SINTEF

RCN-KSP Project proposal **2022**

New Liquids

Thermal Considerations When Choosing Transformer Liquids for a Safe and Sustainable Energy System

Invitation to participate in research project

An application for a knowledge-building project for industry (KSP) will be sent to the Research Council of Norway (RCN) ENERGIX-programme before February 9th, 2022.

Project idea

The project idea is to investigate the functional properties of safe and environmentally friendly transformer liquids to mitigate risks and uncertainties associated with introducing these to the power system**.** The scope of the project will be limited to thermal issues with a special focus on dynamic loading and low temperatures. The liquids will represent the main groups of dielectric liquids, such as synthetic esters and natural esters made from vegetable oils. Conventional transformer oil will be used as a baseline liquid for comparison throughout the project.

Project description

Objectives

The main objective is to *expand the knowledge base on* ***functional properties*** *of different dielectric liquids. The project output will serve as a* ***basis for improved decision making*** *with regards to designing and procuring transformers. An emphasis will be put on* ***low-temperature properties*** *that are especially relevant for operation in cold climates.*

Secondary objectives:

- Identify and understand the functionality and limitations of dielectric liquids with varying hydrodynamic properties at low and dynamic temperatures. This will be achieved by developing an experimentally verified dynamic thermo-hydraulic winding model. The model will be used to investigate pressure, flow, and temperature distributions in various liquids *at low temperatures* and during *cold start*.
- Investigate the main parameters impacting *bubble formation* in new and aged dielectric liquids.
- Investigate breakdown initiation in dielectric liquids in uniform fields down to -40 °C, and investigate which parameters influence breakdown in homogeneous fields at low temperatures.
- Investigate ageing of winding insulation paper under dynamic loading. Experimental studies on water migration will be used to develop dynamic aging models for cellulose in various dielectric liquids.

NB! The project objectives have been chosen because they either use existing expertise and infrastructure among the research partners *or* because they are deemed especially relevant for Norwegian industry.

Background

Liquid-immersed transformers are filled with a dielectric liquid that acts both as electrical insulation and cooling medium. These functions are crucial for safe and optimal operation of the transformer. Today, most liquid-immersed transformers in Norway are filled with mineral oil. Mineral oil has been used in power equipment for over 100 years and is well-tested with a vast bank of knowledge and experience. Mineral oil has many favourable properties such as good aging behaviour, good low-temperature behaviour, low cost, and wide availability. Nevertheless, mineral oil also has drawbacks. Firstly, it has low biodegradability, and it is made from non-recyclable crude oil. This poses challenges related to sustainability and with regards to placing mineral-oil-immersed transformers in areas where it is difficult to control potential oil spill such as offshore, subsea or near shore. Secondly, mineral oil has a low ignition point which makes mineral-oil-immersed transformers less suited for some locations such as densely populated areas, tunnels in hydropower stations and offshore. Thirdly, mineral oil naturally contains corrosive sulphur which has contributed to increased failure rates. Considerable efforts are necessary to mitigate issues related to corrosive sulphur in mineral oil.

In the last decades alternative dielectric liquids with lower environmental footprints and flammability have arrived on the market. In addition to the aforementioned properties, these new dielectric liquids have other functional properties that separate them from mineral oil. For example, many of them have significantly higher viscosity than mineral oil, which impacts their cooling capacity at low temperatures. Their aging behaviour also differs, mainly due to variation in chemical properties such as oxidation stability and water solubility. These properties also influence how the liquids interact with, and degrade, the solid insulation (cellulose) in the transformer. In fact, there is a growing number of studies that indicates that the lifetime of cellulose is longer in esters than in mineral oil, and ester-filled transformers show potential for high-temperature use if combined with Aramid instead of cellulose. While alternative dielectric liquids are already in use around the world, especially in distribution transformers, the knowledge base is still limited. Particularly, knowledge gaps with regards to application in large power transformers and at low temperatures must be closed.

Value Creation

The project will provide knowledge on properties and limitations of dielectric liquids at low and dynamic temperatures, which will provide:

- **Models suited for digitalisation and tailored diagnostics:**
  - *Liquid-specific thermal models*
  - *Aging models for dynamic loading*
  - *Models for catastrophic events (bubbling and breakdown at low temperatures)*
- **Improved knowledge base for introducing new technology with regards to**:
  - *Procurement*: Knowledge can be used to make better liquid-specific specifications and testing procedures. A good understanding of benefits and limitations can help decide which dielectric liquid is optimal when procuring for a specific location.
  - *Asset management*: Liquid-specific models for aging and diagnostics offer more accurate life management.
  - *Operation*: Thermal models for dynamic loading will allow for better control under emergency overloading, and reduced need for investment in redundant capacity.
- **Reduced uncertainty and more accurate risk assessment with regards to introducing new liquids with several benefits:** Better fire safety, reduced environmental impact, no corrosive sulphur, potential for prolonged lifetime for solid insulation, potential for operation at higher temperatures with compact devices.

Implementation

Duration will be 4 years, and the work is split into:

WP1: **Mapping and characterisation of dielectric liquids** – Chemical, physical, and electrical properties of alternative liquids will be gathered from producers and literature. If needed, the liquids will be characterised experimentally.

WP2: **Hydraulic and thermal behaviour of dielectric liquids at dynamic and low temperatures –** An in-house thermohydraulic-model developed at SINTEF [1] will be extended to calculate dynamic temperature and pressure distributions relevant for dynamic loading and cold start in liquids with varying hydrodynamic properties. The model will be validated using an existing winding rig located at SINTEF Energy Research and possibly an in-service transformer.

WP3: **Ageing of cellulose in dielectric liquids –** Moisture dynamics in various dielectric liquids in combination with cellulose will be investigated in conventional and new dielectric liquids. The output from the experimental activity will be used to develop an out-of-equilibrium model of the moisture balance between solid and liquid insulation for liquids with different water absorptivity.

WP4: **Fault mechanisms in dielectric liquids –** This work package will investigate important fault mechanisms in various dielectric liquids, namely bubble formation and breakdown in a homogenous field at low temperature (e.g. due to so-called clouding of the liquid). The rig that will be used to investigate bubbling is already in place at SINTEF Energy Research. For the breakdown tests a new rig with liquid cooling will be built. The focus will be to determine which liquid parameters are most important with regards to these fault mechanisms.

WP5: **Administration and communication**

Budget and funding

A KSP project is expected to receive 65-75% of its funding from the RCN. With partners contributing with a total of 6.5 MNOK balances a 26 MNOK budget with 75 % support from RCN.

Potential partners

NTNU, Statnett, Elvia, Statkraft, Siemens Energy, Nynas, M&I Materials, Norwegian utilities.

Application process

Letters-of-intent: February 1st, 2022
Application deadline: February 9th, 2022.

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[1] https://doi.org/10.1016/j.applthermaleng.2020.116133