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Surface inspection and control algorithms

Quality control (QC) by means of a dedicated post-installation partial discharge (PD) measurement, performed in some HVDC cable projects today, has several limitations. For joints, since the cables and pre-molded joint bodies are rigorously screened and pre-tested in the factory, the scope of this assessment is limited to the on-site created physical interface. The limitations of controlling the quality of this interface by means of AC PD measurements stretch beyond the challenges of long cable length energization and low noise level requirements. The main limitations relate to the joint body being slid into its position using dielectric oil or grease, and that measured PDs do not correlate well with field enhancement into the cable dielectric. This contribution aims to clarify such limitations and to demonstrate a robust alternative QC method.

Manufacturing defects and other non-ideal geometric attributes of the on-site created interface could form cavities between the XLPE cable surface and the accessory component. While a post-installation PD measurement could detect such cavities, a usually overlooked aspect is that the dielectric grease or oil present in the interface greatly increases the dielectric strength in the cavity. While air itself in such cavities can feature a breakdown strength as low as 3 kV/mm (neglecting here Paschen's corrections for pressure and gap distance for sake of simplicity), this value may increase up to tenfold in the presence of sliding grease/oil. Large defects could thus be present without detecting them in the PD measurement. Furthermore, whilst AC PD measurement may correlate with cavity size, the DC performance of the system may better correlate to the degree of field enhancement into the dielectric. The correlation between PD measurement and DC performance may thus be broken by; large spherical cavities creating low inception voltage (IV) but low field enhancement, and small sharp cuts with higher IV but creating high field enhancement into the dielectric. These limitations, intrinsic to PD measurements, call for new advanced surface inspection techniques, spawning a new era of QC methodology in the high voltage (HV) industry.

Rather than indirectly assessing interfacial geometry using electrical methods after installation, laser scanning allows for direct acquisition of the surface geometry utilizing a stereo-camera setup. The resolution (<100 µm) and accuracy (<25 µm) are high thanks to high quality optics and the use of a cross-hatched line pattern projected on the surface. The tool can use 3D markers placed on an external JIG to track its position in relation to the test object. The acquisition software provides live tracking of the generated data cloud, which ultimately is stored as a mesh comprising the fully inspected surface. Subsequently, a tailor-made algorithm can process the mesh further, allowing it to detect the worst regions and perform localized finite element method (FEM) simulations. Laser scanning of cable joint XLPE surfaces has been performed, and a first algorithm tailored towards the inspection cylindrical cable ends has been developed. Given the high spatial resolution, FEM computations on the measured domain as a whole or in looped segments is too computational expensive, creating the need for mathematically identifying troublesome regions in the algorithm. A key computational step of such an algorithm therefore encompasses mathematical computations that identify troublesome regions. From such identifications, an amount n, of smaller surface segments are selected and imported into a FEM model. The FEM model creates a local simulation domain capable of simulating an air-filled cavity or field enhancement into the dielectric, respectively determining PDIV and field enhancement factors (FEF). Having such FEM simulations in the algorithm can create an on-site go/no-go criterion based on macro-geometric deviations as well as estimated PDIV and FEF for the n worst regions on the surface. Compared to PD measurement, this QC approach benefits from providing direct feedback to the operator prior to finalizing the joint. It also assesses the PDIV for the largest detected voids assuming these are air filled, without uncertainties regarding oil presence in such voids. Furthermore, it can also estimate local field enhancement, and compare such results against pre-defined acceptance criteria. The algorithm also generates a QC report on the jobsite which can be shared with all parties involved.

Future work on these surface inspection and control algorithms involves tailoring the FEM computations to meet on-site computational speed, accuracy, and robustness requirements. Laser scanning QC techniques will work regardless of the interfacial dielectric liquid used, and cable lengths connected to the accessory. It will also remove the risk, costs and electric stress imposed by the AC energizations of the cable link dedicated for post-installation PD measurements. PD monitoring during normal AC or DC system operation could still be employed, and here the scanned geometric datasets can be accessed in case incidents are detected. Conclusively, the demonstrated laser scanning approach is a potent alternative to PD measurements for QC of on-site manufactured interfaces. Given the high accuracy and versatility, these surface inspection and control algorithms will enable HV Industry 4.0, greatly improving the reliability of on-site accessory installation works.