Updates about the Horizon Europe NEWGEN Research Project for a New generation of HVDC Insulation Materials, Cables and Systems

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***Abstract*—This article describes the updates about the HEU NEWGEN research project[1], after 18 months since its start. The NEWGEN project aims at developing and proofing a new generation of extruded HVDC cable systems, including not only novel insulating materials, but also new manufacturing, monitoring and diagnostics techniques, as well as models for life and reliability of the cable systems. Such generation of HVDC cables is believed to contribute to a reliable and resilient European transmission grid.**

Keywords—HVDC extruded cable systems, diagnostics, dielectrics, insulation, monitoring, life models, transmission grid.

I. INTRODUCTION

The European Union (EU) has indicated underground and submarine HVDC cables as a key enabler towards the so-called Green Transition, since they reduce transmission losses and ease the environmentally-friendly grid connection of renewable energy sources (RES), thereby supplying clean energy, fostering cheaper electricity prices and favouring climate neutrality and decarbonization according to the EU Green Deal [1-4].

In this framework, the novel extruded HVDC cable systems are taking over traditional lapped HVDC cables [5], as they enable simpler manufacturing and splicing, reduced price and weight, increased compatibility with the environment and high performance [6]. In turn, among extruded cables an appealing alternative to the well-established cross-linked polyethylene (XLPE) is the new polypropylene (PP)-based thermoplastic insulation, which is going to be installed – together with filled and unfilled DC-XLPE – in the three bipoles of the 525 kV, 2 GW, German Corridors [4]. However, details on research on this insulation are few in the literature.

In this scenario, the NEWGEN project "New Generation of HVDC Insulation Materials, Cables and Systems", with a budget of ≈8 Million Euro from EU Horizon Europe innovation and research programme [1-3] began in Oct. 2022 and will go on for 4 years till Sep. 2026. In summary, the goal of the NEWGEN project is fostering the entire EU HVDC industry with new methods and technologies for extruded HVDC cable systems (cable, joints and terminations) in the areas listed below:

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TABLE I. NEWGEN PARTNERS COUNTRY AND TYPE: UNI = UNIVERSITY, IND = INDUSTRY, SME = SMALL AND MEDIUM-SIZED ENTERPRISE, RTO = RESEARCH AND TECHNOLOGY ORGANIZATION

Name	VTT	University of Bologna	Maillefer	Techimp - Doble Eng.	University of Twente	Tampere University	GreenDelta	SuperGrid Institute	CLIC Innovation	Terna
Country	Fin	Ita	Fin	Ita	Ned	Fin	Ger	Fra	Fin	Ita
Type	RTO	UNI	IND	IND	UNI	UNI	SME	IND	SME	IND

1) novel additives for reducing space charge (SC) storage - see Work Package (WP) 1 hereafter - and novel extrusion techniques for a new defect-free generation of HVDC thermoplastic cables - see WP2 hereafter;
2) novel global online condition monitoring and pre-fault detection techniques - see WP3 hereafter;
3) novel life and reliability models for realistic operation of DC cables in AC/DC grids - see WP4 hereafter.

Ten multidisciplinary partners listed in Table 1 - from 5 EU countries: Finland, France, Germany, Italy, Netherlands – contribute to the NEWGEN project, of which three are Universities, four are industries, two are small and medium-sized enterprises, one is a research and technology organization. Moreover, an External Advisory Board (EAB) is providing insightful advices [2].

NEWGEN has 6 WPs; the first 4 have a scientific-technological content with dedicated innovative outcomes [2].

1) WP1 = reducing SC storage within the extruded insulation of HVDC cables via the innovative outcomes listed below:
   - ✓ new molecular, optimally-dispersed and sustainable additives that mitigate SC;
   - ✓ novel PP- and XLPE- compounds with additives, featuring optimum rheology and morphology;
   - ✓ thorough dielectric characterization leading to proper relations between processing, structure and dielectric properties to assess the optimized density of trap states for the insulation of HVDC cables.
2) WP2 = manufacturing HVDC extruded cables with no defects and better performance via the innovations listed below:
   - ✓ novel thermoplastic compounds to reduce the cons of weld lines through distributors with spiral mandrel;
   - ✓ better morphology of insulation through screw designs that enable more uniform extrusion, and optimum temperature drop along power cable cooling sections;
   - ✓ refinement of novel compounds for HVDC insulation from WP1, and of production processes and devices to speed up the production lines of HVDC cables;
   - ✓ simpler, lighter, more sustainable and eco-friendly HVDC cables to reduce costs and social and environmental impact throughout the life cycle.
3) WP3 = achieving a comprehensive diagnostic tool for multi-parameter online health assessment and monitoring of HVDC cables via the innovations listed below:
   - ✓ a monitoring system acquiring cable service data (load, voltage, etc.), ambient parameters (humidity, temperature, etc.), diagnostic markers (DTS, PDs, leakage current measured via a novel magneto-optical sensor cheaper than present sensors of leakage current that rely on coils);
   - ✓ combination of literature data, preliminary measurements, experiments on site, to derive quantities for assessing the global condition of the HVDC cable system;
   - ✓ acquisition of the time trend of observed parameters, to correlate cable duty data with environmental and monitored parameters.
4) WP4 = increased reliability and resilience of the transmission network including HVDC cable lines by means of a model for life and reliability of the overall HVDC cable system via the following innovations:
   - ✓ improvement of state-of-the-art (SoA) models for life and reliability of HVDC cables to tackle all service stresses, together with local SC storage centers;
   - ✓ optimization of the design of HVDC cables through a procedure relying on the estimate of cable life;
   - ✓ set-up of novel models for life and reliability of terminations and joints of HVDC cable systems;
   - ✓ encompassment of the above mentioned models into a comprehensive model for life and reliability of the entire HVDC cable system;
   - ✓ simulation of the whole transmission grid encompassing HVDC cable lines in different topologies to prove grid resilience and reliability.

Non-technical WPs are as follows.

5) WP5: Communication, Dissemination and Exploitation.
6) WP6: Coordination and Management of the Project.

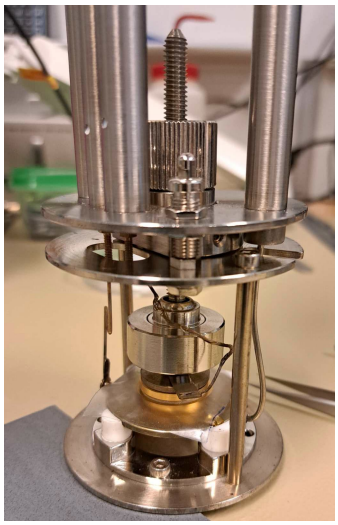
The aim of this article is to show the main interesting and innovative updates and achievements of the NEWGEN project in the first 18 months elapsed since its start.

II. ADVANCES OF THE PROJECT IN THE FIRST 18 MONTHS

The main advances of the NEWGEN Project in the First 18 Months since its start in October 2022 are summarized in this Section. The Section in turn is divided into 5 subsections, one for each Work Package excepted WP6 (= Project Management and Coordination), already detailed in [2] and skipped in this more technical paper.

A. Mitigation of SC in Polymeric Insulation for HVDC Cables: the Goal of WP1

Along with SoA DC-XLPE insulation material, novel thermoplastic HVDC cable insulation materials based on thermoplastic PP resins with novel additives have been developed and extensively investigated in the NEWGEN project (see Fig. 1). Thermoplastic PP-based insulation materials have attracted significant interest for HVDC cable



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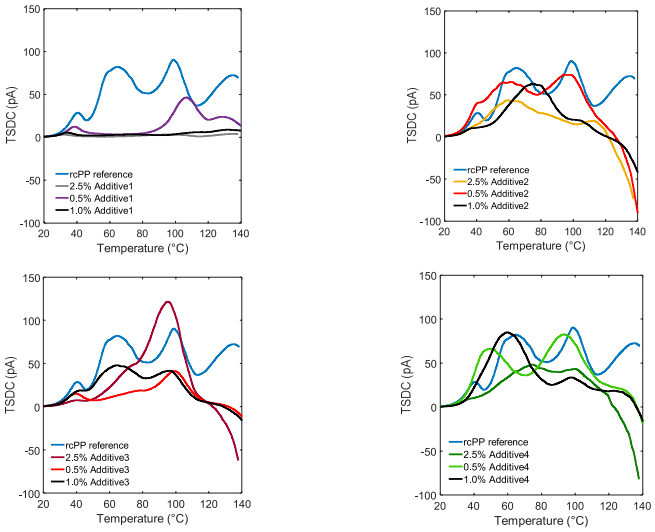

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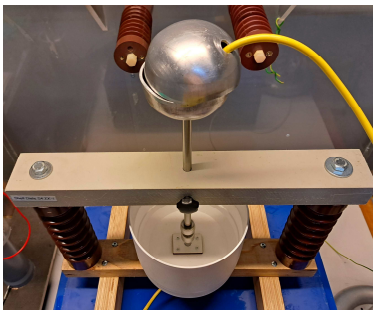

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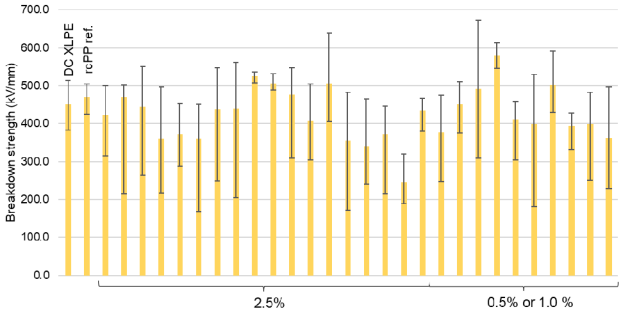

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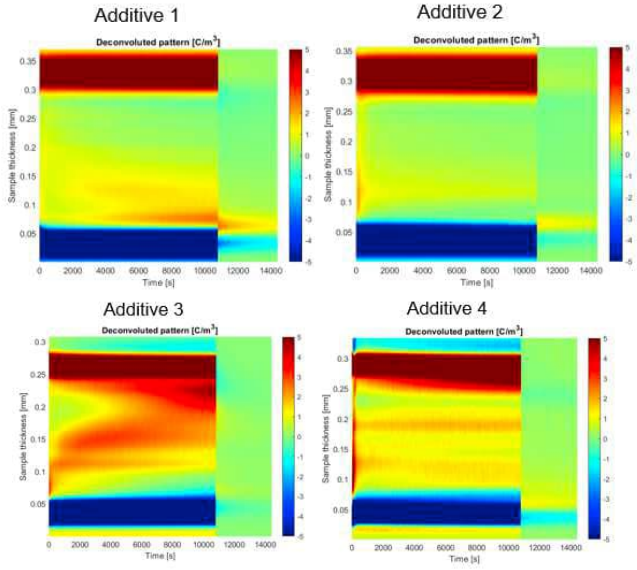

(F)

Fig. 1. Preliminary Screening of Combinations of PP-Based Compounds and Additives: (A) TSDC Cell; (B) TSDC Measurement results for some selected additives; (C) Breakdown Strength Cell; (D) Breakdown Strength Measurement results for references and additives; (E) PEA SC Cell; (F) PEA SC Measurements.

applications due to their superior dielectric properties, higher thermal stability and recyclability, for instance. In the first stage, various PP-based insulation blend formulations comprising primarily of PP homopolymers and PP random copolymers have been explored in NEWGEN, focusing on their insulation performance under HVDC stresses and compliance with the HV cable mechanical property requirements as imposed e.g. in [6]. The base insulation material processing has been performed using mini- and pilot-scale twin-screw extrusion and hot-pressing approaches at VTT, yielding suitable flat specimens for dielectric and material characterization.

The best-performing PP-based insulation candidates have been shown to exhibit promising thermomechanical and short-term dielectric performance in comparison to the SoA DC-

XLPE. For instance, all the PP-based insulation blends were found to exhibit acceptable tensile and flexural properties for HV cable application along with extended high-temperature thermo-mechanical performance at 80-100 °C range where conventional XLPE shows loss of mechanical integrity due to softening and, finally, melting of the PE. Moreover, importantly, the best performing PP base insulation formulations were found to exhibit high dielectric breakdown strength (BDS) and reduced SC accumulation vs. DC-XLPE.

To enhance the dielectric characteristics of PP- and XLPE insulation further, NEWGEN is developing and demonstrating novel molecular additives to suppress SC in PP- and XLPE-based HVDC cable insulation matrices where polar species capable of acting as charge trapping sites are directly anchored to suitable polyolefin (PO) backbones via chemical modification. So far, 46 combinations of PP-based compounds with different additives (as for the type of base compound, and type and percentage of additives) have been screened to assess their dielectric performance by measuring:

- trapping properties by means of TDSC method, (Fig. 1.(A) presenting the measurement cell). Results for some promising additivated compounds are shown in Fig. 1.(B). Additives reduce the shallower traps related current while allowing still certain amount of deeper traps, indicating thus a modified trap density more suitable for cable dielectric;
- breakdown strength, by means of a breakdown strength cell (Fig. 1.(C)). The results for all additivated compounds and references are shown in Fig. 1.(D). Many compounds have really promising breakdown behavior when compared to the SoA fully degassed DC XLPE and PP reference;
- SC accumulation by means of PEA (Pulsed Electro-acoustic) method in (Fig. 1.(E)). Fig. 1.(F) shows the space charge pattern in the sample thickness over 3 hours of polarization and 1 hour of depolarization. Some grafted additives show reduced space charge accumulation.

In the next stages, the clean compounding process at VTT is up-scaled, and larger insulation material batches (up to 300+ kg) will be produced for cable models and full-size prototype of HVDC cable demonstrators in NEWGEN project.

B. *Reliable-by-design Production of HVDC Cables: the Goal of WP2*

WP2 has the following targets.

- To develop cable production lines and control techniques of the process of extrusion leading to thermoplastic cables without defects.
- To demonstrate full-size HVDC cable prototypes with new formulations of the insulation at pilot-scale level.

From the empirical/theoretical viewpoint, WP2 adopts the following global methodological approach [1].

SoA production lines of polymeric power cables are conceived and tailored on XLPE cables, with the exception of HPTE, a novel PP-based insulation [7]. On the other hand, the challenges to extrusion involved by the reactivity of Di-Cumyl Peroxide (DCP) in XLPE are missing for thermoplastic compounds from WP1. Thereafter, WP2 first and foremost target is to develop extrusion devices for thermoplastic HVDC cables - from mini-cables [8] to life-sized cables - starting from known weaknesses of SoA manufacturing lines.

The life cycle and extended sustainability will be assessed according to ISO 14040 to reveal the various aspects implied by the use of HVDC cables, also in comparison with possible alternative systems [9]. The environmental assessment will follow the Environmental Footprint methodology [10] closely, considering also that the commercialization of novel cable types is less developed; therefore, nanoelements difficult to evaluate might be implied when focusing on additives and upscaling. As a consequence, a proper risk assessment will be carried out, too, and correlated to the whole Life Cycle Assessment (LCA) procedure. The effective "openLCA" (open-source) software will be used to implement LCA models, resorting to both general and dedicated databases.

C. *New Monitoring Techniques for HVDC Cable Systems: the Goal of WP3*

The main focus of the initial stage of the WP3 has been on the assessment techniques for the health status of the HVDC cables, in particular Partial Discharges (PD), where the approach used has been on one hand to understand the behavior of different defects on various insulating materials and, on the other hand, to validate the current state-of-the-art detection approach used under HVAC when applied to HVDC conditions. The work has been split into different tasks: creating artificial defects prone to incept discharges, detecting and optimizing the acquisition of the PD signals, analyzing and characterizing them, and, lastly, using the gathered experience to focus on the samples manufactured during WP1 and WP2 to characterize them to create a related diagnostics.

There are two main differences related to the constant electric field applied:

1) under the AC regime, the most common graphical representation is the Phase-Resolved PD (PRPD) pattern (Fig.2.(A)), while under DC there is no phase (Fig. 2.(B));
2) the Inception Voltage (PDIV) is much higher in DC conditions with respect to the one under AC.

Artificial defects have been engineered to create PD signals consistent with the ones that can be detected in the field. In particular, Corona, Surface, and Internal defects have been created and the relevant PD signals have been detected. Fig. 3 shows a schematic representation of the specimens for these defects.

The tests have been performed both under AC and DC conditions to be able to characterize the defects. A particular focus has been used for the study of the waveforms as highlighted in Fig. 4. As a result, for the different defects it is possible to define statistical markers that support the analysis and contribute to the development of a diagnostic approach able to identify the different defects as reported in Fig. 5.

D. *Models for Resilient and Reliable HVDC Cable Systems: the Goal of WP4*

Since the beginning of the project, WP4 has tackled Task 4.1 "*Development of a dedicated algorithm for life and reliability modelling of HVDC cables*", split in turn into two subtasks: Subtask 4.1.1, relevant to algorithm development; Subtask 4.1.2, relevant to algorithm validation.

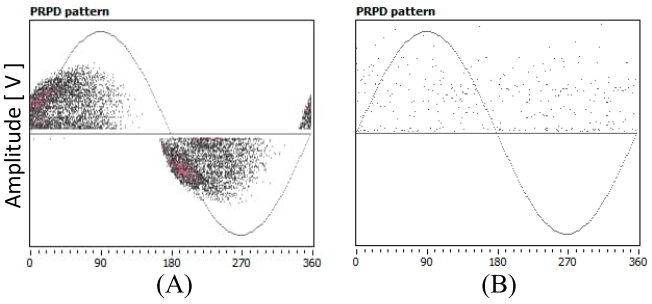

Fig. 2 PDPR pattern under AC (a) and DC (b) conditions.

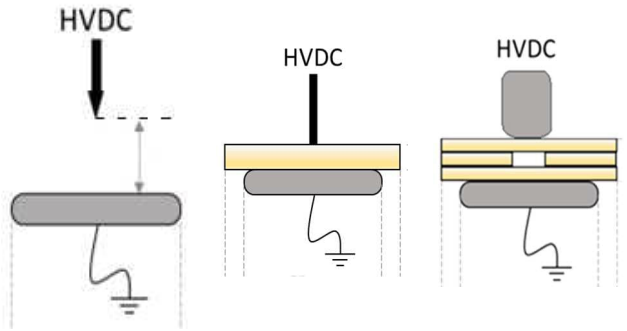

Fig. 3 Test sets for Corona (a), Surface (b) and Internal (c) discharges.

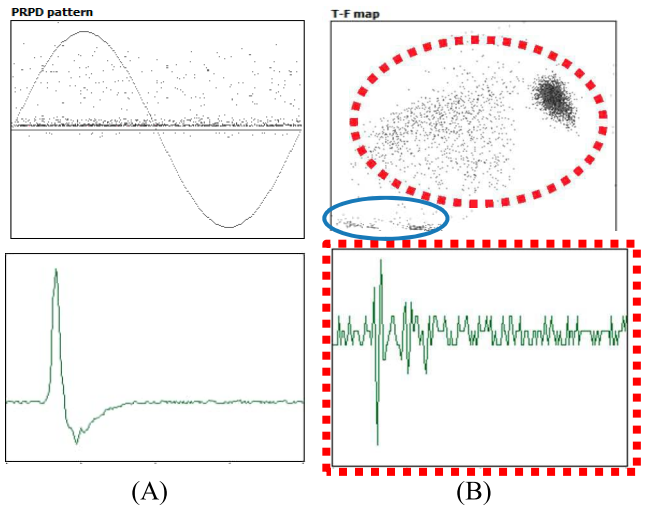

Fig. 4 PRPD pattern and TF map of an HVDC acquisition with PD (a) – blue and noise (b) – dotted red.

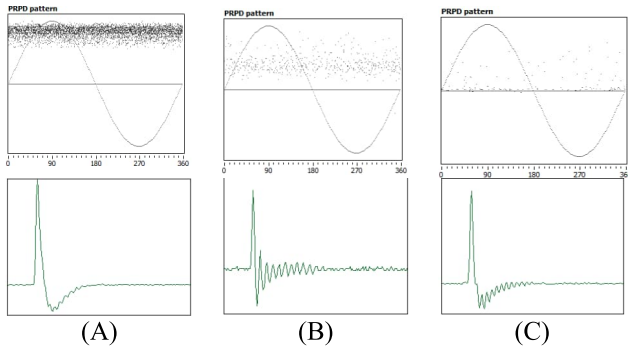

Fig. 5 PRPD pattern and waveform for the signals relevant to Corona (a), Surface (b), and Internal (c) signals.

Subtask 4.1.1 started with a literature review of most commonly used models for life and reliability of HVDC cable systems [7]. Among these, an algorithm for life modelling with load cycles developed e.g in [11] was applied to the new generation of HVDC cable systems subjected to load cycles during qualification tests and in service.

From the literature, the geometric design of HVDC cables relying on life estimates [12] has been taken for the novel generation of HVDC cable systems targeted by the NEWGEN project. Subsequently, a Bipolar Charge Transport (BCT) model based on the injection and mobility [13] of charge carriers inside the insulation has been developed and currently an algorithm for local and global optimization to find the parameters of the BCT model using the SC measurements carried out in the framework of WP1 (see above) is being refined. This algorithm will be applied to SoA XLPE, as well as to the selected PP-based compounds; different values of temperature and electric field will be considered, according to the flowchart in Fig. 6. Investigating macroscopic conductivity models and fitting all models to the experimental data is another topic accomplished in the 1st 18 months of the project in the framework of Subtask 4.1.1 [14].

Next, Subtask 4.1.1 will focus on dimensional effects due to insulation enlargement as cable cross-section and length rise from laboratory specimens to full-size cables on site, as well as on the inter-connection ageing processes vs. pre-fault monitoring data of novel dielectrics for HVDC cables, to improve HVDC cable pre-fault monitoring in WP3.

The second subtask of Task 4.1 is Subtask 4.1.2 "*Algorithm validation*". This subtask will start soon at month 19, hence preparatory activities are ongoing, with the selection of the test cell for Accelerated Life Tests (ALTs) to validate the developed life models for the best PP-based compounds with additives, and the planning of ALTs under selected combinations of electric field and temperature.

Task 4.2 "*Life model development for HVDC cable systems*", has started at month 12. The aim is to broaden the algorithm in Subtask 4.1.1 to cable joints and terminations to estimate the reliability and the life of the entire HVDC cable system. Task 4.2 is ongoing, with a literature review on the reliability modelling for cables accessories, to help estimate life model parameters for cable system accessories. Focus here is on cable joints, due to their greater number, which makes them more critical vs. terminations for overall cable system reliability. 2D & 3D FEM (Finite Element Method) calculations of temperature and electric field in HVDC cable system joints are ongoing – carried out via Comsol Multiphysics™, see Fig. 7 after [15] - to locate possible overstressed points that might set challenges to the joints.

Last but not least Task 4.3, relevant to the resilience of HVDC cable lines to contingencies in the AC grid, also started at month 12 with a preliminary evaluation of the mixed AC/DC grid configurations of interest to TERNA, the TSO partner of NEWGEN. Different configurations of the integration cases of HVDC cable systems and renewable energy sources (RES) in the AC grid are being selected, based on the utility experience, needs, and priorities. On these configurations, simulations of the various possible contingencies will be performed, to provide voltage and current profiles along HVDC cable links that will serve to evaluate the risk to HVDC cable systems and their resilience to such contingencies.

E. Dissemination, Communication, Exploitation: the goal of WP5

WP5 has the following targets [3].

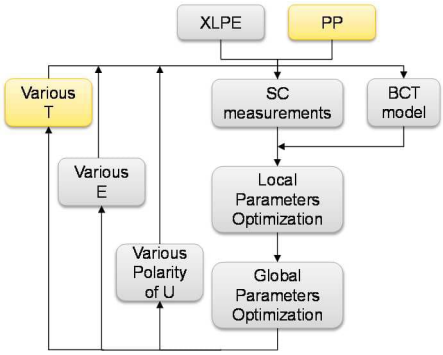

Fig. 6. Flow chart of the algorithm for local and global optimization of the BCT model parameters with the SC measurements carried out in WP1.

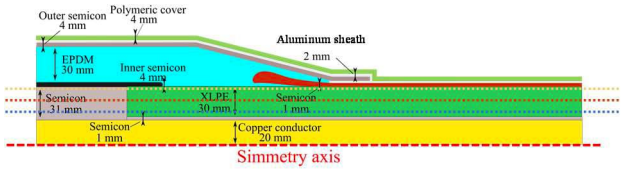

Fig. 7. Geometry of HVDC cable system joint analyzed via Comsol MultiphysicsTM in the framework of Task 4.2 (after [15]).

- To gain visibility in the society to reveal the effects and advantages of the NEWGEN project.
- To deliver the achievements of the project to selected groups of interest.
- To improve useful synergies by means of interactions with interesting networks and projects.
- To evaluate the patent landscape, and to define and implement the IPR strategy.
- To single out and manage the KERs (Key Exploitable Results) to grant effectiveness of exploitation.

To disseminate the NEWGEN activities and results, a website has been developed [3] and social media channels have been created in YouTube, LinkedIn and Twitter. Moreover, consortium members have published one journal article [7] and four conference papers [2], [14], [15], [16], these latter presented with three oral presentations and one poster. One newsletter has been published to highlight NEWGEN project activities. The NEWGEN project consortium members are actively collaborating with the working groups of BRIDGE, an initiative of the EC (European Commission) linking Horizon 2020 to Horizon Europe Smart Grid, Energy Storage, Islands, and Digitalisation Projects.

An exploitation plan for NEWGEN project based on key exploitable results identified by the project partners has been developed. In order to advise on the aspects of commercialization and exploitation of project results, NEWGEN has an external advisory board consisting of seven leading industry experts. Two external advisory meetings have already been conducted where the external advisory board members advised on the exploitation plan and intermediate results of the project members.

III. Conclusions

This paper reports the updates of the NEWGEN research project, highlighting the significant developments in all Working Packages. In summary, in the WP1 PP/PEC blends with/without grafted additives have been characterized and showed promising electrical insulating properties compared to XLPE. In the WP2, extrusion solutions as well as the LCA have been investigated. In the WP3, prefault monitoring solutions in HVDC cable systems have been investigated starting with PD measurements under DC voltage on specimens engineered with artificial defects. In the WP4, the life and reliability model has been developed by considering the electric field calculated using bipolar charge transport model with optimized parameters delivered using an ad-hoc space-charge-based optimization software.

These promising results pave the way to a broader use of PP/PEC blends with/without grafted additives as new HVDC cable insulating materials beside State-of-the art DC- XLPE.

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