LIFE CYCLE EVALUATION OF INNOVATIVE SOLID STATE TRANSFORMER

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Overview

Transformers, as fundamental components of the electricity transmission and distribution system, are pivotal in facilitating the efficient transfer of electrical energy across various voltage levels. As a matter of fact, solid-state transformers (SSTs), a revolutionary technology that can expand the standard functions of a conventional transformer, continue to rise in acceptance. Its efficiency impacts the overall safety and stability of the power system. They may enhance the distribution of energy in a more sustainable way and add a significant amount of digitalization and intelligence into the network. The environmental impact of electrical transformer production differs based on the transformer's power distribution capability and materials (Mansilha et al, 2018). An innovative High Voltage Solid-State Transformer (HV-SST) is developed and its environmental impacts are evaluated in the framework of SSTAR project. An interesting feature is the usage of non-hazardous, recyclable, and durable materials such as utilizing a bio-based dielectric fluid as insulation mean, instead of mineral oil-based fluid, which contributes to reducing CO_2 emissions.

Methods

A life cycle assessment method of HV-SST with power capacity 75 kVA is conducted throughout all lifetime phases. The boundaries include energy and mass balances of the production, transportation, operation and maintenance and disposal phase adopting a cradle-to-grave approach. The functional unit considered is "one kilowatt-hour (kWh) of transferred electricity". Outcomes are obtained through SimaPro software and to comprehensively assess the environmental impacts three complementary life cycle impact assessment (LCIA) methods are employed: Environmental Footprint 3.0 (EF3.0), ReCiPe 2016, and Impact World+.

Results

The Global Warming Potential (GWP) of 1kg of bio-based dielectric fluid ranges from 1.32 to 1.35 kg CO_2eq, and the Cumulative Energy Demand (CED) ranges from 15.5 to 17.5 MJ, with minimal variation between LCIA methods. This consistency suggests that the environmental performance of the dielectric fluid remains robust regardless of the assessment approach, providing confidence in its lower environmental impact across different evaluation frameworks. According to the literature, comparing the GWP of the dielectric fluid developed in the framework of SSTAR project with the only transformer dielectric fluid reported in Scatiggio et al, (2020), which estimated a GWP of 1.99 kg CO_{2eq}, reveals an approximately a 33% decrease. This substantial reduction highlights the improved environmental performance of the SSTAR dielectric fluid compared to traditional mineral oil. Furthermore, McManus et al., 2001 refered that 1kg of mineral oil-based fluid in mobile hydraulic machines had a GWP of 3.56 kg CO_{2eq} and Ekman et al. (2011) repored that the production of 1kg mineral oil-for hydraulic systems emits 4.31 kg CO_{2eq}. Both studies demonstrated significantly worse environmental performance compared to the present study bio-based dielectric fluid.

Conclusions

An LCA was performed to analyze the production, the operation and maintenance and the disposal of a HV-SST throughout its lifetime, using three different assessment methods. Emphasing the innovation of HV-SST related to the bio-based fluid produced in the project's framework, this fluid outperforms traditional mineral oils in environmental performance, particularly in terms of GWP, with decreases ranging from 33% to 69%. This increase the possibility the transformers manufacturers and energy suppliers to use the obtained results as a decision making tool.

The paper is funded by Horizon Europe project SSTAR, Grant Agreement No: 101069702

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