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IN DEPTH

# Nano-dielectrics: a step change in materials performance

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*Nanodielectrics have shown immense potential for applications in high voltage transmission systems. The NanocompEIM project explores ways to develop a set of materials design and process rules to achieve reliable production and process scaling in component manufacture.*

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*Nanodielectrics are expected to make a step change in future AC and DC power plants designs*

Nanotechnologies focus on tailored structures from hundreds of nanometres down to a few nanometres in size. They are already known for their ability to produce materials with enhanced thermomechanical performance, such as improved strength and fatigue properties, resistance to corrosion, superhydrophobicity and fire retardation. Other potential applications include improved conducting and insulating materials and coatings, as well as high performance dielectrics.

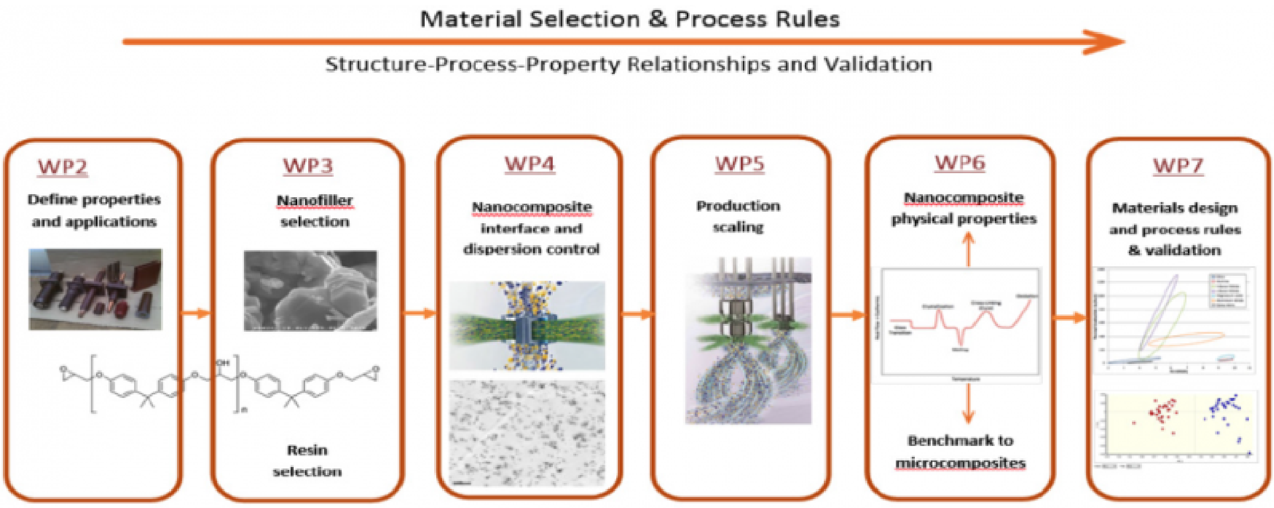
"To cope with the stresses in high voltage transmission systems, there is a need to develop materials with controlled and balanced electrical properties, higher thermal conductivity, higher dielectric strength and enhanced voltage endurance," explains Fabrice Perrot, Alstom Grid Technology Programmes Director in Stafford, UK. "If the balance of properties, performance and process requirements are achieved thanks to nanotechnologies, this may lead, for example, to HVDC insulation systems and equipment with reduced footprint, higher power densities, and greater multi-stress resilience with longer service lifetimes. All this will open the door to radically new designs."

## 1__Producing at nanoscale remains very complex

Despite the potential, producing structures and materials at nanoscale remains extremely complex. There are several challenges, not least of which is to develop new materials that significantly outperform the old ones at only a marginal increase in cost. "It is very difficult to incorporate nanostructures into an electrical polymer matrix reliably, consistently and economically with proven long-term stability," notes Perrot. Nanocomposites lack process specifications, which integrate purity, quality and reproducibility, and for now, it is only possible to produce them on a relatively small scale. "You can get small samples with differing, step-change improvements in properties, but it is not yet economically possible to produce them at large-enough scales for applications in HVAC or HVDC."

## 2__The NanocompEIM project

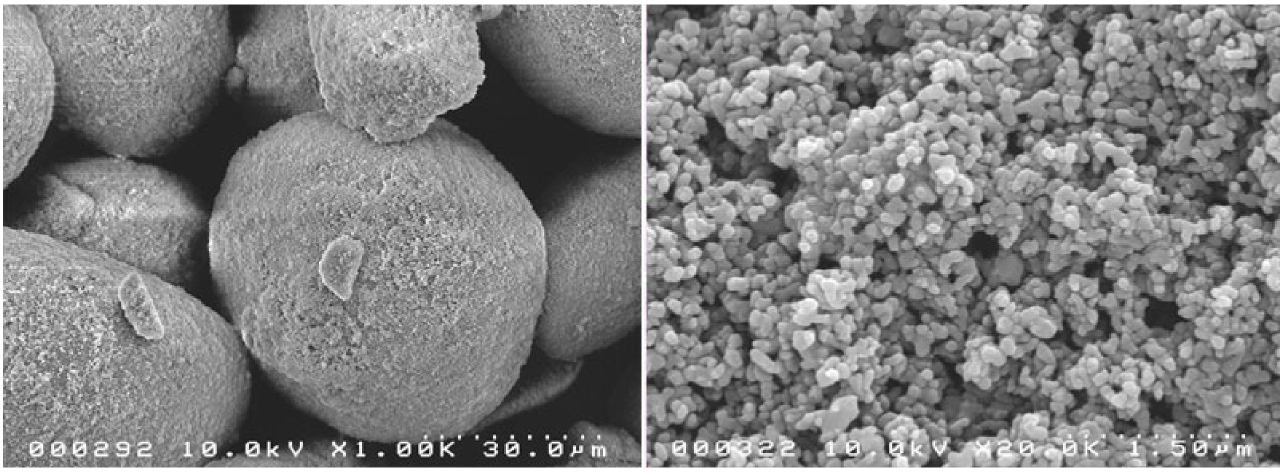
To advance on that issue, Alstom Grid launched – with the help of the UK Technology Strategy Board, now Innovate UK – the NanocompEIM project (see sidebar), which aims to "both integrate and advance understanding and practical experience of the processing of nanocomposite electrical insulation materials in order to develop a set of materials design and process rules to achieve reliable production and process scaling in component manufacture". Scalable processing methods have therefore been developed to produce components using materials with controlled dispersion and interfacial characteristics in order to achieve appropriate balanced property and performance enhancements. “Achieving this is of immense benefit to power equipment users, particularly in the context of integrating renewable power generation and the move to develop smarter, low-carbon networks,” adds Perrot.




*Material selection and process rules*

## 3__The importance of being (well) dispersed

Nanodielectrics based on epoxy resin systems can be prepared by dispersing nano-sized inorganic fillers in the polymer matrix. A key feature of nanodielectrics is the large specific surface area of nanoscale fillers and the many properties and performance factors linked to interfacial effects. These include increased resistance to surface corona and partial discharge, enhanced dielectric strength and voltage endurance, and the potential mitigation of space charge formation. They also bring the potential to tailor other properties such as permittivity, conductivity, thermal conductivity, mechanical properties and thermal stability.




*On the left : SEM image of an alumina taken as received (x 1000 magnification) ; On the right : SEM image of the same alumina after ultrasonic mixing (x20,000 magnification)*

Alstom recognises that there is a major need to master dispersion of nanoparticles if property enhancements are to be optimised and then fully translated into advanced components and systems. “Another challenge is understanding several quantitative structure-property-process relationships for these materials and learning to controllably manipulate them to yield complex nanostructures,” says Perrot. Several methods of dispersion, both mechanical and chemical, have been trialled throughout this project, and using a novel, rapid mechanical-stirring method appears to be the most effective. But high dispersion alone is not sufficient to obtain enhancements in properties. A wide variety of materials containing various nanofiller types, loadings and surface treatments were also investigated and subjected to a range of measurements including thermal, electrical, mechanical, spectral and optical to check the dispersion of the materials. “It is very important to obtain a balanced outcome of properties as modification of composition to optimise one property might lead to a reduction in another important property.”

## 4 __Electrical breakdown strength increased by more than 40%

Out of all the materials tested it was found that nanosilica treated with epoxide-functionalised agents gave the best performance of electrical properties with no significant decrease in thermal conductivity or mechanical properties. Up to 40% performance increase in electrical breakdown strength is obtained with 2% nanosilica compared to a commercial micro-composite. Also, samples containing boron nitride (BN) could be made with notably higher thermal conductivity without a significant drop in electrical breakdown strength, making BN a strong contender for use in electrical power applications.

*Examples of NanocompEIM demonstrators*

In the NanocompEIM project, a number of options for deploying nanomaterials in future HVDC plants and key HVAC equipment have been identified.

## 5__Master batches in excess of 20 kg

To ensure that any processes used are scalable from the laboratory to potential future use in industry, the project has generated master batches of up to 20 kilograms in size, which were then mixed and formed into demonstrator medium-voltage components using traditional industrial casting processes. The thorough testing of these demonstrator components has now been completed successfully.

## 6__Open innovation with public funding leverage

In building the NanocompEIM project, Alstom developed a vertically integrated "Open Innovation" partnership that combined technology providers, developers, integrators, a component supplier, an OEM (Alstom Grid) and the three UK transmission system operators (TSOs).

Phase I of the project integrated:
- Southampton and Warwick universities, with researchers at the cutting edge in nanotechnology and nanodielectric materials research and characterisation;
- GnoSys Global Ltd, a nanotechnology-focused SME research organisation with a proven international track record for developing processing and design rules for complex material combinations;
- Alstom Grid's Research & Technology Centre in Stafford, with its component testing and composite materials process expertise

and scaling capabilities together with Alstom's applications expertise;

- Mekufa UK Ltd, a composite component manufacturer/supplier;
- The three UK TSOs (National Grid, Scottish & Southern Energy, Scottish Power), a key partnership to include TSO needs and promote them in order to fast-track their use.

In Phase II, technology development will be transferred to Alstom's Supergrid Institute in Villeurbanne (France), with the continued support of developers and TSO customers.

Phase I of the €1 million NanocompEIM project was 50% funded by the UK government's Innovate UK Materials for Energy competition programme; 25% came from the OFGEM's RIIO Network Innovation Allowance (NIA) funding mechanism for TSO-supported projects and additional UK government support for the two university partners. The plan is to achieve a similar level of gearing for the funding of Phases II and III for the ultimate deployment of high voltage equipment containing nanodielectrics.

## EXPERTS

**Fabrice Perrot**

*External Funding & R&T Program Director, Alstom*

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