

Plastic nanocomposite insulation material enabling reliable integration of renewables and DC storage technologies in the AC energy grid (“GRIDABLE”)

2 open PhD and one open Post-doc position within the frame of the granted EU project “GRIDABLE”

Start: January 2017

Duration: 4 years

General Project Description:

High voltage direct current (HVDC) technology and integration of stationary energy storage (SES) are an essential part of the future electricity grid. Wide adaptation of the new DC technology brings also challenges like space charge accumulation in insulation, which requires new material solutions. Space charge accumulation and breakdown reliability in DC insulation can be improved by optimizing the trap depth and charge mobility. Chemical functionalization of nanoparticles and their successful dispersion in polymer matrix is a route for higher performance DC insulation materials. GRIDABLE project demonstrates novel polypropylene based silica nanocomposite insulation material in HVDC cable and in DC capacitor insulation. They are both key components in voltage source converter (VSC) technology that is used in modern grid connection for renewable production and SES sites. The novel polypropylene-silica insulation material has a potential to improve the reliability of HVDC applications. By utilizing HVDC power transmission and VSC the required space for SES-to-grid integration is reduced by half compared to conventional design, geographical constraints are lowered, and power production reliability is improved.

Detailed description of the task of different partners:

Fumed SiO₂ nanoparticles that are smaller than 20 nm will be mixed into PP based thermoplastic polymer so that no larger than 80 nm agglomerates are formed up to 5 mass-% filler concentration. The production batches will be up to 2000-5000 kg for both cable and film application. The nanodispersion will be analysed by AFM and/or TEM microscopy for both laboratory and pre-production scale compounds.

Polypropylene based thermoplastic matrix polymers for HVDC cable insulation are selected from a wide variety of commercial polymer resin materials based on their mechanical and electrical properties, but also according to their suitability for nanocompounding. Experience for cable resins is available from Nexans. A semiconducting layer is required to complete the cable structure with the new thermoplastic insulation. A semiconducting resin will thus be also developed to match with the properties of the PP-based insulation layer. PP resin for capacitor films will be fixed to the grades used successfully on earlier pilot scale tests.

Commercially available relatively inexpensive and mass-produced fumed silica nanoparticles will be used as such as nanofillers, but will also be further optimized by chemical functionalization treatments. University of Twente will develop the chemical functionalization for the fumed SiO₂ nanoparticles, which are smaller than 20 nm in primary

size and will be mixed into PP. The goal of the silica surface treatment is to develop the chemical functionalization for fumed (pyrogenic) SiO₂ nanoparticles which are smaller than 20 nm in primary size.

The surface modification of nanoparticles will be carried out by two different techniques: chemical and physical treatment. The physical modification is based on the Plasma Polymerisation (PP). The PP surface treatment offers a wide variety of high efficiency of surface functionalization of the filler. Chemical methods involve the use of coupling agents (e.g. alkylsilanes, polysiloxanes or polymeric coupling agents) or by grafting polymers. Furthermore, both treatment can be combined. The novel filler technology with chemical and / or physical modifications of silica is the key enabling technology for the polymer improvement in the GRIDABLE project.

State of the art in silica nanoparticle functionalization at UTwente:

University of Twente has a long experience in silica technology and its modification [xx-yy]. The highest knowledge of modification of silica was gained inside the elastomeric world, mainly for tire tread applications. The currently used technology for silica reinforcement of elastomers is an in-situ modification of the filler: when blending the elastomer with the different ingredients, the filler is added together with a coupling agent. This coupling agent has two functionalities: to improve the dispersion of the filler and to establish a strong bond between the polymer and the silica.

The most commonly used coupling agents are silanes. During blending of the rubber additives with the elastomer, the coupling agent enhances the dispersion of the silica by a chemical reaction with the silanol groups on the silica surface. As a consequence, there is less chance of hydrogen bonds between the silica particles, thus enhancing and stabilizing the dispersion of the filler. Furthermore, the coupling agent molecules contain a hydrocarbon spacer, which shields the filler surface and makes it less polar. It can also physically interact with the polymer, as their chemical nature is comparable. For a reaction with the polymer, the coupling agent contains polysulfidic groups, which can form sulfur bridges during the crosslinking process. The final structure of the silica-silane-polymer complex is illustrated in Fig. 1.

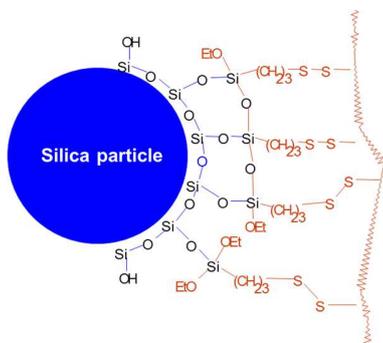


Fig. 1: The silica-silane-polymer complex after the reactive mixing steps of a silica compound.

The specific structure of interpenetrating filler-polymer and polymer-polymer networks gives the silica-filled rubber its specific properties: a strong filler-polymer bond, which

reduces energy losses due to de- and adsorption of polymer chains on the filler surface, and thus a reduced hysteresis [1]

Beyond the state of the art in silica nanoparticle functionalization at UTwente:

The goal of this project is to modify a silica in such a way that these effects (high re-agglomeration tendency, accessible polar surface) are avoided. An optimum dispersion and an optimum coverage of the whole silica surface has to be reached. Therefore, the silica has to be modified in such a way that the smallest accessible units (normally called silica aggregates) are exposed to the modifying agent. On the other hand, the polar character within the primary particles of the silica should remain in order to guarantee a high electrical resistivity.

The idea is to cover the smallest accessible silica units with a very thin coating layer (preferable a monolayer) of an unpolar agent which leads to a superior distribution of the silica in the PP matrix and avoid a re-agglomeration of the silica. This has several advantages. If a distance between the silica-aggregates is maintained for the whole product life, the formation of unwanted conductive pathways can be avoided, too. In such a way, a significantly improved volume resistivity can be achieved. The formation of the very thin coating layer should be reached by the application of two new techniques: molecular layer deposition (MLD, organic films) and / or plasma polymerisation.

The choice of the chemical nature of the modifying agent is as well of high importance. With the right choice of it, together with the molecular level controlled thin coating technique, a surface of the silica can be formed which match the dielectric matrix of the PP in the best suitable way. This results in a control of the electrical properties of the polymeric product. For that reason, modifying agent with a higher molecular weight like alkylsilanes with a long alkyl chain (e.g. octyl or hexadecyl), polysiloxanes, polymeric coupling agents and grafting polymers are taken as grafting molecules into account. Those modified silica has another advantage: the electrical polarization inside the PP matrix can be avoided which leads in the existing PP compounds to an unwanted charge accumulation.