GE
Grid Solutions

SUPERBUTE Instrument Transformers: 60 Years of Reliable Performance

A GE white paper discussing the application of novel design features for outdoor instrument transformers

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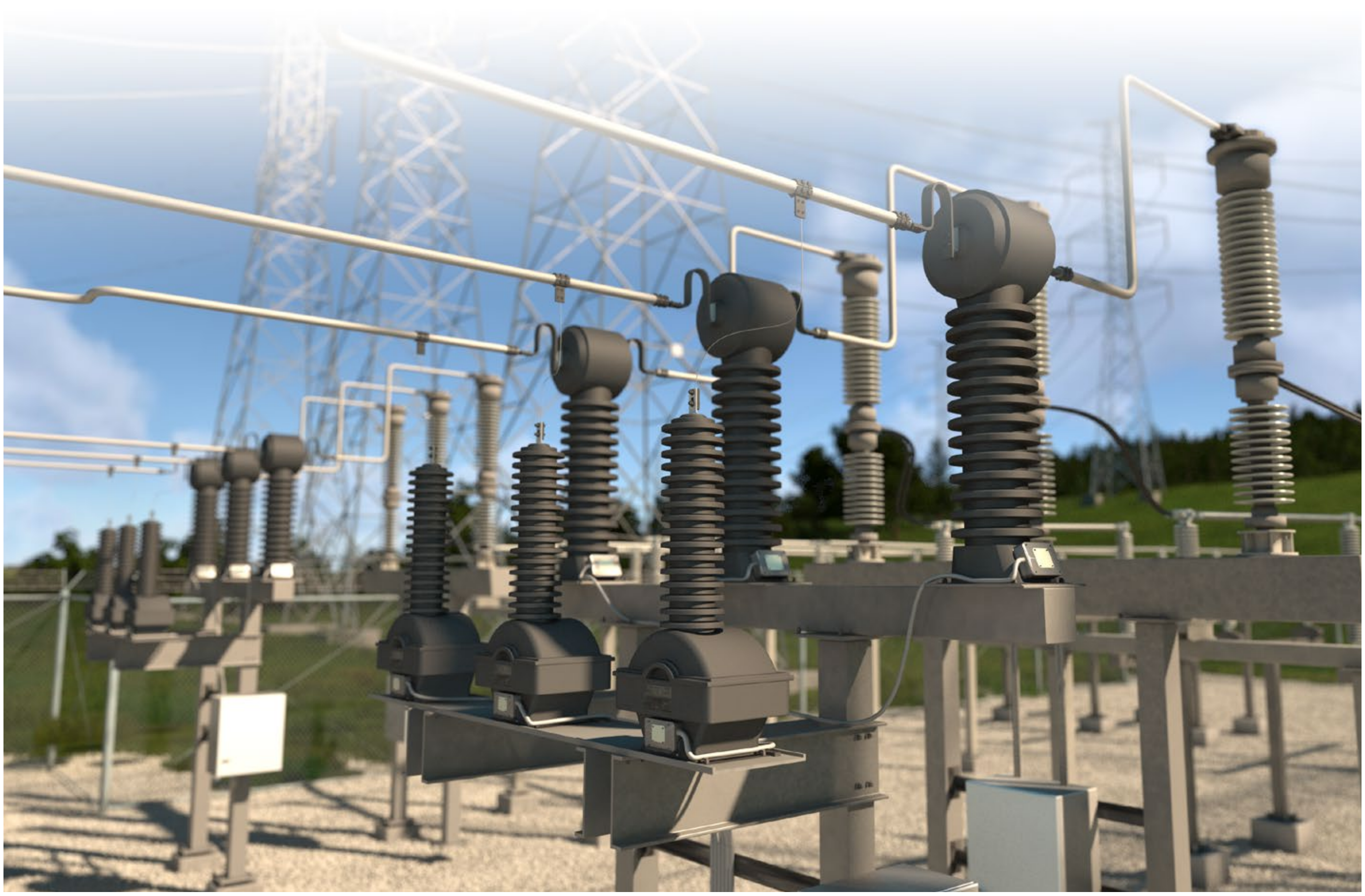


imagination at work

Abstract

Instrument transformers are the inputs to the most important functions of managing a power system: measurement, protection, and control. Therefore, reliable operation and longevity of instrument transformers is critical to delivering reliable power.

In 1955, GE solved the challenge of designing an outdoor instrument transformer with a dry-type insulation that could reliably withstand the elements. The result was a durable design that has proven to withstand the test of time, and outperform industry benchmarks in measures of longevity and reliability.

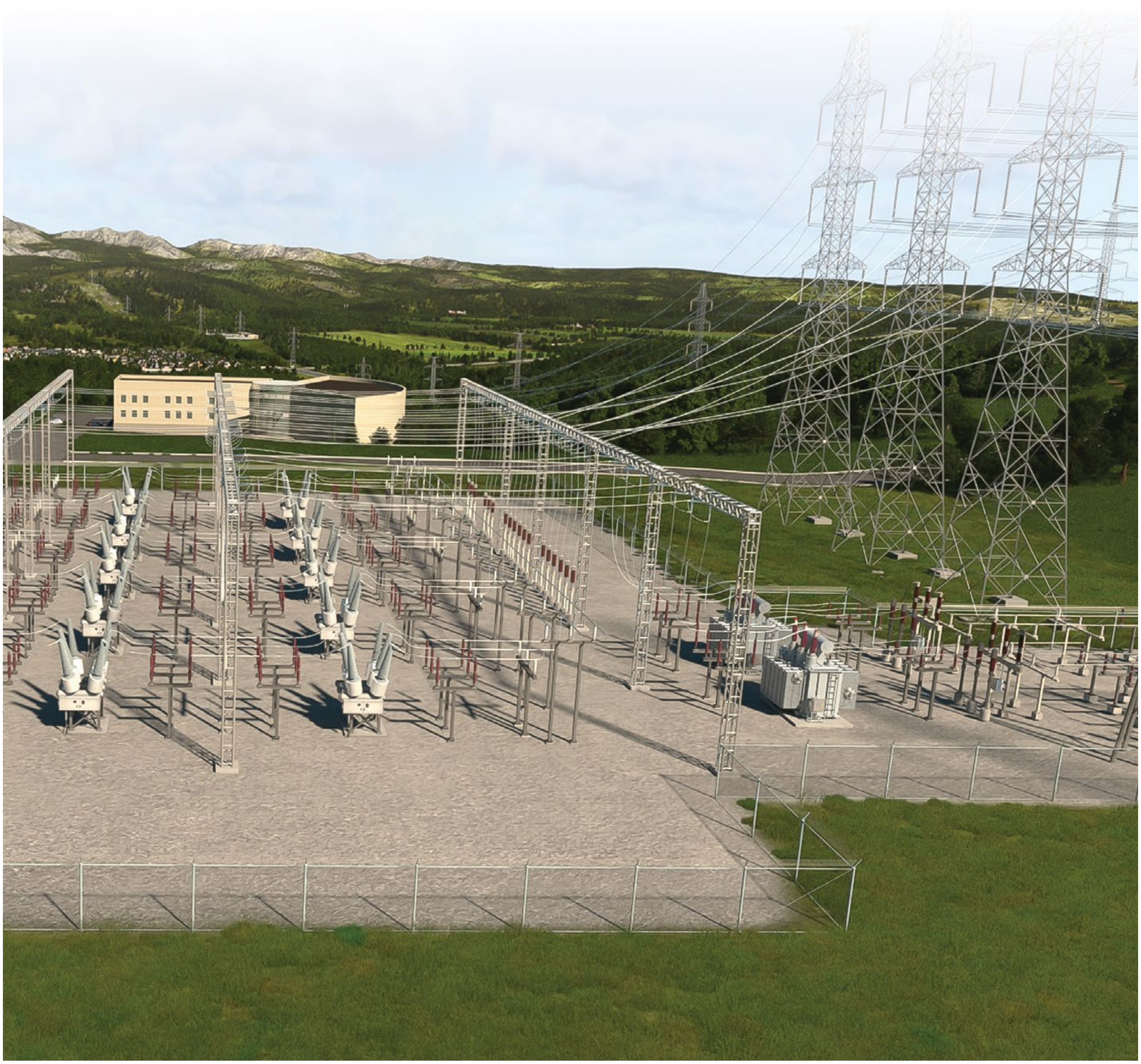
This has been accomplished with a proprietary insulation and protection system, a unique primary winding design, and a robust testing and inspection program. These features have provided for a product which remains, even several decades later, among the most reliable in the industry and still perfectly designed to meet the modern needs of today's utilities.

The Challenge

Revenue metering and system protection and control play a vital role in electrical utility operations. Instrument transformers are a critical component, serving as the input into these business processes.

When instrument transformers are installed in outdoor environments, they must be able to withstand unpredictable and extreme environmental conditions, grid events and external factors such as vandalism and tampering. Environmental conditions can vary depending on the installed location, exposure to extreme weather conditions (hot to cold, snow and ice, wind, lightning strikes, ultraviolet radiation and corrosive atmospheres), or grid events such as surges and transients. All these factors provide challenges against the unit longevity and reliable operation.

In the 1950s, GE designed an innovative dry-type design which could better address the above challenges, and the resulting product was called SUPERBUTE™.



Proven Reliability

2015 will mark the 60th anniversary of the first butyl rubber molded product from GE, and time has proven the superior reliability of this design, above what is expected from a typical liquid filled transformer.

Industry Benchmarking

Several studies on electrical equipment have been completed over the years by IEEE®, which have generated failure statistics that serve as a useful baseline for measuring reliability. IEEE Standard 493 "IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems" contains information from these studies and is a useful reference on failure data of electrical equipment. The IEEE published rate for all liquid-filled transformers is 0.6%.[1] In other words, each year an average population would expect to see 6 in every 1,000 units fail.

GE Field Studies on SUPERBUTE Survival Rates

In 2013, GE conducted a survey with four (4) utilities covering an estimated 12,000 GE instrument transformers. The results of this survey are shown in table 1. The survey demonstrates a significantly better performance, compared to the IEEE published rate, with GE field failure rates ranging from 0.01% to 0.24%. Table 2 illustrates the environmental demographics of these utilities, with particular diversity in amounts of ice/snow as well as lightning strikes without an appreciable difference in results.

Characteristic Life - Defined

Another important reliability statistic is characteristic life. This can be estimated using the maximum likelihood method, which takes into account the history of both surviving (i.e. censored), and failed transformers.

This method is based on the observation that the log of the time to failure is approximately a normal distribution, and the characteristic life (alpha) is the statistic that defines the period required for 63.2% of the original population to fail. Published papers support the observation that the distribution failures in electrical coils due to aging fit this model and accelerated life tests and field studies confirm that this model applies to our dry-type instrument transformers.

GE Field Studies on SUPERBUTE Characteristic Life

A 2013 study on 867 units from three (3) utilities performed by GE with St. Joseph's University and Villanova University illustrated a characteristic life on GE SUPERBUTE units of 40.7 years.

These results are in line with other major field studies that GE has previously performed. For example, past studies ranging in location from Alaska to Minnesota to Louisiana have shown a range of results from 24 to 59 year life expectancies.

These multiple studies, which span the six (6) decades of SUPERBUTE production, highlight how variation in environment conditions, application, and system maintenance can impact instrument transformer reliability.

One constant across all studies, regardless of time period or geographic location, is that the SUPERBUTE product has proven to be consistently reliable, with an average life over 40 years and field failure rates much lower than published IEEE expectations.

Table 1: GE Survey Results on SUPERBUTE Annual Failure Rates

Survey Participant	Region	Approx. number of installed units	Annual Field Failure Rate
Utility A	Southeast	3,000	0.08%
Utility B	Mid-Atlantic	3,000	0.01%
Utility C	Atlantic Coast	600	0.23%
Utility D	Northeast	5,000	0.02%

Source: GE customer interviews

Table 2: GE Survey, Customer Demographics

Survey Participant	Region	Avg. Annual Temp Range (Lo-Hi)	Avg. Annual Temp	Annual Precipitation	Annual Snowfall	Annual Lightning Strikes
Utility A	Southeast	-8 to 36°C	15°C	46"	--	6.0 per km²
Utility B	Mid-Atlantic	-7 to 36°C	14°C	41"	--	5.0 per km²
Utility C	Atlantic Coast	-13 to 33°C	11°C	44"	44"	1.2 per km²
Utility D	Northeast	-16 to 31°C	9°C	40"	94"	1.5 per km²

Source: 2014 US Climate Data, except Annual Lightning Density, 2014 Cooperative Institute for Applied Meteorological Studies, Texas A&M University

A Breakthrough Insulation System

Challenge

A primary concern for designers of outdoor electrical apparatus is surface creepage in contaminated locations. Under conditions of moisture, salt, fog or dust, leakage currents may result which produce arcing on the exposed surface of the insulation.

Under arcing conditions, conventional organic insulating materials break down to form localized carbon paths. Once an initial spot is carbonized from arcing, this spot serves as the starting point for further degradation and a surface carbon path forms at an ever-increasing rate until eventual flashover and failure.

The External Insulation: HY-BUTE 60™

In 1955, GE discovered a new formulation for butyl that would not arc-track, and named it HY-BUTE 60. When surges or leakage currents were subjected to the surface of HY-BUTE 60 at temperatures high enough to cause burning of the transformer insulation, no carbon residue resulted. This major insulation break-through was accomplished by adding large amounts of an oxidizing agent (Alumina Trihydrate) to butyl as it was mixed and formulated.

Alumina Trihydrate (ATH or hydrated alumina) is a non-toxic, non-corrosive, flame retardant and smoke suppressant utilized in elastomer applications. It is the most frequently used flame retardant in the world due to its thermodynamic properties which absorb heat and release water vapor. [2] These same properties also provide arc suppressing abilities when added to electrical insulating materials, such as HY-BUTE 60.

When high temperatures (sparks and scintillations) occur on the surface of HY-BUTE 60, the chemical reaction that takes place between the surface arc and the ATH in the butyl forms carbon dioxide, carbon monoxide or water, rather than free carbon. There is enough oxidizing material in HY-BUTE 60 to provide superior arc resistance over the full life of the transformer.

Early comparative salt-fog testing showed carbonized surface failure on conventional butyl rubber after 107 hours and porcelain bushing after 400 hours, while non-tracking HY-BUTE 60 showed no carbonization after 4,000 hours.[3]

Thus, for the first time, porcelain could be replaced by HY-BUTE 60 as a high voltage insulating material. Today, the SUPERBUTE design uses HY-BUTE 60 as the external shell for its unique non-arc tracking, hydrophobic, and impact resistant properties.

A Durable Primary Winding

Challenge

The butyl rubber material was considered a practical breakthrough at the time. However, it proved to be a challenge to mold a transformer using this material, as the butyl molding process was very mechanically abusive to the core and coil assemblies. A high number of failures plagued the first few years of the product release, due to high stresses in a number of displaced turns.

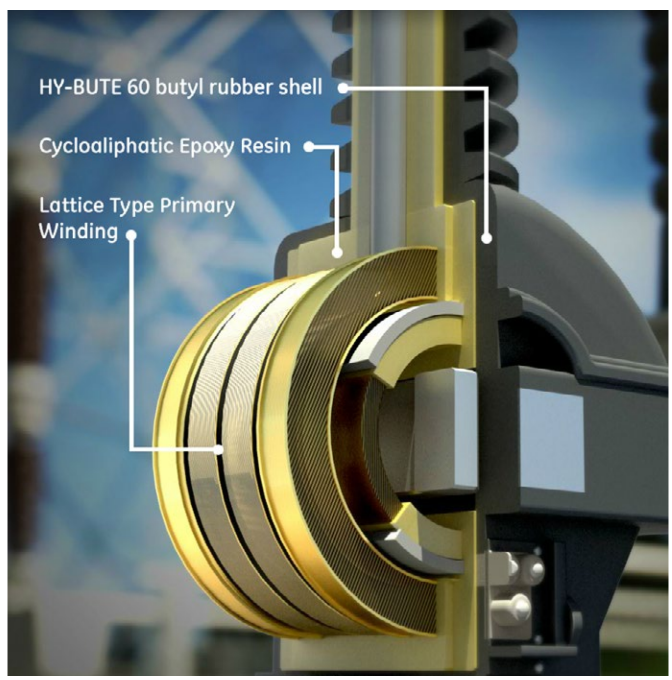
Lattice-Type Winding Design

GE addressed this challenge by changing the primary design of the transformer to a lattice-type winding. In this design, the position of each turn is precisely controlled for an even distribution, and then the winding is impregnated with a cycloaliphatic epoxy to permanently secure and protect the winding during the butyl molding process.

In addition to eliminating the necessity of butyl molding on any of the core and coil parts, the use of epoxy provided advantages including mechanical rigidity and mounting strength. This design, patented at the time, was a significant breakthrough and allowed for a highly repeatable and reliable process.

In 1981, an improved primary design was released with a 50% reduction in layer-to-layer and turn-to-turn operating voltage stress within the primary coil. Accelerated life testing on the lattice-type coil, performed at 180% of rated voltage, has validated this design meets a minimum life of 40 years. The best test result to date, in which one coil survived 2500 hours or a simulated 104 years, demonstrated the extreme durability that this unique design is capable of.

The lattice-type winding's ability to handle high voltage stresses is a major factor why SUPERBUTE transformers are capable of operating beyond 40 or even 50 years in the field.



Construction of station-class voltage transformer

Robust Process Control

Since the creation of HY-BUTE 60 in 1955, GE has shipped more than 9,000,000 instrument transformers manufactured with this material. Extensive field experience combined with decades of test records have helped us find ways to improve our products, create enhanced testing procedures, highlight application problems, and better understand customer expectations.

In 1988, GE began an accelerated life program to continually monitor and ensure high in-service reliability of our instrument transformers. While life of a product can be accelerated in many ways (e.g. temperature, speed, load), the special model developed by GE is based on over-voltage. Our database is now quite mature, and tracks well with actual in-service results. A random sampling of units is tested under overvoltage conditions for which GE has correlated 1 day of testing to be equivalent to 1 year of field life. The criteria for all designs is a minimum of 1000 hours, or the rough equivalent of 40 years of field life.

Conclusion

Field studies conclude that the SUPERBUTE instrument transformer has proven reliable with an average life of more than 40 years and field failure rates lower than published IEEE studies.

This demonstrates that SUPERBUTE addresses the environmental challenges that impact the longevity of traditional liquid-filled instrument transformers with an innovate insulation system, unique lattice winding design and robust manufacturing and testing processes.

References

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