The NEWGEN European Union Research Project for a New Generation of HVDC Cable Systems

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***Abstract*—This paper illustrates the European Union NEWGEN research project, entitled "New Generation of HVDC Insulation Materials, Cables and Systems", with 10 partners over 5 EU Countries. The objective of NEWGEN is to develop and proof new insulation materials, manufacturing solutions, online condition monitoring, and comprehensive life and reliability modelling tools for next-generation of extruded HVDC cables and cable systems, thus fostering the reliability and resilience of the European HVAC/-DC transmission grid.**

Keywords—HVDC cable systems, extruded insulation, diagnostics, monitoring, life modeling, grid simulation, firewall.

I. INTRODUCTION

HVDC land and subsea cables are essential for long-distance power transmission with low losses, thus easing the grid-integration of renewables to provide clean energy, create a more competitive EU transmission system, reduce electricity prices for consumers and businesses, thereby enabling decarbonization and climate neutrality of Europe by 2050 in line with the EU Green Deal. [1].

Extruded HVDC cables with cross-linked polyethylene (XLPE), and more recently also thermoplastic polypropylene (PP)-based insulation, represent a new generation of HVDC cables, with several benefits vs. traditional mass impregnated (MI) HV cables, e.g. simpler manufacturing, easier installation due to less complex jointing, lower weight, and lower price, better environmental compatibility. This makes them a very compelling new alternative especially for both on-shore applications and off-shore usage at moderate sea depths, nowadays - with the so-called German Corridors - up to ±525 kV with a transmission capacity above 1 GW [2].

However, while extruded HVDC cables will be a key technology moving into the future, expanding their utilization to higher voltages – now the 800 kV voltage level is being targeted, as witnessed by the CIGRE' Technical Brochure 852:2021 [3] – and powers, while ensuring their reliable operation over the expected lifetime of up to 40 years still requires new technological innovations. The reliability of the HVDC cables and systems is crucial for the reliability and resilience of the whole transmission grid, to ensure satisfactory firewall properties against disturbances in the hybrid AC/DC network, and to foster the massive integration of remote renewables into the grid.

In this framework, the NEWGEN project entitled "New Generation of HVDC Insulation Materials, Cables and Systems" in April 2022 received around 7.6 MEuro funding from the European Union's Horizon 2020 research and innovation programme under the Grant Agreement No 101075592 (see the website at https://www.newgen-project.eu/ [4]). The NEWGEN project has started in October 2022 to last over four years until the end of September 2026. It aims at delivering technological solutions for the whole European HVDC industry in three following thematic areas:

1) new space charge mitigating additives for extruded HVDC insulation materials, and cable extrusion solutions for next generation of defect-free thermoplastic HVDC cables;
2) online global condition monitoring and novel pre-fault detection methods for extruded HVDC cable systems;
3) tools and models for life and reliability evaluation of extruded HVDC cable systems (cable, joints and terminations) under realistic operation conditions within HVAC/-AC grids.

The NEWGEN project concept and its impact in the short-term (2027) and long-term (2032) are summarized in Fig. 1. NEWGEN is gathering a multidisciplinary consortium composed of 10 partners from 5 different European countries: Finland, Italy, Netherlands, Germany & France. The NEWGEN partners are listed in Table 1, with 4 industrial partners (IND), 2 small and medium-sized enterprises (SMEs), 1 research and technology organization (RTO), and 3 Universities (UNI). In addition, several external Advisory Board (AB) members will foster the project [4].

The goal of this paper is to illustrate the main details of the NEWGEN project, with a focus on objectives, ambitions, Work Packages (WPs), relevant scientific background, and the role played by the various partners. Section II illustrates the objectives and ambitions, highlighting the innovation potential beyond the state-of-the-art of the project. Section III describes the WPs which the research, dissemination, and management activities of the project are split into; more emphasis is put on the first four technical-scientific WPs, for which the theoretical and empirical background is recalled and the activities to be carried out are illustrated in greater detail. Section IV reports the expected outcomes of the project in terms of final results and future exploitation.

II. OBJECTIVES AND AMBITIONS OF THE PROJECT

NEWGEN innovation potential and beyond state-of-the-art is achieved by the following Specific Objectives (SO) [1]:

i) develop novel space charge mitigating additives and cable extrusion solutions for next-generation highly-reliable polymeric HVDC cables. This SO is covered in WP (Work Package)1 and WP2;

ii) new pre-fault monitoring solutions for HVDC cables and accessories. This SO is covered in WP3;

iii) life and reliability model of HVDC cable systems fostering the overall reliability and resilience of the inter-connected grid. This SO is covered in WP4.

NEWGEN has four ambitions to overcome the state of the-art, each corresponding to one single technical-scientific WP and relying on ad hoc innovations and solutions [4].

I) Solving the issue of space charge accumulation within extruded HVDC cable insulation, by means of the following innovations and solutions:

  - novel molecularly defined and sustainable space charge mitigating additives with optimized dispersion;
  - new additivated XLPE- and PP-insulation compounds with optimized morphology and rheological properties;
  - extensive characterization and establishment of processing-structure-dielectric property relationships to unravel optimum trap density of states for HVDC cable applications.

II) Enabling production of defect-free extruded HVDC cables with improved performance and lifetime, by means of the following innovations and solutions:

  - novel thermoplastic HVDC cable extrusion to e.g. reduce negative effects of insulation weld lines by utilizing spiral mandrel distributors;
  - improved insulation morphology by means of more homogenizing extruder screw designs, as well as optimized thermal gradient during HVDC power cable cooling phase;

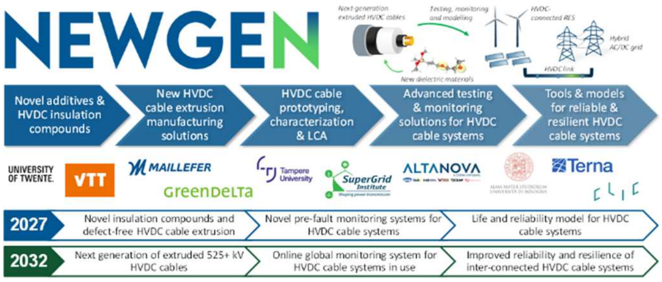

Fig. 1. NEWGEN project and short (2027) & long (2032) term impact [4].

TABLE I. LIST AND INVOLVEMENT OF NEWGEN PARTNERS [4]

Name	Country	Type	Acronym	WP leader	WP involv.
VTT	FI	RTO	VTT	1, 6, project coord.	1, 2, 5, 6
University of Bologna	IT	UNI	UBO	4	1, 2, 3, 4
Maillefer	FI	IND	MAI	2	2
Altanova Group	IT	IND	TAG	3	3, 4
University of Twente	NL	UNI	UT		1, 5
Tampere University	FI	UNI	TAU		1, 2, 3, 4
GreenDelta	DE	SME	GD		2.
SuperGrid Institute	FR	IND	SGI		1, 2, 3, 4
CLIC Innovation	FI	SME	CLI	5	5
Terna	IT	IND	TRI		4

  - optimization of new HVDC insulation materials in WP1, and of manufacturing equipment and process in WP2, to increase the efficiency (production speed) of HVDC cable manufacturing lines;
  - development of lighter and less complex HVDC cables to attain superior environmental and sustainability performance, with benefits for the environment, and also for costs and social impacts over the life cycle.

III) Realizing a multi-parameter combined diagnostics system for online global condition monitoring and health status evaluation of HVDC cable systems, by means of the following innovations and solutions:

  - development of a monitoring system able to gather data from the management of the cable (voltage, load, etc.), from the environmental quantities (ambient temperature, relative humidity, etc.) and the monitored quantities (PDs, leakage currents, distributed temperature);
  - information from literature, preliminary measurements from WP1 and WP2, and dedicated field tests, to determine the useful parameters to describe the overall status of the monitored HVDC cable system, with proper graphical outputs;
  - proper information on the time behavior of the monitored quantities, which will allow determining a correlation between the cable service parameters (load, voltage, etc.), and environmental and monitored parameters;
  - proper diagnostics algorithms for the monitored quantities (based on how such quantities affect the health status of the cable system) and combined-analysis correlation studies among the various parameters to support the diagnostics responses of

every single assessed quantity;

- development of a novel high-sensitivity magneto-optical technique for monitoring the pre-fault HVDC cable leakage current, to overcome the limitations of state-of-the-art (SoA) coil-based leakage current monitoring sensors.

IV) Increased reliability and resilience of the overall interconnected electrical system including HVDC cable links through a comprehensive life and reliability model of the whole HVDC cable system, by means of the following innovations and solutions:

- extension of the validity of existing life and reliability models of HVDC cables so as to treat all stresses found in service, as well as the effect of localized space charge distributions;
- derivation of a procedure for an optimized design of HVDC cables based on cable life estimation;
- development of innovative life and reliability models for HVDC cable joints and terminations;
- inclusion of the previously developed models into a unique life and reliability model of the whole HVDC cable system (cables, joints, terminations);
- grid simulations of the overall interconnected electrical system including HVDC cable links in various configurations to demonstrate the reliability and resilience of the system.

III. WORK PACKAGES

The overall NEWGEN project technical structure and methodology are summarized in Fig. 2. The objectives and the leaders of all WPs are presented in the following Sub-sections, where for technical WPs the theoretical/empirical background and the overall methodology are also given [4].

A. *WP1: Space Charge Mitigation in Polymeric HVDC Cable Insulation*

The objectives of WP1, led by VTT, are as follows [4].

- Development of novel chemical additives for mitigating space charge accumulation in polymeric HVDC cable insulation materials, and evaluation of their sustainability and up-scaling potential.
- Demonstration of the space charge mitigation in novel pilot-scale HVDC insulation compounds, and providing material samples and extensive characterization data to WP3 & WP4 for life and reliability modelling.
- Optimization of novel PP- and XLPE-based HVDC insulation compounds for manufacturing and extrusion of large compound batches for mini-cable and HVDC prototype cable extrusion trials in WP2.

The theoretical/empirical background and the overall methodology of WP1 are as follows [1].

Fundamentally, the space charge phenomena and the bulk DC electro-thermal properties of polymeric HVDC cable insulation materials are trap-controlled – i.e., the electrical trap states formed within the energy band gap of semi-crystalline polymer dielectrics due to physical disorder and chemical defects dictate the temperature- and field-dependent mobility, trapping and scattering of free charge carriers [2]. The main theoretical premise for NEWGEN in improving the HVDC insulation performance by polar (electro-active) moieties chemistry has been demonstrated in H2020 project GRIDABLE (see www.gridable.eu [5]). The functional chemistry was applied on silica nanoparticles where, however, agglomeration was a significant issue limiting the effectiveness of the modified space charge density and bulk dielectric performance.

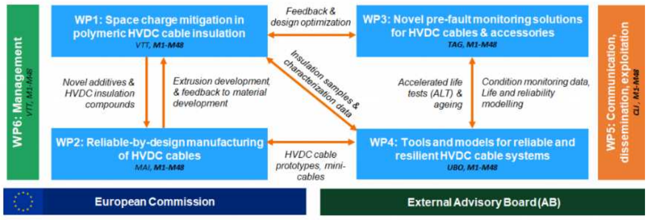

Fig. 2. NEWGEN WP structure and correlations (after [4]).

The primary goal of this WP1 task is to synthesize novel chemically functionalized polyolefins which can be used as homogeneously dispersing additives in various XLPE- and thermoplastic PP-based HVDC cable insulation matrices to mitigate space charge accumulation and improve the HVDC cable dielectric performance. This new approach will allow to tackle the dispersion problems by means of molecularly defined additives, which allow precise tailoring of chemical, and physical (i.e. electrical) properties combined with a better dispersion and miscibility with the polymer matrix. Further, the overall sustainability of the materials will be improved by using biobased reagents and materials when possible.

In NEWGEN, both DC-XLPE polymer matrix and prototypical thermoplastic PP-based insulation blend matrices will be used that match the electrical, thermal, mechanical, and processing-related parameters required for extruded HVDC cables, so as to develop and demonstrate the space charge mitigating additives in WP1 to be suitable for various different polyolefin-based HVDC insulation matrices. This approach, not restricted to any specific XLPE/PP-based polymer insulation matrix, aims at providing new widely applicable additive solutions (in WP1) and cable extrusion solutions (in WP2, see below) which can serve the whole HVDC cable industry, thus maximizing NEWGEN's impact.

Characterization of HVDC insulation compound samples is pivotal in NEWGEN for developing and optimizing the space charge mitigating additives and compounds in WP1, and for providing samples and data for the life and reliability modelling in WP3 & WP4 (see below). In addition to profound dielectric studies, characterization will include morphology and additive dispersion analysis, to provide feedback for additive synthesis and HVDC compound processing, and to enable establishing of structure–dielectric property relationships. Thermal stability, crystallization kinetics and degree of crystallization will be assessed through calorimetric measurements (DSC). Crystalline phase structure, thickness of the crystalline lamellae, and the chain orientation/texture will be evaluated by wide-angle X-ray scattering (WAXS) technique. Microscopic analysis of crystalline morphology, sectional structure, and film surface topography will be based on scanning electron microscopy (SEM), atomic force microscopy (AFM), optical microscopy (OM), and 3D optical profilometry. Size and distribution of the additives in polymer compounds will be studied by structural imaging using SEM and optionally by HR-TEM.

First, mini-scale compounding and sample manufacturing will ease resource-efficient screening of the best HVDC insulation compounds with space charge mitigating additives. In the next step, selected best insulation formulations will be compounded, followed by manufacturing of extruded cast film specimens. Finally, the most potential HVDC insulation compounds will be up-scaled to produce large insulation batches for the production of type-A minicables and HVDC cable prototypes in WP2, reaching TRL 6. The above procedure will be done iteratively, with the extensive material and dielectric characterization providing feedback between each subsequent production round for optimizing the additives and HVDC insulation compounds in WP1.

B. *WP2: Reliable-by-design Manufacturing of HVDC Cables*

The objectives of WP2, led by Maillefer, are as follows.

- Development of cable manufacturing equipment and extrusion process control aiming at defect-free thermoplastic cables.
- Pilot-scale demonstration of life-size HVDC cable prototypes with novel insulation formulations.

The theoretical/empirical background overall methodology of WP2 is as follows [1].

Current power cable manufacturing equipment is designed and optimized for XLPE cables for many decades, apart from a newly-developed PP-based compound referred to as HPTE [2]. However, peroxide reactivity in XLPE compounds sets technical challenges for extrusion equipment which do not exist for thermoplastic insulations developed in WP1. The primary goal of WP2 is to out engineer known weak points and optimize extrusion equipment to be better suitable for thermoplastic HVDC cables.

Another property of XLPE is the limited shear mixing during extrusion due to strict limit of insulation temperature. Such a limitation is not present for thermoplastic insulation, which makes it possible to develop more homogenizing extruder screw geometry. Insulation morphology and poor homogeneity areas have been shown to decrease dielectric strength, therefore designing a new screw geometry without limitations of XLPE is expected to improve HVDC cable reliability. Equipment and process development is done in WP2 with a suitable thermoplastic base material without new space charge mitigating additives developed in WP1.

Changing from XLPE to thermoplastic material sets new challenges for the cable manufacturing process, in which industry has little experience. The first studies showed potentially severe geometry deformation for thermoplastic PP-based HV prototypes. Evaluations in WP2 will lead to relationships on the effects of increasing insulation thickness and extrusion speed on geometrical defects for thermoplastic HVDC cables together with dielectric measurements. Primary variables are extrusion speed, cooling rate and cooling pressure. The goal is to optimize process conditions for new materials to have similar/ higher production efficiency than XLPE at existing cable manufacturing lines. Efficiency optimization is important to transfer thermoplastic HVDC cable technology to industrial production. New compounds will be first investigated on small flat specimens, later on in the form of model A cables and then as full-size cable prototypes (characterized via cable peelings to establish a dependency with dielectric properties, extrusion equipment and process parameters).

The steps of cable design to attain a voltage upgrade of the HVDC cable systems are related to the capability of the cable and accessories to withstand higher levels of electrical – and possibly thermal-mechanical – stresses. Focusing on voltage upgrade from 320 to 525 kV, careful screening of insulation compounds for both cables and accessories shall be carried out focusing on very low and stable electrical conductivity and bulk-/interfacial space charge storage.

Life Cycle Assessment (LCA) and extended sustainability assessment will follow ISO 14040 to better understand the implications of the HVDC cables and compared alternatives [6]. For the environmental assessment, the methodology of Environmental Footprint [7] will be followed as far as possible. The modelling will consider that the market for the new cable types is less developed and thus address upscaling, and additives may include nanoelements which are harder to assess. A risk assessment will thus also be performed and linked to the LCA. LCA models will be implemented in the powerful openLCA open-source software, with specifically collected and generic databases.

C. *WP3: Novel Pre-fault Monitoring Solutions for HVDC Cables and Accessories*

The objectives of WP3, led by Altanova, are as follows[4].

- Optimization of acquisition techniques under HVDC for diagnostics parameters derived from HVAC.
- Development of a fault location device based on the time-of-flight of partial discharges.
- Development of an online leakage currents monitoring device.
- Prototype of global online monitoring system for HVDC cables.
- Development of single/multi parameters diagnostics techniques.

The theoretical/empirical background overall methodology of WP3 is as follows [1].

Electrical assets maintenance has now shifted from Time-Based Maintenance (TBM, where operators do maintenance at fixed times, with the risk of being too soon or too late) to condition-based maintenance (CBM, which calls for maintenance only when and where needed by evaluating the conditions of the asset via online measurements of ad hoc diagnostic parameters. The insulation status assessment is a major indicator of the health status of the whole asset, as the insulation bears the highest stresses, and is characterized by a degradation rate of dielectric properties. Nowadays, online monitoring of the insulation system of electrical assets is very common for HVAC applications, but not for HVDC. This is reflected in the tasks related to the WP3, where the focus is on: 1) Implementing solutions derived from HVAC applications or 2) developing brand new solutions to design an online monitoring system for the assessment of the status of the HVDC cable system.

There are many instruments/monitoring systems able to acquire, elaborate, and provide the end-user with a response about the presence of Partial Discharges (PD) – and thus, defects able to lead to a fault - in an HVAC cable system, but not under HVDC. The goal of the first task of WP3 is to improve the detection of PD under DC conditions by exploiting the materials and cables obtained from WP1 and WP2 and state-of-art PD equipment commonly used for HVAC tests. Tests will be carried out on known defects starting from the materials and cables manufactured from WP1 and WP2. This will also help in understanding the behavior of the materials and their degradation rate.

The goal of the second task of WP3 is to validate the proof of concept of a non-intrusive optical technique based on the Zeeman Effect to measure DC leakage current, and to develop a working prototype. Optical techniques are widely used for measuring currents, but none has ever been developed to measure the leakage currents of HVDC cable systems. After the validation of the proof of concept and successful development of a working prototype, tests will be carried out on cable sections

Leakage current analysis could also provide rapid and accurate indication of fault localization in case of a breakdown. Minimizing downtimes of the faulted HVDC cable is important to quickly restore the power supply and have a reliable distribution network. PD time-of-flight technique will be used to rapidly locate a fault.

The instruments acquiring the diagnostics and asset status parameters derived from the HVAC online monitoring systems and the leakage currents monitoring instruments developed and validated in WP3 will be integrated into a global monitoring system for HVDC cable, a platform able to gather the data from each monitoring device, i.e. PDs, fault location, leakage currents, distributed temperature on fiber-optic (DTS), environmental parameters (ambient temperature and relative humidity), service parameters (voltage, current). Data will be collected and stored in the database, for subsequent processing and graphical visualization, inference of historical trends, long-term tests, and single-parameter diagnostics algorithms. Tests with the prototype of the online monitoring system will be performed on a higher scale than the flat or mini-cable specimens to fit also the DTS, and fault location systems that require a distributed electrical asset.

The strength of an online global monitoring system is the combined analysis of the diagnostic parameters. Combined diagnostics logics will be defined considering the correlation between the acquired parameters and the physics behind their behavior. Moreover, from the historical trends of parameters, the tests of WP3, and the life models of WP4, the aging/ degradation rate of the insulation material properties will be determined offering a rough idea of the residual life of the asset based on the models applied. The outcome of these activities will be a laboratory long-term test on an MVDC cable with or without defects, where the lab environment will allow to control of most of the monitored parameters and thus having a demonstration (TRL5) or a validation (TRL6) of the features of the prototype implemented.

D. *WP4: Tools and Models for Reliable and Resilient HVDC Cable Systems*

Here are the goals of WP4 led by University of Bologna[4]

- Development and validation of a life and reliability model for HVDC cable systems consisting of cables, joints and terminations.
- Development of a design optimization procedure for HVDC cables.
- Establishment of a relationship between pre-fault monitoring data and cable system life model.
- Evaluation of the impact of HVDC cable systems on the overall transmission system reliability, with the HVDC cable link acting as a "firewall" within the synchronous AC transmission system.
- Evaluation of the effects and resilience to faults of the HVDC cable connection in the AC network, by modelling and quantifying the impact on system reliability of an increasing number of HVDC links.

The theoretical/empirical background and the overall methodology in WP4 is as follows [1].

The evaluation of the reliability and resilience of HVDC cable systems requires the development of life and reliability models for the insulation of each HVDC cable system component, i.e.: cables; joints; terminations. The main stresses on HVDC cable system insulation are electrical, thermal, and mechanical stresses in the various test and service conditions, including: rated design voltage and temperature; load cycles [8]; voltage transients, like voltage polarity reversals (VPRs) - for HVDC cable links with Line Commutated Converters (LCC), long Temporary Over-Voltages (TOV) due to faults - for HVDC cable links with Voltage Source Converters (VSC) [9], switching overvoltages [10].

The first step is the development of a life and reliability model for the HVDC cable insulation under constant electrical and thermal stress, relying on life models developed over the years (see e.g. [11],[12]). The life model for the HVDC cable will be recast – when needed due to transients – into a time-varying stress framework by means of the well-known Miner's law of cumulated damage. The model will also yield a procedure for an optimized design of HVDC cables.

The second step will be the development of life models for HVDC cable joints and terminations. The main challenge here is that life models for accessories are missing in the literature. 3D Finite Element Method calculations of electric field and temperature distribution in joints will also be performed, to single out possible hot-spots and field enhancements.

The third step will be the inclusion of life models for the HVDC cable, joint and termination into a comprehensive life and reliability model for the whole HVDC cable system consisting of several cable lengths, several joints and a couple of terminations at cable system ends. The effect of the overall enlarged volume of cable lengths compared to the small volume of insulating specimens tested in the lab in WP1 will be accounted for via the so-called enlargement law.

The validation of the life models for the HVDC cable will be performed by means of Accelerated Life Tests (ALTs) carried out on laboratory specimens subjected to combinations of constant temperature and DC voltage. The validation of the life models for the HVDC cable accessories, in particular joints, will require further dedicated ALTs to be performed on composite insulation specimens in WP4. The reliability model for the HVDC cable system will also provide indications for establishing the correlation between pre-breakdown monitoring data and ageing phenomena of new dielectric materials for the insulation of HVDC cables and accessories, which will be useful for WP3.

The reliability model for the HVDC cable system will enable to evaluate its impact on the overall transmission system reliability, to assess the real capability of the HVDC cable link to act as a “firewall” against the spread of disturbances within the synchronous AC transmission system. Such evaluation will be performed via proper grid simulation codes, in order to assess the resilience to faults of the HVDC cable connection in the AC network under various different configurations and different types of disturbances (e.g electro-mechanical oscillations, line and generator faults, overloads, and over/under voltages), and to quantify the impact on system reliability of an increasing number of HVDC links and of renewables connected to the grid.

E. WP5: Communication, Dissemination and Exploitation

The objectives of WP5, led by CLIC Innovation, are as follows [4].

- Achieving visibility and reaching out to society to show the impact and benefits of NEWGEN project.
- Disseminating results to identified target groups.
- Enhancing synergies through clustering with relevant projects and networks.
- Assessing the patent landscape, defining and implementing the IPR strategy.
- Identifying and managing the key exploitable results to ensure effective exploitation.

F. WP6: Project Management and Coordination

The objectives of WP6, led by VTT, are the overall management, administration, coordination and execution of the project, and that the project progresses and results are achieved in accordance with the Grant Agreement (GA) and expectations of the call [4].

CONCLUSIONS

As a conclusion, Fig. 3 shows the timelines (1-5 and 5-10 years perspectives) of NEWGEN Impact Pathways #1-4. There are in total four Expected Outcomes (EO), for the project. The NEWGEN Impact Pathways are all contributing to HVDC technologies as described in EO1 (“*HVDC technologies contribution achieving climate neutrality of the electricity generation sector allowing the integration of large share of renewables while concurrently addressing the security of supply*”) that are necessary for the reliable transmission of electricity from numerous new renewable sources. All NEWGEN impact pathways also contribute to EO2 (“*HVDC interconnections can act as a firewall blocking the spread of disturbances while permitting the interchange of power*”) where the HVAC/DC links can fully act as “firewalls” only when the HVDC cable systems therein are ensured to be reliable. NEWGEN opens new European business opportunities as described in EO3 (“*Mastering HVDC technologies will open new business horizons for European companies in the global clean energy markets*”) through all of the four impact pathways towards the new generation of extruded HVDC cable systems, and thus strengthens the position of European companies in global clean energy markets. Moreover, NEWGEN contributes directly to EO4 (“*Increased electricity system reliability and resilience throughout the overall interconnection system, which includes High Voltage cables. Furthermore, the use of buried HVDC cables reduces the visual impact and improves the social acceptance compared to the classical AC overhead lines*”), with a life model and monitoring systems contributing on the transmission system level, and additive and extrusion technologies offering new solutions for the whole European HVDC cable industry. NEWGEN Impact Pathways will contribute to impact areas ‘Industrial leadership in key and emerging technologies that work for people’ and ‘Affordable and clean energy’, as well as to increased integration of RES and resilience of the whole energy system.

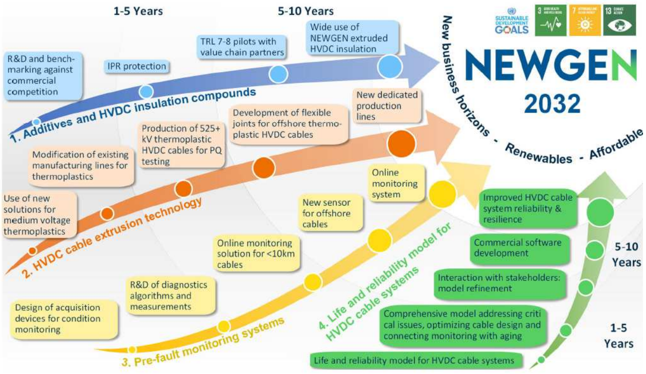

Fig. 3. Timelines of NEWGEN Impact Pathways #1-4 [1].

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