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new Technology Changing the Heart of Power Systems

High Temperature Insulation Systems: An Option for Resilient Transformers

Interview with Jon Trout, FirstEnergy

High Temperature Insulation Systems: An Option for Resilient Transformers

by **Richard P Marek**

Richard P Marek received his BSEE from Purdue University and has been employed with DuPont since 1998. His previous work experience includes a total of 28 years as a transformer design engineer. He is a senior life member of IEEE where he has been active in the Transformers Committee since 1982 and he was chairman/convenor of the high temperature liquid immersed transformer standards IEEE C57.154 and IEC 60076-14. He is also an IEC TC14 delegate for the US TAG.

For many years, utilities have used mobile transformers or complete mobile substations to mitigate outage risks in their smaller capacity substations. These fast deployable units have offered the advantages of quick availability of replacement equipment. They are mobile, compact, lightweight, and versatile, generally covering multiple voltage ratings. Designed to match the regional road weight limits, they can be installed and operating in a very short time. Now, this same concept is being applied to large power applications.

This article reviews the latest developments and trends towards highly moveable large power transformers designed to improve grid resiliency. Using advanced insulation systems allows innovative design techniques that result in smaller size and lower weight transformers. Initially developed specifically for mobile transformers and substations, the hybrid insulation system has evolved to allow much larger units to be transported more easily and rapidly to areas with emergency situations. **Among various design methods for reducing the size and weight of power transformers, high temperature insulation systems offer a key tool.**

Many modern design techniques and state-of-the-art optimal technical

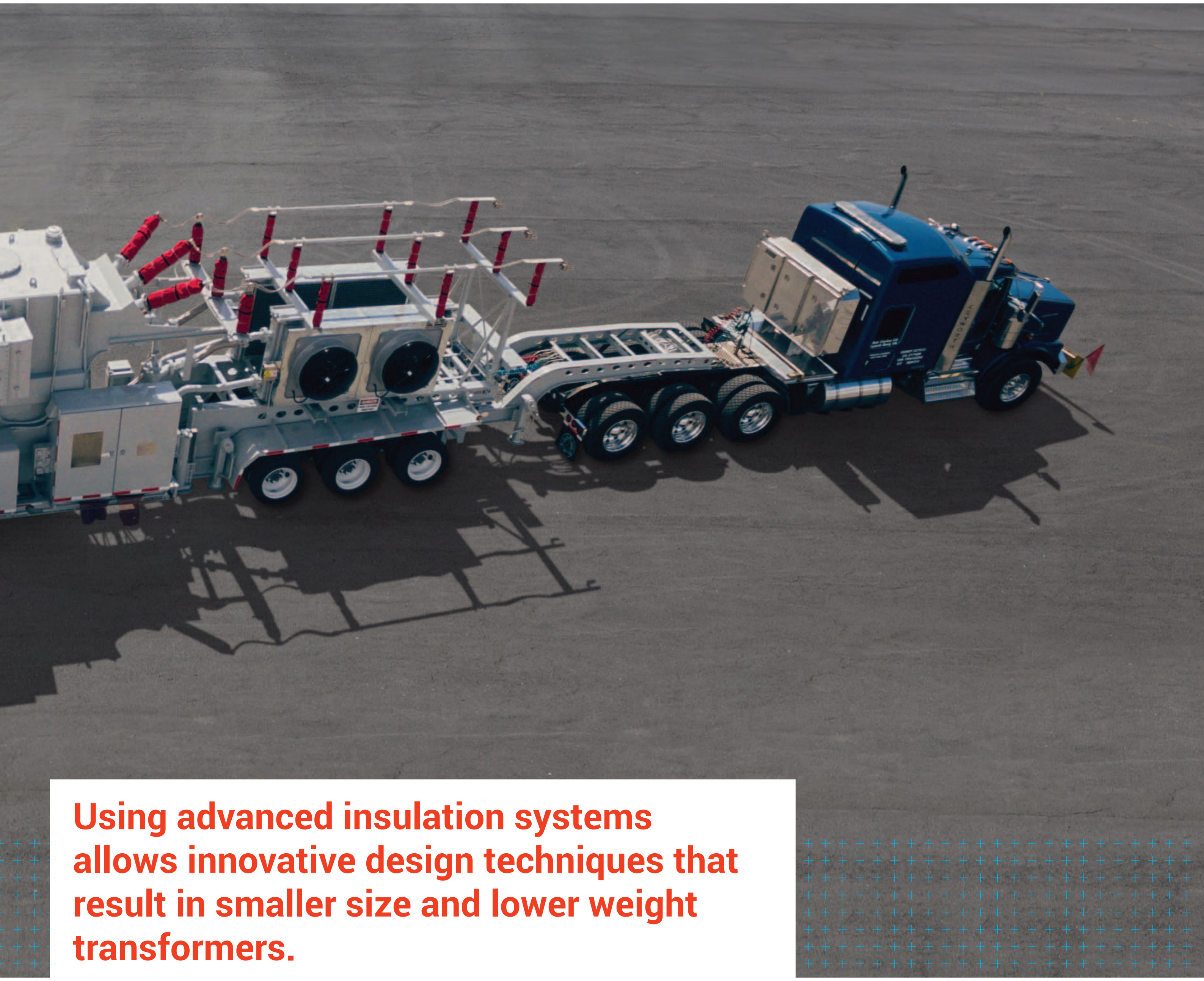

Photo: Delta Star

Using advanced insulation systems allows innovative design techniques that result in smaller size and lower weight transformers.

solutions have already driven designs to be smaller and more compact. However, the use of high temperature materials and insulation systems allows a step change in the ability to make designs significantly more compact, compared to so-called "conventional" designs, based on cellulose insulation and mineral oil. In order to reach maximum size reduction, new insulation components must also be developed using high temperature materials.

For many years standards development has played a major role in expanding high temperature liquid immersed transformer applications. In 1997, IEEE Standard 1276 – "Guide for the Application of High-Temperature Insulation Materials in Liquid-Immersed Power Transformers" [1] was published after this working group first published a thorough background paper in 1994 titled "Background Information on High-temperature Insulation for Liquid-Immersed Power Transformers" [2]. In 2008, the development of a document was begun by IEEE: IEEE Standard C57.154 – "Standard for the Design, Testing, and Application of Liquid-Immersed Distribution, Power, and Regulating Transformers Using High-Temperature Insulation Systems and Operating at Elevated Temperatures" [3], which was published in 2012.

This document introduced many key definitions necessary to describe new insulation systems which are defined by temperature class rather than by specific combinations of solid materials in a liquid. These concepts were patterned after the insulation system approach to motors and dry type transformers which has worked well for many years.

Among various design methods for reducing the size and weight of power transformers, high temperature insulation systems offer a key tool.

Hybrid insulation system, one of these key definitions, uses mineral oil and high temperature materials throughout the transformer on the windings, but only limited to the hottest areas. Typically, the conductor insulation and the radial and axial spacers separating the coil windings are high temperature materials. Conventional cellulose-based insulation is used in all other areas, such as cylinders and angle rings that operate at conventional temperatures. While mineral oil is restricted to a 65°C temperature rise, other liquids may also be used in a hybrid application at higher temperatures, as long as the temperature capability of the cellulose is not exceeded.
for the use of DFR technology and interpretation of transformer's insulation dielectric response in the frequency domain.

Unlike the hybrid insulation systems, the high temperature insulation system consists of mostly high temperature solid insulation materials for all insulation components and an insulating liquid operating at high temperature. Clamping plates, cylinders, tubes, angle rings, molded lead exits, snouts, spacer blocks, caps and stress rings are all made from high temperature materials. Currently some of these insulation components do not yet exist in high temperature material for power transformers. However, prototypes have already been developed for some of these fabricated parts to facilitate the development of ultra-compact transformers for resilient systems. For example, new insulation parts to be available in aramid material could include wet formed 3-dimensional components and large laminated clamping rings.

Mobile units have been built in US since the 1950s. Over the years, the size (MVA) and voltages have increased and the protection and trailer designs have become more refined. Aramid insulation started to be used to reduce the size and weight by increasing the operating temperature. Some of these units are built as simple mobile transformers, equipped with surge arresters. Others are complete substations with all the typical accessories such as lightning arresters and switchgear. They are capable of completely replacing a small substation, especially in rural areas. High temperature insulation systems are commonly used in mobile transformers to allow higher winding temperatures. Aramid insulation is commonly used for conductor insulation and for pressboard parts exposed to temperatures that would exceed the thermal capability of cellulose based components.

In 2012, ABB partnering with the U.S. Department of Homeland Security (DHS), the Electric Power Research Institute (EPRI) and CenterPoint Energy, delivered three modular transformers from its St. Louis facility to a substation in Texas within 20 hours, in an emergency drill [4]. These "spare" transformers, designed with aramid high

Photo: ABB

temperature insulation, were shipped and were fully energized in less than a week.

From a design standpoint, the transformer, called the RecX, had to meet numerous installation requirements, including storage and transportation specifications that required a small footprint and light weight to ship on standard trucks. Building on ABB's mobile transformer expertise, they chose a high temperature hybrid insulation system to reduce both size and weight. Alone or in hybrid solutions with cellulosic pressboard, insulation systems based on aramid maintain excellent electrical, thermal and mechanical characteristics over a transformer's service life. Reduced aging, high resistance to shrinkage and compression, combined with the excellent dynamic mechanical strength of aramid paper and board, all help ensure that coil structures will remain tight and are able to withstand short-circuit forces, even after years of service. The RecX 200 MVA prototype bank of single phase units were designed to replace a 600 MVA, 345/138 kV autotransformer. The RecX design principle was to make the units modular, transportable and quick to install. The challenge was to reduce the transformer's size and weight to less than 59,000 kg. The final design actually weighs in at less than 57,200 kg and is small enough to be shipped by truck, while maintaining its performance and reliability.

A similar fast-deployable transformer concept was developed in another ABB project in Spain. In this case, three 250 MVA, 400 kV units with multiple voltage ratings on the LV side were built using a shell type construction. The design evaluation showed significant weight and size reduction was possible by using a hybrid insulation system in the transformer windings. The new unit with hybrid insulation not only achieved a base rate increase of 25% compared to the installed unit (250 MVA vs. 200 MVA), but it represented a more than double base rate increase, compared to the maximum rating of the conventional cellulose mineral oil unit (250 MVA vs. only 117 MVA).

A new step of innovation was reached when SIEMENS delivered resiliency units to the New York City utility in 2016 for its network. These units will act as emergency replacements in case of unplanned outages, such as those caused by hurricanes or may also be used for planned outages. Normally, failure of one of these large transformers causes many issues including:

- Long lead times for new transformers (up to 14 months)
- Multiple spares needed for various rated transmission transformers
- Shipping and logistic issues
- On-site assembly that can take weeks and is weather dependent

As it was demonstrated in January 2017, the mobile resilience transformers allowed the utility to respond to these events, where multiple transformers may be impacted and normal spares or system redundancy may not be able to address the issues. SIEMENS provided six transportable resilience transformers to help replace units within days rather than weeks in times of outages due to extreme weather or other major events. The new transformers are highly optimized for weight and dimension through advanced design and

Photo: PTI Transformers

New insulation parts to be available in aramid material could include wet formed three-dimensional components and large laminated clamping rings.

environmentally-friendly synthetic ester liquid technology. The use of a hybrid insulation system in combination with the synthetic ester enabled this remarkable performance. This solution is aimed at quickly restoring power to the areas served by the unavailable transformers within one to three days, compared to the weeks it may take to transport and install normal available spare units. In cases where utilities do not have existing spare units, it may take twelve to fourteen months for new units to be procured, shipped and installed.

The concept of ultra-compact large power transformers operating with high temperature insulation systems is now under evaluation, but not only for grid resiliency emergency applications. The concept could be of benefit for upgrading existing space constrained substations, as well.

The main drivers for the innovation are:

- Need to replace and upgrade aging transformers within physical station space constraints
- Need for higher capacity to meet load growth
- Desire for sustainable solutions – environmentally friendly insulating liquid
- Use of high temperature insulation system for higher output and compact size

As shown in the above examples, the high temperature insulation systems can be important in the design of compact, transportable and fast-deployable large power transformers. Transformers with reduced size can then bring various benefits to power utilities in selected installations and improve the resiliency of the overall system, since they can be deployed faster using conventional trucks.

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