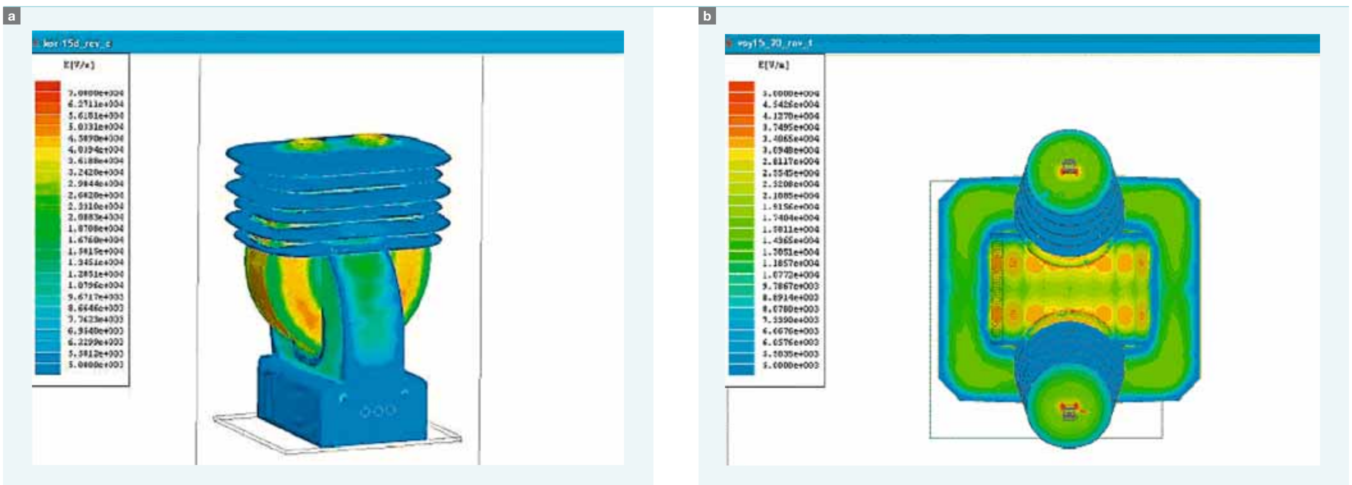
A variety of OIT designs can be evaluated using the simulation software to determine the predicted electric field-stress distribution that would be generated when using different insulating materials with their unique dielectric properties. Furthermore, the environmental conditions surrounding the 3-D model of the device can be altered to simulate various environmental conditions and their effect on field stress distribution 3.

Design optimization to reduce field-stress distribution must also coincide

4 Example of how RAMZES was used to optimize the curing stage for the 36 kV current transformer [1].



3 Typical output of the electrostatic simulation of the 36 kV outdoor current transformer and potential (voltage) transformer in a conductive environment. The goal is to optimize the design geometry to obtain the lowest surface field-stress value (Ansoft simulation tool was used here).



5 Automatic pressure gelation (APG) press in ABB's Pinetops facility in North Carolina.

6 Epoxy blending equipment in ABB's Pinetops facility in North Carolina.

with ease of manufacturing and mechanical robustness so that the instrument can withstand the extreme temperature variations it is likely to encounter in the field. ABB uses proprietary simulation software called RAMZES (reactive molding zero defects solution) to optimize the process and mechanical design. The 3-D model of the instrument design, within its preliminary insulating mold design, is analyzed using RAMZES. The program optimizes the process parameters, such as mold temperature distribution, mix temperature, filling rate or curing profiles for the resin filling, curing and cooling cycles 4. It calculates the resulting mechanical stresses and strains that develop inside the cured cast device as it cools to ambient temperature. By optimizing the casting and curing parameters these stresses and strains can be minimized.

Improved process technologies

Even with the best material and design, product performance is not guaranteed. Only by ensuring controlled, reproducible manufacturing conditions can product reliability and long-lasting performance be assured.

In the early stages of resin-casting technology, a vacuum-encapsulating process was commonly employed. This mild process allows minimum mechanical reinforcement of the core-coil assembly, which is certainly not the case with the high-pressure molding and curing of butyl rubber. One drawback of the process, however, is a long total cycle time. The mold-filling, curing and mold-removal cycle usually takes several hours.

During the 1980s, liquid injection casting of epoxies was introduced. The process was further refined and automated with sophisticated controls for consistent results. Today, the automatic pressure gelation (APG) process effectively shortens the total cycle time to less than 90 minutes and is the current process of choice for epoxies.

ABB's new OIT are encapsulated in HCEP, an excellent insulating material that protects against aggressive outdoor environments, while guaranteeing excellent mechanical properties.

Recognizing the importance of proper manufacturing in the production of reliable instrument transformers is paramount. Advanced APG casting process equipment 5, along with a state-of-the-art automated blending and dispensing system 6, are essential manufacturing components required to blend and process the various ingredients for the epoxy mixture, on demand. This combination ensures that the flow properties of the mixture are optimized for the casting, impregnation of the core-coil assembly and for subsequent curing. The end result is a finished product of consistently high quality.

Innovate for better performance

The production of a new generation of OITs demonstrates ABB's commitment to product innovation and advancement in manufacturing technology. ABB is constantly evaluating the long-term performance of new outdoor materials and products, including OITs, in aggressive environments such as KIPTS.

New HCEP products are emerging that provide improved reliability in aggressive outdoor environments, while guaranteeing excellent dielectric and mechanical properties. These new product developments equate to the longer life expectancy of OITs, reduced maintenance costs for customers and ultimately to reduced risk of costly substation power failures.

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Reference

[1] **Kasza K., Nowak T., Sekuła R.** (2004). APG process simulation of KOR15/20 ANSI current transformer cast of out-door cycloaliphatic epoxy. *PLCRC technical report TN 04-076.*