



NEWGEN Project Final Results Webinar

Advancing Next-Generation High-Voltage Direct Current Insulation Materials, Cables and Systems for Reliable and Resilient Energy Grids

13:00-16:30 CET, 24th September 2026, Online Microsoft Teams



Webinar Etiquette

Please review these quick guidelines before we start!



Microphone and Camera Muted

To ensure the best audio and video quality for everyone, both your microphone and camera will be muted during the webinar.



Session Recorded

This webinar is being recorded. A link will be shared with all participants after the session concludes.



Q&A

Please write your questions in the chat box and the moderator will read your question for our presenter to answer.

Agenda 24th September, 1 PM-4:30 PM

Time	Topic	Speaker(s)	Duration
Introduction (20 min)			
13:00-13:10	NEWGEN project introduction	Ilkka Rytöluoto (Project coordinator, VTT)	10 min
13:10-13:20	Perspectives on the current state and future directions of European transmission grids	Eric Lecomte (Policy Officer, European Commission DG ENER)	10 min
Session 1: Space charge mitigation in HVDC cable insulation (50 min)			
13:20-13:35	Formulation and clean compounding of novel PP insulation materials for HVDC cables	Ilkka Rytöluoto, Eetta Saarimäki (VTT)	15 min
13:35-13:50	Synthesis and characterization of novel additives for space charge suppression	Andrea Bernardi, Frederik Wurm (UT)	15 min
13:50-14:05	Dielectric characterization of insulation specimens	Kari Lahti, Minna Niittymäki (TAU)	15 min
14:05-14:10	Q&A	Moderator, all	5 min

Agenda 24th September, 1 PM-4:30 PM

Time	Topic	Speaker(s)	Duration
Session 2: Reliable-by-design manufacturing of HVDC cables (45 min)			
14:10-14:25	Advancements in HVDC cable extrusion machinery optimized for PP insulated cables	Anders Nordström (MAI)	15 min
14:25-14:40	Manufacturing and characterization of model “A” cables	Ludovic Boyer (SGI), Anders Nordström (MAI)	15 min
14:40-14:50	LCA and sustainability	Kirill Maister (GD)	10 min
14:50-14:55	Q&A	Moderator, all	5 min
14:55-15:05	Break (10 min)		
Session 3: Novel pre-fault monitoring solutions for HVDC cables and accessories (35 min)			
15:05-15:20	Detection and acquisition of partial discharges under HVDC and development of global monitoring system	Andrea Caprara (TAG)	15 min
15:20-15:35	Novel magneto-optic method for cable system leakage current detection	Anais Leproux (SGI)	15 min
15:35-15:40	Q&A	Moderator, all	5 min

Agenda 24th September, 1 PM-4:30 PM

Time	Topic	Speaker(s)	Duration
Session 4: Tools and models for reliable and resilient HVDC cable systems (30 min)			
15:40-15:55	Life and reliability model of the HVDC cable, accessories and of the whole HVDC cable system	Giovanni Mazzanti (UBO)	15 min
15:55-16:05	Effects and resilience to faults of the HVDC cable connection in the AC network	Rolando Ezequiel Diaz (UBO) Sayantani Maiti (UBO)	10 min
16:05-16:10	Q&A	Moderator, all	5 min
Session 5: Project impact and exploitation of the results (15 min)			
16:10-16:25	Exploitation & Impact	Merie Kannampuzha (CLI)	15 min
16:25-16:30	Wrap-up & End of the webinar (5 min)		

NEWGEN

Introduction

13:00-13:20





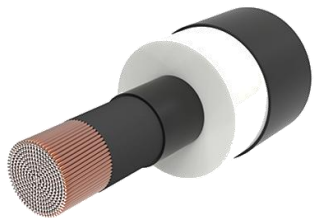
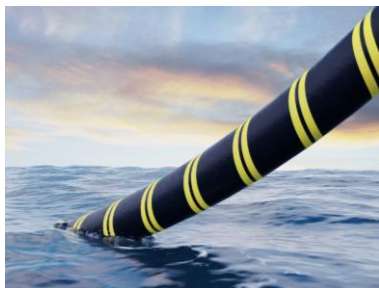
NEWGEN project introduction

"New generation of HVDC insulation materials, cables and systems"

Ilkka Rytöluoto (Project coordinator, VTT)



The energy transition is also a transmission challenge



**More
renewable
generation**

Variable, offshore and
geographically distributed

**More
demanding
transmission**

Large power flows over
longer distances

**Required
system
qualities**

Capacity, reliability, resilience
and security of supply

Europe's electricity networks must:

- Integrate increasing shares of variable renewable energy
- Connect offshore generation and centers of demand
- Maintain grid stability and security of supply

**HVDC technologies enable efficient long-distance
and offshore electricity transmission.**

From the Horizon Europe scope to European-level impact

Horizon Europe topic (HORIZON-CL5-2021-D3-01-08):

“Electricity system reliability and resilience by design through HVDC-based systems and solutions”

Specific call topic scope

- 1 System reliability and dynamic “firewall” properties**
Assess the reliability impact of increasing numbers of HVDC links
- 2 HVAC monitoring methods applied to HVDC**
Develop fault-location and condition-monitoring approaches for HVDC cables
- 3 Novel pre-fault monitoring**
Assess the actual condition of HVDC cables and accessories before failure
- 4 Advanced HVDC cable insulation materials**
Higher-capacity dielectric materials with reduced space-charge-related ageing
- 5 Reliable and sustainable HV cable technology**
Improve HV cable design and processing; assess sustainability



Expected outcomes

- Renewable integration**
Larger shares of renewables with security of supply
- Resilient HVDC interconnections**
HVDC links can help contain disturbances
- Transmission system reliability**
Including HVDC cable systems
- European HVDC competitiveness**
New opportunities in global clean-energy markets

NEWGEN project

"New generation of HVDC insulation materials, cables and systems"

Horizon Europe programme & topic:

Electricity system reliability and resilience by design: High-Voltage, Direct Current (HVDC)-based systems and solutions

Research and innovation action:

Aim for TRL 5-6 by the end of the project

Project duration 48 months:

1.10.2022 – 30.9.2026

10 Partners:

5 EU countries

Budget:

7.6 M€ EU funding

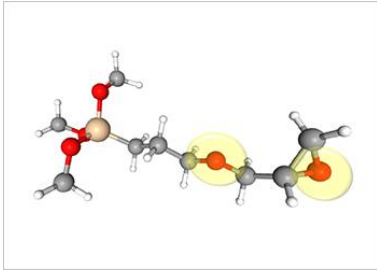
Coordination:

VTT

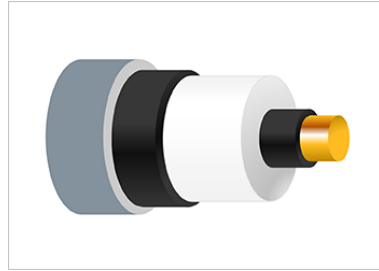


NEWGEN project objectives: The four pillars

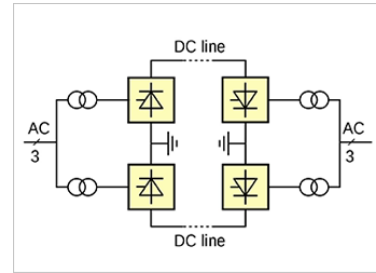
Project objective is to develop and demonstrate:



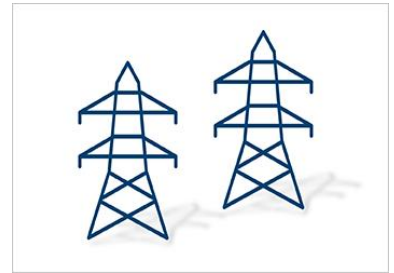
Novel HVDC cable insulation materials and additivation to suppress space charge accumulation.



New HVDC cable extrusion manufacturing solutions tailored for PP-based insulation.



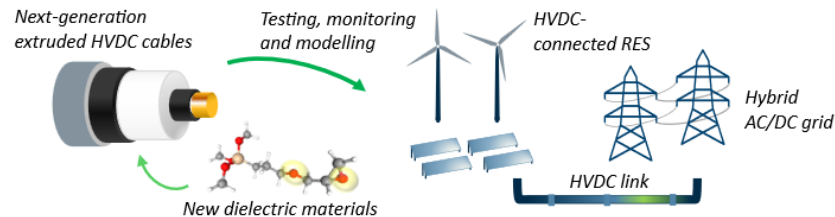
Pre-fault monitoring system for HVDC cable systems.



Life and reliability model for HDVC cable systems.

NEWGEN project concept and impact

NEWGEN



Novel additives & HVDC insulation compounds

New HVDC cable extrusion manufacturing solutions

HVDC cable prototyping, characterization & LCA

Advanced testing & monitoring solutions for HVDC cable systems

Tools & models for reliable & resilient HVDC cable systems

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greenDelta



2027

Novel insulation compounds and defect-free HVDC cable extrusion

Novel pre-fault monitoring systems for HVDC cable systems

Life and reliability model for HVDC cable systems

2032

Next generation of extruded 525+ kV HVDC cables

Online global monitoring system for HVDC cable systems in use

Improved reliability and resilience of inter-connected HVDC cable systems

NEWGEN



From call expectations to demonstrated NEWGEN results

Call scope	NEWGEN development	Project result
New electrical insulation materials	Thermoplastic PP insulation materials, functional additives and extensive dielectric characterization	Space charge mitigation through grafted additives; up-scaling of selected PP insulation compounds for cable prototypes
Reliable HV cable manufacturing	Clean compounding, pilot-scale material production and new thermoplastic cable extrusion solutions.	New HV cable extrusion solutions for defect-free thermoplastic cables
Pre-fault monitoring	Methods for detecting and assessing developing faults in HVDC cable systems	Online monitoring concepts advanced and demonstrated within the project; some of the solutions are market-ready
Life and reliability	Assessment connecting material, cable and system-level information	A stronger evidence base for reliability-oriented cable development and assessment

NEWGEN advanced complementary HVDC cable technologies toward TRL 5–6 and established a foundation for further qualification and industrial demonstration.



Perspectives on the current state and future directions of European transmission grids

Eric Lecomte (Policy Officer, European Commission)





HVDC grids – essential for the EU

24/09/2026

Eric Lecomte, DG Energy, Unit B4 Research, Innovation, Competitiveness, Digitalisation

Key messages

- **Climate**
- **Prosperity**
- **Security**

Key messages

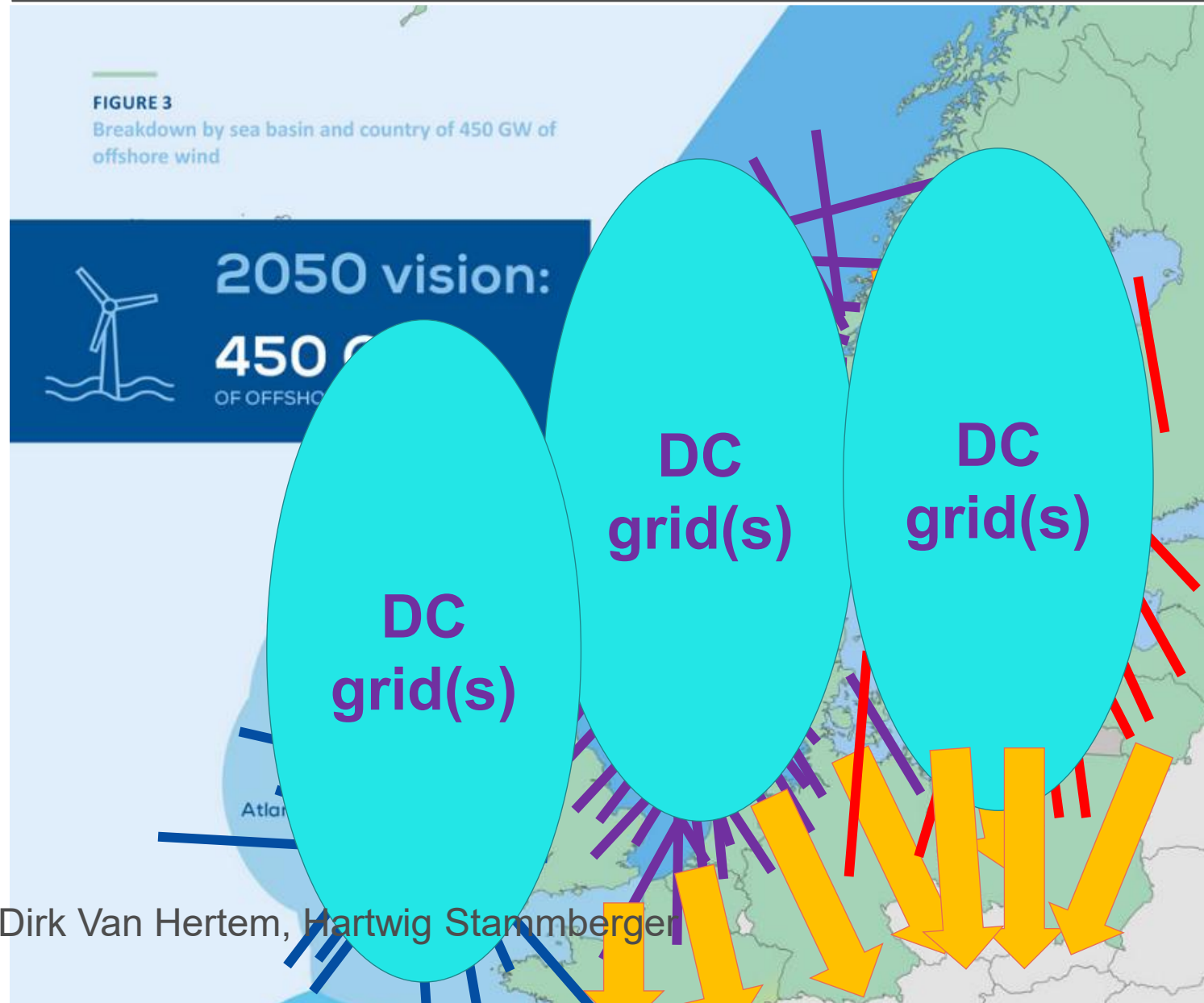
- **Climate and Prosperity**
 - **sustainable and clean energy,**
available in sufficient quantities and at **competitive** prices

Key messages

- **Climate and Prosperity**
 - **sustainable and clean energy**,
available in sufficient quantities and at **competitive** prices
 - **target of 42.5% of renewable energy sources** in the EU energy mix by 2030
 - **Member States non-binding goals for offshore** (December 2024),
 - 88 GW by 2030 / 360 GW by 2050 / vs. 20 GW at end 2024
 - **Electricity Market Design** (PPA, flex) - **Grids Package** (planning, cost sharing)
 - **AccelerateEU toolbox** (April 2026) support EU's energy independence, through a resilient energy system based on homegrown clean energy and electrification
 - **Electrification Action Plan** (June 2026) – demand electrification

► Interoperable
Multi-terminal
Multi-vendor
HVDC grids are
necessary

We need to connect 200 GW from the north
→ Assume 5 GW links



EU SET Plan DC, Dirk Van Hertem, Hartwig Stammberger
Figure: WindEurope

#SETPlan

24. Jan. 2025

Key messages

- **Climate and prosperity**
 - **HVDC grids** must be developed at **affordable system cost**, thanks to
 - incremental construction,
 - mesh configuration, transfer power where/when needed
 - interoperability, standardization

Key messages

- **Security of**
 - **energy supply – Sovereignty**
 - More offshore, less fossil imports
 - **infrastructure - cyber and physical**
 - Mesh configuration, monitoring and protection systems
 - **clean technologies supply chains**

EU R&I funding for DC technologies

In total for DC technologies: 281 M€

- **FP7: 35.5 M€**
- **H2020: 34.5 M€**
- **HEU: 211 M€**
 - Running projects: 12 topics, 22 projects, 167 M€
 - Topic 2026 - equipment for multi-terminal HVDC Systems, 24 M€
 - Topic 2027 - Innovative (LVDC) microgrids for in urban contexts, 20 M€

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In total for DC technologies: 281 M€

- **DC – any V: 63 M€**
- **HVDC: 176 M€**
- **MV/LVDC: 42 M€**

FP7 – H2020 - closed topics and projects

Title	Budget	Type	Projects
FP7-ENERGY.2013.7.2.3 - Large-scale demonstration of innovative transmission system integration and operation solutions for (inter)connecting renewable electricity production (HVDC)	35.5 M€		Best Paths Oct 2014- Sep 2018
H2020-LCE-05-2015 - Innovation and technologies for the deployment of meshed off-shore grids (HVDC)	34.5 M€		Promotion Jan 2016 – Sep 2020

HEU – closed topics and running projects

Title	Budget	Type	Projects
HORIZON-CL5-2021-D3-01-02 - Laying down the basis for the demonstration of a Real Time Demonstrator of Multi-Vendor Multi-Terminal HVDC with Grid Forming Capability	1 M€ (1 pj)	CSA	Ready4DC Apr 2022 – Sep 2023
HORIZON-CL5-2021-D3-02-08: Electricity system reliability and resilience by design : High-Voltage, Direct Current (HVDC)-based systems and solutions	15 M€ (2 pj)	RIA	HVDC insulation materials, cables and systems NEWGEN EUR 7.6m; Oct 2022 - Sep 2026 HVDC architectures for hybrid AC/DC systems HVDC-WISE ; EUR 6.6m; Oct 2022 - Mar 2026
HORIZON-CL5-2021-D3-02-10: Demonstration of advanced Power Electronics for application in the energy sector (<i>notably for MV-HVDC</i>)	10 M€	IA	AdvanSiC - EUR 3.2m, Jan 2023 - Dec 2025 FOR ² ENSiCS - EUR 4.4m, Jan 2023 - Dec 2026 SiC4GRID - EUR 3.8m - Oct 2022 - Sep 2026

HEU – closed topics and running projects

Title	Budget	Type	Projects
HORIZON-CL5-2022-D3-01-09: Real Time Demonstrator of Multi-Vendor Multi-Terminal VSC-HVDC with Grid Forming Capability (in support of the offshore strategy)	55 M€ (topic)	IA	InterOPERA , EUR 50.7m Jan 2023 – Apr 2027

InterOPERA:

- **Concrete results** will be delivered through this practical work: **detailed functional specifications for each subsystem**, standardised models, simulation platforms and interaction study processes, **multi-vendor cooperation agreements**. Those frameworks will be generalised into **operational and strategic tools** available to all European stakeholders for the development of multi-terminal HVDC grids.
- **Solutions for multi-vendor project procurement**, compliant with existing and future regulations, standards and laws, **integrating the technical specifications and interoperability assessment** tender stages, will be provided to **pave the way to the first real-life projects in Europe**.

HEU closed topics and projects

Title	Budget	Type	Projects
HORIZON-CL5-2023-D3-01-11: Demonstration of (LV)DC powered data centres, buildings, industries and ports	18 M€ (2 pj)	IA	SHIFT2DC , EUR 9.0m, Dec 2023 - May 2027 Direct Current – Power fLOws in megawatt-scale Energy gRids DC-POWER EUR 7.1m, Jan 2024 - Dec 2027
HORIZON-CL5-2023-D3-01-12: Development of MVDC , HVDC and High-Power Transmission systems and components for a resilient grid	22 M€ (2 pj)	IA	eMiSSion-free HV and MV transmiSION switchgear for AC and DC MISSION EUR 10.4m; Jan 2024 - Dec 2027
HORIZON-CL5-2024-D2-01-04: Emerging energy technologies for a climate neutral Europe	30M€	RIA	NOVETROL - Novel current control for climate neutral energy infrastructure ; Dec24-Nov27; 2.5M€
HORIZON-CL5-2024-D3-01-13: DC and AC/DC hybrid transmission and distribution systems	13 M€, 2pj		PAN-EUROPEAN INTEROPERABLE AC-DC HYBRID ELECTRICITY NETWORKS HYNET Oct 2024 – Sep 2027, 6 MEUR Transmission and distribution Hybrid nEtworks with enhanced resilience and robUstnesS THEUS Sep 2024 – Aug 2027; 6 MEUR
HORIZON-CL5-2024-D3-01-14: Condition & Health Monitoring in Power Electronics Wide Band Gap for the energy sector	13 M€, 3 pj		Flagship advanced solutions for Condition and Health monitoring In Power electronics FLAGCHIP Sep 2024 – Feb 2028 – 4 MEUR Condition Monitoring and Wide Bandgap Power Electronics - Leading Innovations for the European Energy Sector MoWiLife Oct 2024 - Sep 2027; 4 MEUR SAFEPOWER - Oct 2024 - Sep 2028; 4.3 MEUR

HEU closed topics and projects

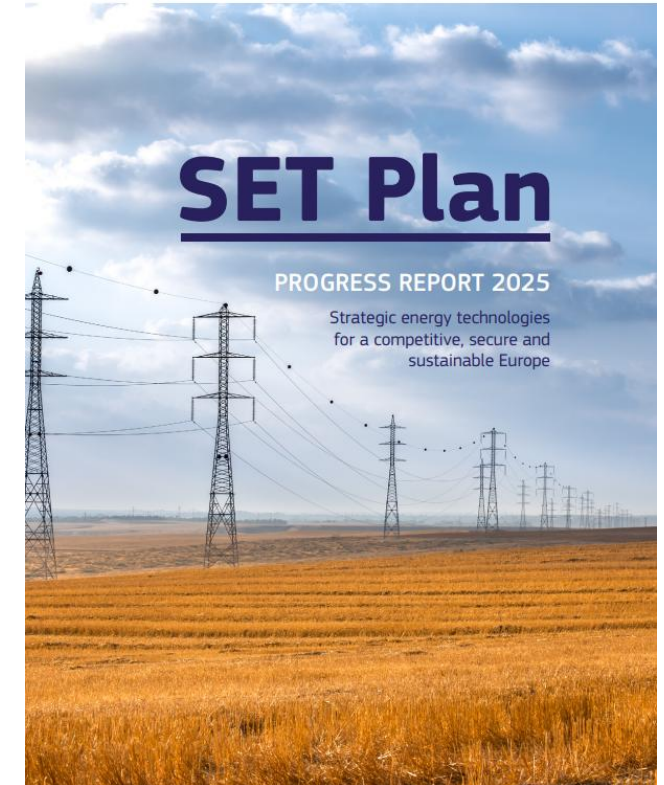
Horizon Europe - All topics - Title	Budget	Type	Projects
HORIZON-CL5-2024-D3-01-15: HVAC, HVDC and High-Power cable systems	16 M€, 3pj		DCDYNAMIC , HVDC dynamic cables for floating offshore; 5.4 M€, Nov24-Oct28 EasyDC-FOS ; novel HV cable system; 5.5 M€, Sep24-Aug27 CABLEGNOSIS ; innovative HVDC HVAC cable technologies ; 5.4 M€; Sep24-Aug27
HORIZON-CL5-2024-D3-01-17: Development and integration of advanced software tools in SCADA systems for High, Medium and Low voltage AC/DC hybrid systems	12 M€	IA	InterSCADA - Interoperable, Scalable and seCure Ac-Dc modular Automation system; Oct24-Sep27; 6M€ DAEDALOS Dev., demo of Adv software tools in SCADA systems to reAlize H/M/LV hybrid AC/DC gridS; Sep24-Aug28; 6M€

HEU-Cluster5 – recent / future topics

Horizon Europe - All topics - Title	Budget	Type	Projects
HORIZON-CL5-2026-03-D3-19: Affordable and sustainable primary equipment for Future-Ready multi-terminal HVDC Systems	24 M€, 4to12M€/pj 3 pj	IA	Opening: 18 Dec 2025 - Deadline: 31 Mar 2026
HORIZON-MISS-2027-04-CIT-01: Innovative (LVDC) microgrids for improved energy system integration and efficiency in urban contexts	20 M€, 7M€/pj, 3pj	IA	Opening: 09 Feb 2027 - Deadline: 07 Oct 2027 HORIZON-MISS-2027-04-CIT-01 in EU Funding Portal
HORIZON-CID-2026-01-02: R&I in Support of the Clean Industrial Deal: Clean Technologies for Climate Action (including innovative electricity grids)	150 M€, 15to25 M€/pj	IA	Opening: 18 Dec 2025 - Deadline: 15 Sep 2026 HORIZON-CID-2026-01-02 on EU Portal
HORIZON-CID-2027-01-02: R&I in Support of the Clean Industrial Deal: Clean Technologies for Climate Action (including innovative electricity grids)	150 M€, 15to25 M€/pj	IA	Opening: 12 Jan 2027 - Deadline: 15 Sep 2027

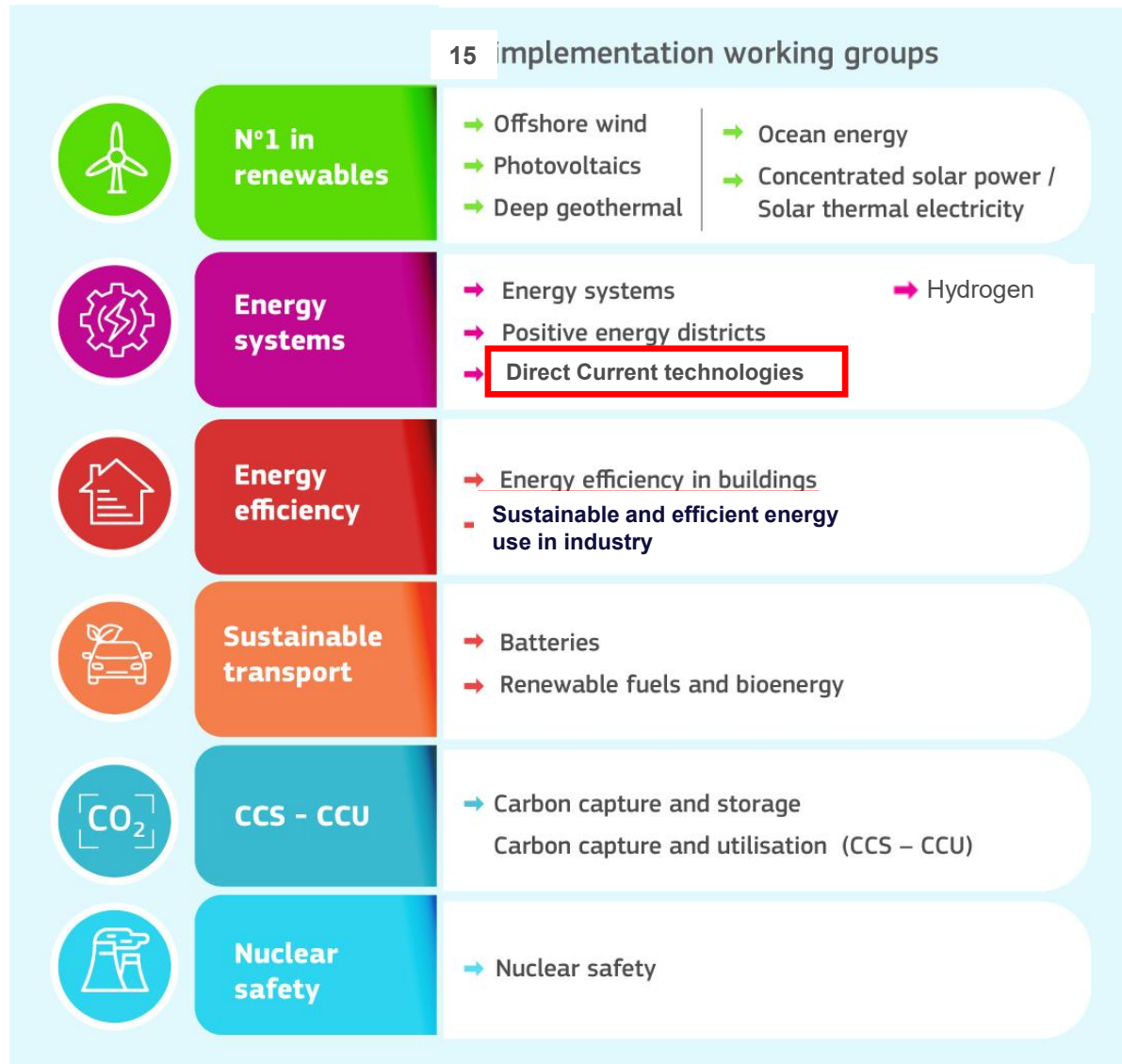
SET Plan – Strategic Energy Technologies plan

- **Goal:**
 - to align national and European R&I priorities and programmes
- **Cooperation between**
 - Member States, Associated Countries,
 - industry,
 - research institutions
 - the European Commission



[SET Plan Progress Report 2025](#)

SET Plan – Implementation Working Groups (IWGs)



https://setis.ec.europa.eu/working-groups/direct-current-technologies_en

New governance

from

Implementation Plan

to



Conclusion

Interoperable multi-terminal multi-vendor **HVDC grids**
– **are critical for EU Prosperity and Security, and Climate**



Thank you!

HorizonEU

<http://ec.europa.eu/horizon-europe>



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BACKUP SLIDES

Other funding / Financing sources

- **The Innovation Fund – examples of breakthrough projects, (as of Oct 2023)**
 - One project integrates **several energy sources**, including wave and wind energy, as well as a full hydrogen system (electrolyser, storage and fuel cells).
 - a **manufacturing topic** covering innovative technologies for clean-tech manufacturing.
- **National funding**
 - **North Sea Energy Cooperation** [NSEC High Level Group](#); Beatriz.SINOBAS@ec.europa.eu
 - [Clean Industrial Deal State Aid Framework CISAF](#), adopted with the intention to facilitate Member States support clean energy and clean technologies.
- **CEF funding for PCI/PMI projects**
 - second PCI/PMI list was adopted 01/12/2025. [Commission boosts energy interconnectivity across Europe and beyond](#)
- **InvestEU Programme, (as of Oct 2023)**
 - supporting private investments in offshore renewables, more than EUR 1 billion of loans to offshore projects has so far been approved.
 - co-finance the construction of the first offshore wind farm in Poland — with a **loan of up to EUR 610 million, EUR 350 million of which backed by the InvestEU programme**
- **Tripartite on Offshore and grids**

NEWGEN

Session 1: Space charge mitigation in HVDC cable insulation

13:20-14:10



NEWGEN

Formulation and clean compounding of novel PP insulation materials for HVDC cables

From prototypical PP blends to up-scaled production for cable prototypes

Ilkka Rytöluoto (VTT, WP1 lead)



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NEWGEN public webinar, September 24th, 2026

NEWGEN project, Grant Agreement N° 101075592



Why explore thermoplastic PP insulation?

A materials route aligned with higher capacity, reliability and sustainability ambitions

Established DC-XLPE insulation

- Industrial benchmark for extruded cable insulation.
- Crosslinking and de-gassing required.
- Thermoset structure limits remelting/recycling.
- Thermomechanical properties are limited at elevated temperature ($\geq 90\text{ }^{\circ}\text{C}$).



Thermoplastic PP insulation concepts

- Melt-processable with no cross-linking or de-gassing needed.
- Promising electrical performance and high-temperature integrity.
- Potential advantages for material circularity (recyclability).
- Property balance must include flexibility, morphology, dielectric performance and processability.

Main insulation
(XLPE, PP; thickness
e.g. ~25-30 mm)



NEWGEN target:

New PP dielectric materials with reduced ageing related to space-charge accumulation, progressing toward TRL 5–6.

One integrated development loop

VTT connected materials formulation, representative specimens and pilot-scale production

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Feedback from characterization and cable processing
refined the HVDC cable insulation materials selection.

1. Additive synthesis and
chemical characterization

VTT

2. PP insulation formulation,
compounding, sample
manufacturing, characterization

MAILLEFER

4. Cable prototype manufacturing and
processing feedback

Tampere
University



ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA



3. Dielectric characterization and
modelling inputs

Thermoplastic HVDC cable insulation

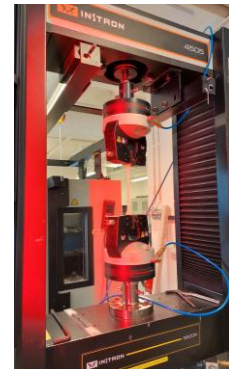
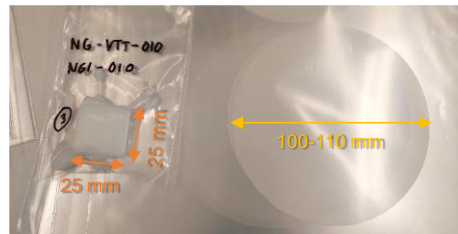
Selection of the most promising PP insulation blends

Exploration of multiple PP blend families:

- ✓ Random homophasic PP copolymers (RACO)
- ✓ Random heterophasic PP copolymers (HECO)
- ✓ Propylene-ethylene copolymers (PEC)
- Isotactic PP homopolymers (iPP)
- Ethylene-octene copolymers (EOC)

Multiple selection criteria for overall property balance:

- Extrusion processability
- Tensile and flexural properties
- High-temperature integrity
- Rheology
- Morphology & crystallization
- Cleanliness
- Thermal conductivity

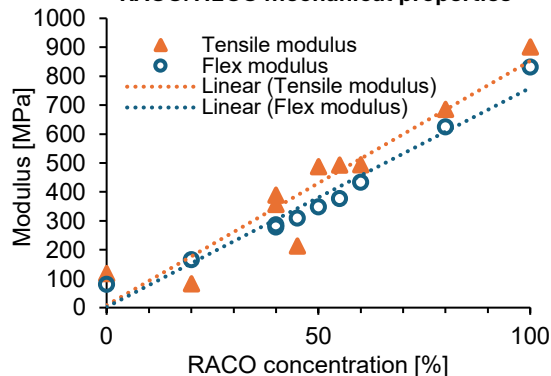


- ✓ Selection of **binary** and **ternary** RACO/HECO(/PEC) PP insulation blends for pilot-scale extrusion and up-scaling.

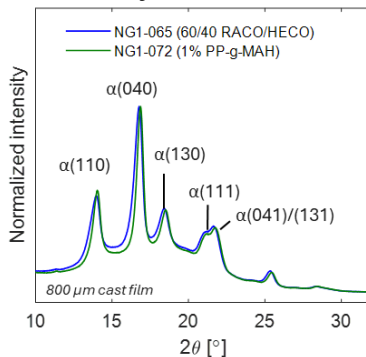
Binary PP insulation blend characterization

Target balance of processability, flexibility and insulation performance

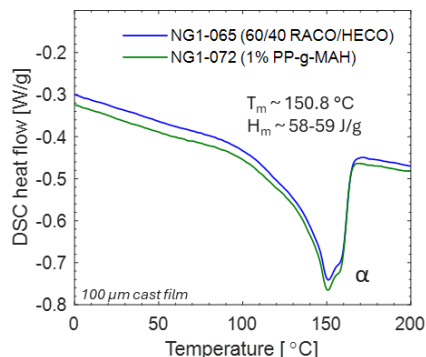
RACO/HECO mechanical properties



X-ray diffraction



DSC (2nd heating)



Suitable mechanical balance for HV cables

60/40 RACO/HECO (unaged):

- $E_{flex} = 435 \text{ MPa}$
- $\sigma_{break} = 23.3 \text{ MPa}$
- $\varepsilon_{break} > 500 \%$
- ✓ Higher high-temperature modulus than DC-XLPE

Controllable morphology

- ✓ Efficient PP copolymer dispersion in twin-screw extrusion.
- ✓ Crystallization vs. cooling rate relationships established.
- ✓ Host matrix for grafted additives for space charge suppression.
- Thermal conductivity improvement required for future development

Improved extrudability

- ✓ Fewer issues in life-size cable prototype processing (melt flow homogeneity, stickiness, output stability, void-defects).

VTT's clean compounding process

3. Hot-pressing (w/ optional cross-linking)

Inside VTT's clean compounding facility:

Materials & pre-treatment

(Clean material handling, drying & pre-mixing)

Twin-screw extrusion

(Leistritz ZSE18 MAXX)

De-gassing, melt-filtration

(Superior melt quality and removal of VOCs)

In-line spectroscopy

(In-line UV/VIS and NIR)

Inside ISO-6 clean room:

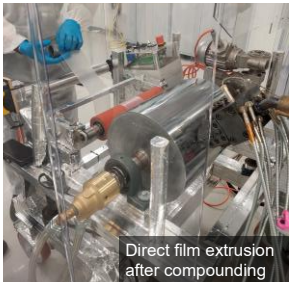
(1.) Material pelletizing or (2.) Direct film extrusion

(For further conversion or sample manufacturing directly after compounding for characterization)

ZSE18 MAXX twin-screw extruder



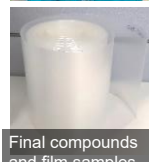
Extruded polymer compound, and cooling in filtered water bath



In-line UV/VIS and NIR spectroscopy

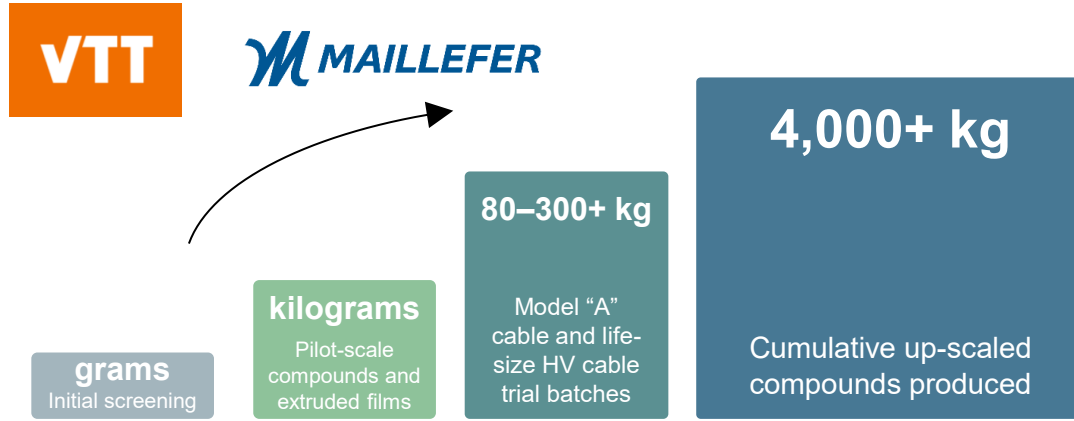


Clean processing inside ISO-6 mobile clean room



Final compounds and film samples

Up-scaling of PP insulation compounds for prototype cable demonstration



Up-scaling of the PP insulation blends for cable prototypes

- ✓ **Clean compounding and up-scaling** of PP insulation blends for HVDC cable prototypes achieved with several formulations.
- ✓ **Production of 4000+ kg** of PP insulation compounds, allowing for several model “A” and HVDC cable prototypes to be produced and optimization of PP cable production parameters.



Summary and outlook

Demonstrated in NEWGEN

- ✓ Prototypical thermoplastic PP insulation blends with suitable thermomechanical properties for HVDC cable application.
- ✓ Manufacturing of flat specimens (hot-pressed films, extruded cast films) for material and dielectric characterization.
- ✓ Controlled pilot-scale clean compounding and up-scaling.
- ✓ Transfer of the most promising PP insulation candidates to model “A” and life-size HV cable prototypes.



Outlook beyond NEWGEN

- Dedicated cable-grade PP insulation resin development
- Industrial-scale resin or compound production
- Extended long-term electrical testing and qualification (flat specimens, cable prototypes)
- Higher-TRL cable demonstrations (MV-/HVDC)
- Improving thermal conductivity of PP insulation
- Recyclability / circularity evaluation



Synthesis and characterization of novel additives for space charge suppression

Andrea Bernardi, Frederik Wurm (UT)

UNIVERSITY
OF TWENTE.

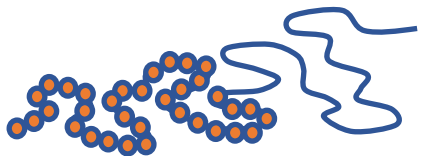


PP additives in PP matrix – three routes

1. Maleic anhydride mediated amine grafting



2. PP block copolymers



3. PP random copolymer



Charge Transport Modeling in Insulating Polymers: From Molecular to Macroscopic Scale

G. Teyssedre and C. Laurent
Laboratoire de Génie Electrique de Toulouse
Université Toulouse III et CNRS

IOP Publishing

J. Phys. D: Appl. Phys. 49 (2016) 415301 (9pp)

Journal of Physics D: Applied Physics

doi:10.1088/0022-3727/49/41/415301

Mechanism of highly improved electrical properties in polypropylene by chemical modification of grafting maleic anhydride

Yao Zhou, Jun Hu, Bin Dang and Jinliang He

Department of Electrical Engineering, State Key Laboratory of Power Systems, Tsinghua University,
Beijing, 100084, People's Republic of China
<https://doi.org/10.1007/s11664-021-09147-5>

ORIGINAL RESEARCH ARTICLE



Preparation and Electrical Properties of 4-allyloxy-2-hydroxybenzophenone Grafted Polypropylene for HVDC Cables

Yue Liang¹ · Ling Weng^{1,2} · Wenlo



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Article

Improved Insulation Properties of Polypropylenes in HVDC Cables Using Aqueous Suspension Grafting

Yiyi Zhang¹, Keshuo Shi¹, Chunyan Zang^{2,*}, Wenchang Wei¹, Chuanhui Xu³ and Junwei Zha⁴

¹ Guangxi Key Laboratory of Intelligent Control and Maintenance of Power Equipment, Guangxi University, Nanning 530004, China

² College of Electrical and Electronics Engineering, Huazhong University of Science and Technology, Wuhan 430074, China

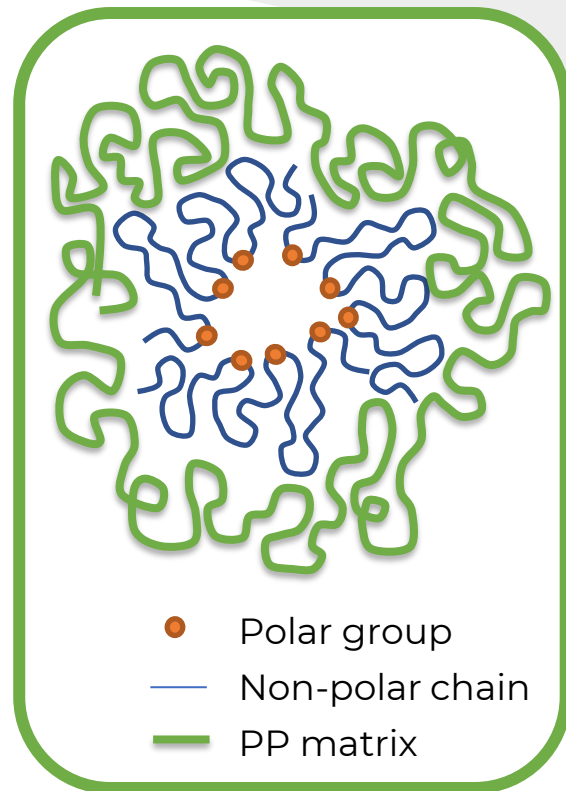
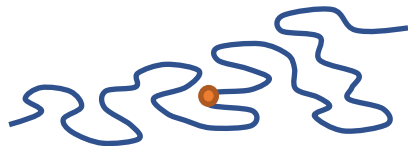
³ School of Chemistry and Chemical Engineering, Guangxi University, Nanning 530004, China

⁴ School of Chemistry and Biological Engineering, University of Science and Technology Beijing, Beijing 100085, China

* Correspondence: zzy_peace@hust.edu.cn

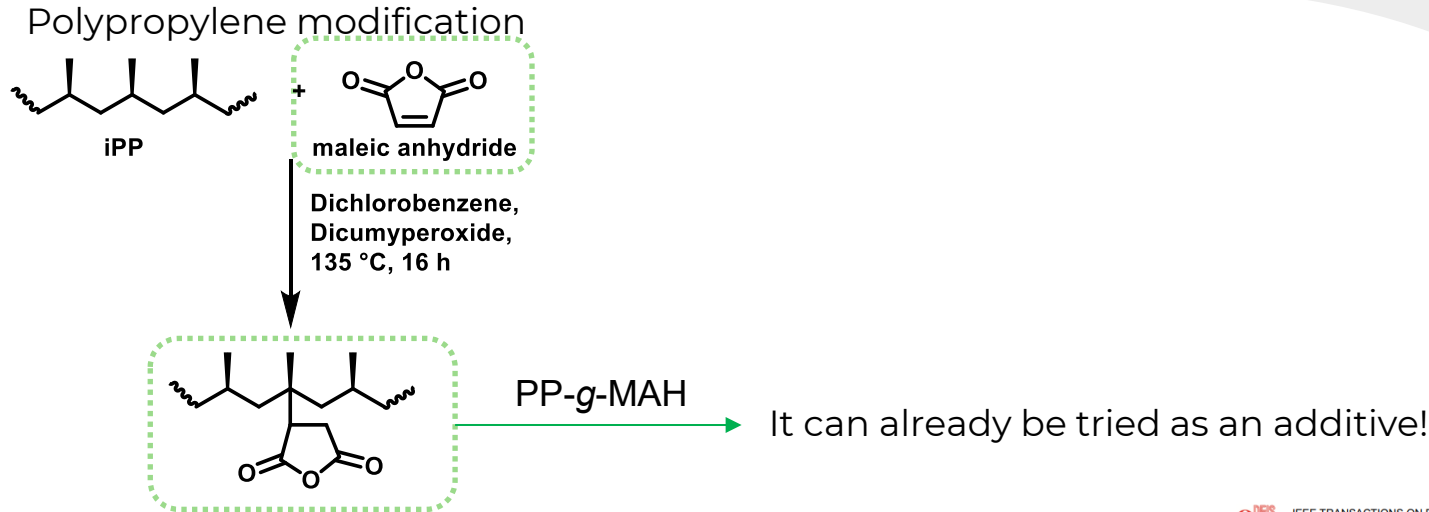
PP additives in PP matrix – 1st approach

1. Maleic anhydride mediated amine grafting



Possible arrangement
of modified PP in the PP matrix

1. 1st step: *i*PP modification with MAH



2025 IEEE Conference on Electrical Insulation and Dielectric Phenomena (CEIDP)



IEEE TRANSACTIONS ON DIELECTRICS AND ELECTRICAL INSULATION

1

Novel Grafted Additives for Space Charge Mitigation in Extruded HVDC Cable Insulation

M. Niittymäki¹*, I. Rytöluoto², K. Lahti¹, B. Diban³, G. Mazzanti³, T. Rheinberger⁴

¹Tampere University, Finland, ²VTT Technical Research Centre of Finland,

³University of Bologna, Italy, ⁴University of Twente, Netherlands

*minna.niittymaki@tuni.fi

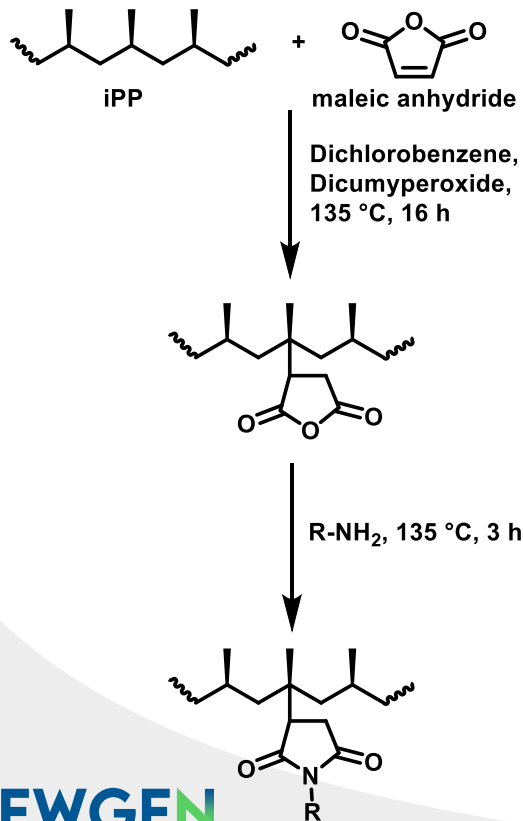
The Influence of Space Charges on the Life Exponent from Accelerated Life Tests on PP-based HVDC Cable Insulation. Part 2: Binary Blends and Final Comparison with Ternary Blends

Giovanni Mazzanti, *Fellow, IEEE*, Bassel Diban, *Member, IEEE*, Rolando Ezequiel Diaz, *Member, IEEE*, Paolo Seri, *Member, IEEE*, Ilkka Rytöluoto, *Member, IEEE*, Kari Lahti, *Member, IEEE*, Minna Niittymäki, *Member, IEEE*, Antoine Perez, Anaïs Leproux, Andrea Bernardi.

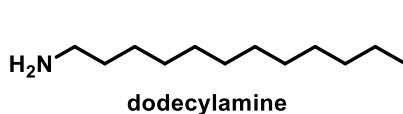
- Niittymäki, M. et al. Novel Grafted Additives for Space Charge Mitigation in Extruded HVDC Cable Insulation. in *Annual Report - Conference on Electrical Insulation and Dielectric Phenomena*, CEIDP. doi:10.1109/CEIDP61707.2025.11218281.
- Mazzanti, G. et al. The Influence of Space Charges on the Life Exponent from Accelerated Life Tests on PP-based HVDC Cable Insulation. Part 2: Binary Blends and Final Comparison with Ternary Blends. *IEEE Transactions on Dielectrics and Electrical Insulation* 1-1 (2026) doi:10.1109/TDEI.2026.3710179.

1. 2nd step: PP-g-MAH modified with different amines

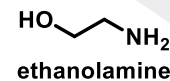
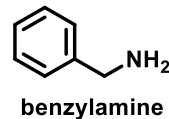
Polypropylene modification



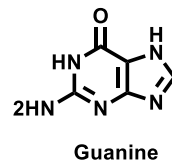
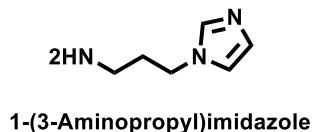
Used Amines



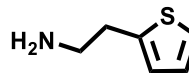
Polarity ↓



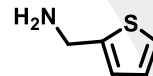
Polarity ↑



Two **electron-poor** amines



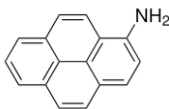
2-(thiophen-2-yl)ethan-1-amine



2-thiophenemethylamine

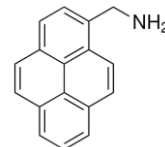
Two **electron-rich** hetero aromatic amines

Amino-modified fluorescent compounds



Aminopyrene:

- excitation peak at 336 nm
- emission peak at 384 nm

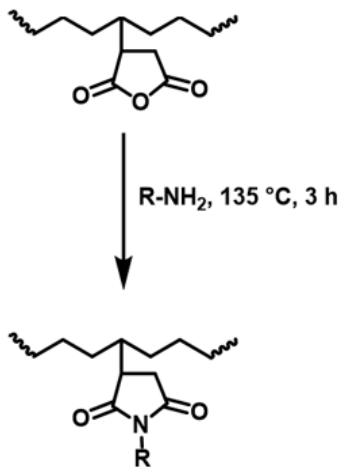


1-pyrenemethylamine:

- excitation peak at 345 nm
- emission peak at 400 nm

1. PE-g-MAH modification with different amines

Polyethylene modification

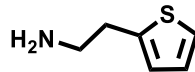


Starting material:

Commercial PE-g-MAH

(Licocene™ PE MA 4351 from Clariant)

Used Amines

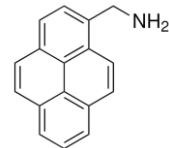


2-(thiophen-2-yl)ethan-1-amine



Aminopyrene:

- excitation peak at 336 nm
- emission peak at 384 nm

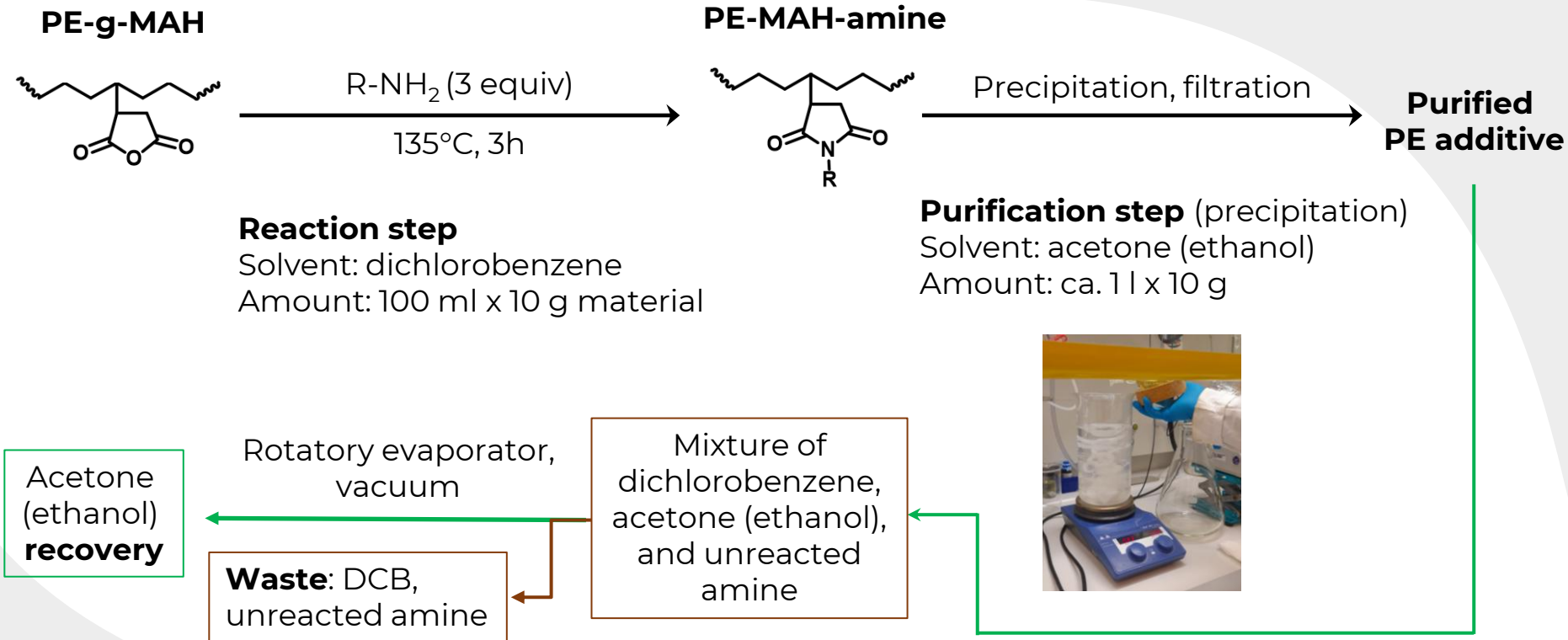


1-pyrenemethylamine:

- excitation peak at 345 nm
- emission peak at 400 nm



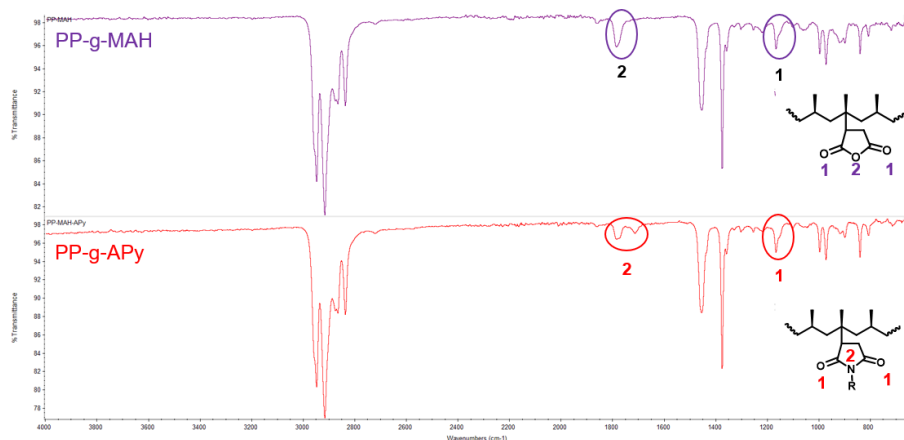
1. PE-g-MAH modification – solvent recovery



Solvent recovery after filtration

1. Functionalization degree

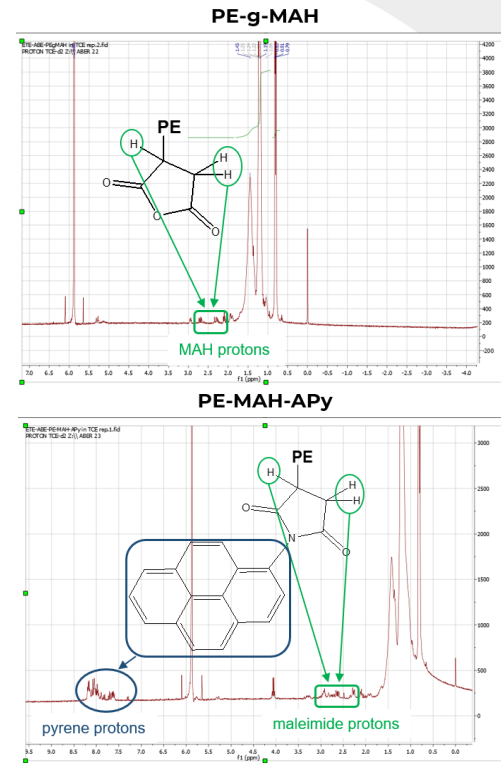
PP-based additives: FTIR (ATR)



$$\text{Carbonyl index (CI)} = \frac{A_{1785\text{cm}^{-1}}}{A_{1167\text{cm}^{-1}}}$$

$$\text{Grafting (wt\%)} = 0,44038 \times \text{CI} \approx 0,9 \text{ wt\%}$$

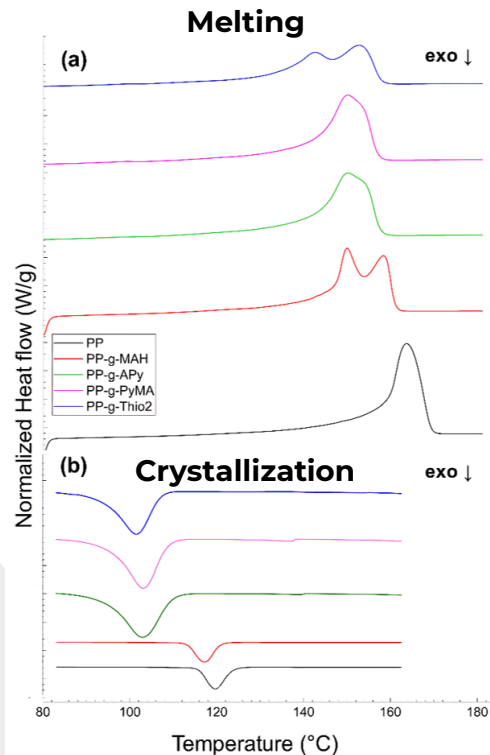
PE-based additives: ¹H NMR



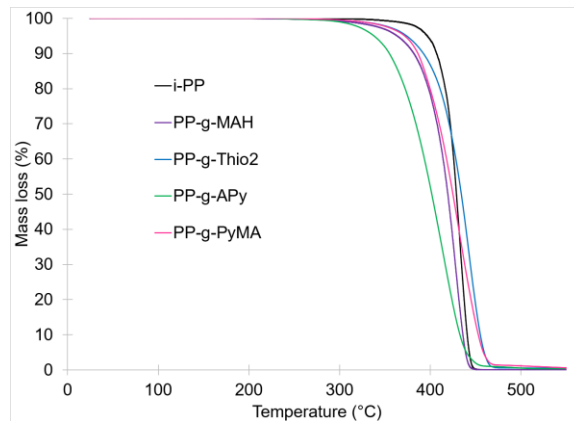
$$\text{Grafting (wt\%)} \approx 0,25 \text{ wt\%}$$

1. Characterizations (example PP-based additives)

DSC results

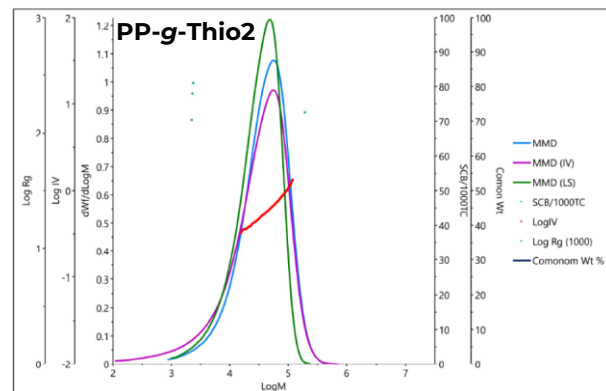
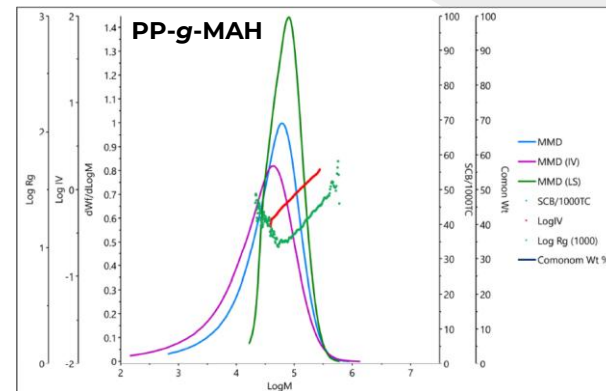


TGA results



	T ₁ (°C)	T _{max} (°C)	T ₉₉ (°C)
PP	364	433	446
PP-g-MAH	258	425	445
PP-g-BA	280	426	443
PP-g-DA	269	428	444
PP-g-EA	288	422	445
PP-g-Thio1	271	405	470
PP-g-Thio2	326	411	468
PP-g-Gua	301	410	550
PP-g-Imi	322	407	473
PP-g-APy	301	367	466
PP-g-PyMA	326	394	514

GPC (Gel Permeation Chromatography)

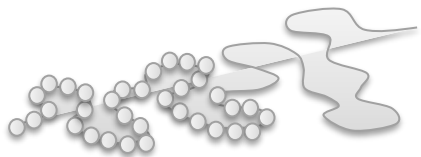


PP additives in PP matrix – 1st approach

1. Maleic anhydride mediated amine grafting



2. PP block copolymers



3. PP random copolymer



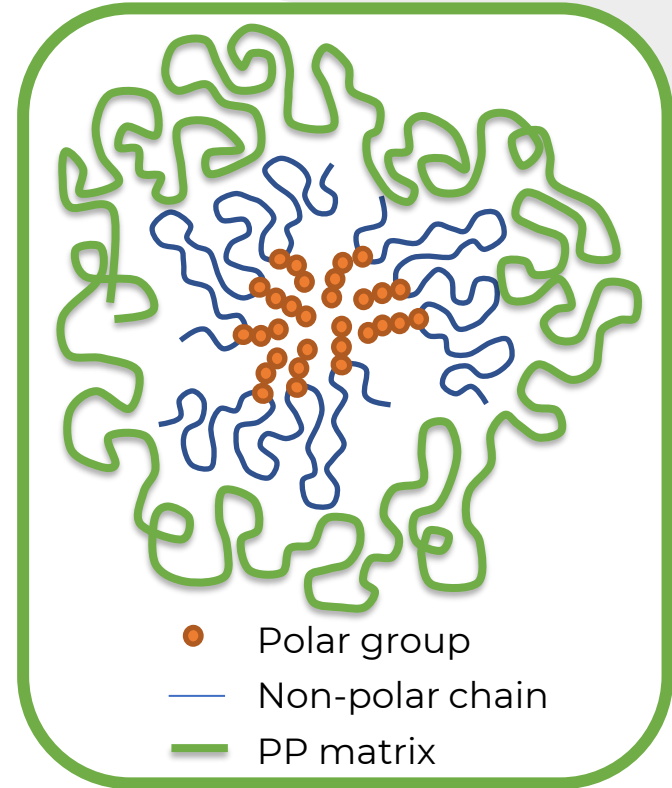
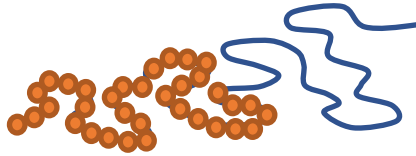
- Versatile approach:
 - Used to prepare both for **PP** and **PE** additives;
 - Starting material: commercial PP (or PE) or commercial PP-g-MAH.
- Possibility of **scale-up**:
 - Up to 100g of PP-g-MAH /batch;
 - Up to 50 g of PP-MAH-amine/batch.

PP additives in PP matrix – 2nd approach

1. Maleic anhydride mediated amine grafting



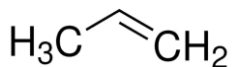
2. PP block copolymers



Possible arrangement
of modified PP in the PP matrix

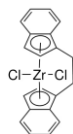
2. Block copolymer synthesis

1st
block



Propylene

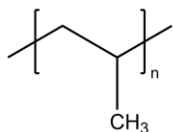
Toluene,
1 atm,
0°C, 1 h,
vigorous stirring



Co-catalyst:
15 mmol MAO (*methylaluminoxane*)

Catalyst:
5 μmol EBIZrCl₂
Dichloro[rac-ethylenebis(indenyl)]zirconium(IV)

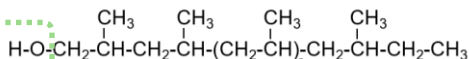
Chain-transfer agent:
33 mmol TEA (*triethylaluminum*)



i-Polypropylene

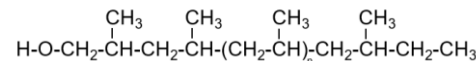
O₂,
1 atm,
0°C, 1 h,
vigorous stirring

H₂O₂ (30%),
methanol



PP-OH

2nd
block



PP-OH

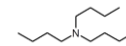
α-bromoisobutyryl bromide
0,05 mol

Toluene,
110°C,
5 h, stirring

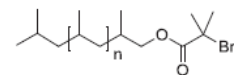
catalyst



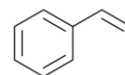
Diamino pyridine
0,025 mol



Bu₃N
0,025 mol

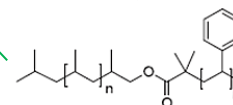


iPP-Br macroinitiator



Styrene

O₂-free environ.
110°C, 16 h, stirring

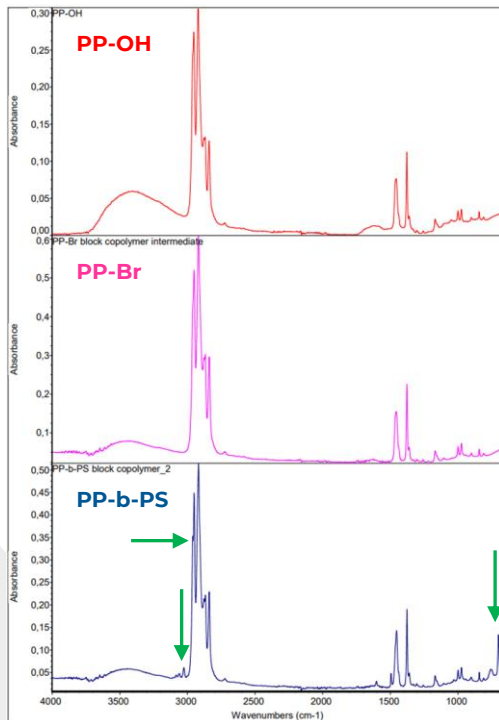


PP-b-PS



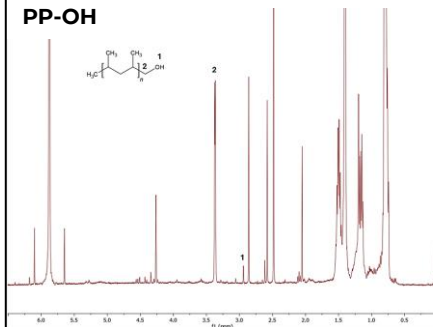
2. Block copolymer characterization

FTIR (ATR):

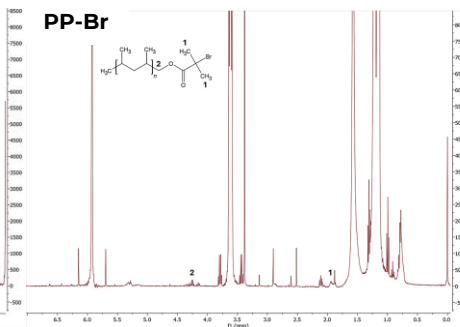


¹H NMR:

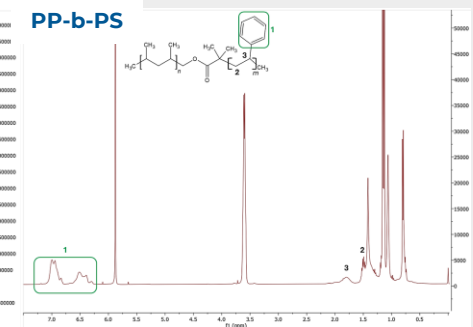
PP-OH



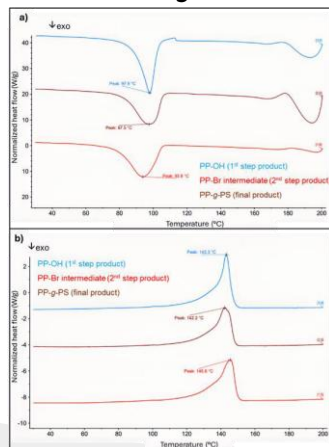
PP-Br



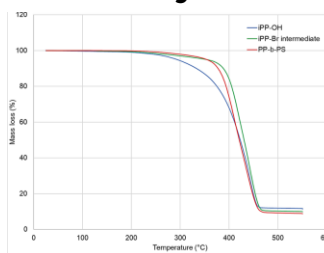
PP-b-PS



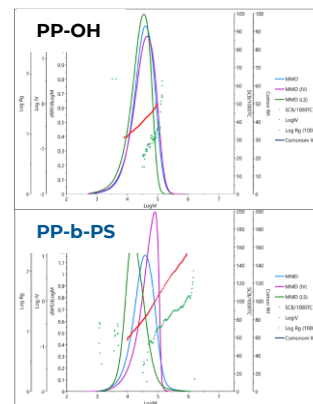
DSC analysis:



TGA analysis:



GPC analysis:



	iPP-OH	PP-b-PS
Mw (g/mol)	44200	46000
Mn (g/mol)	21100	21300
PDI	2,1	2,2

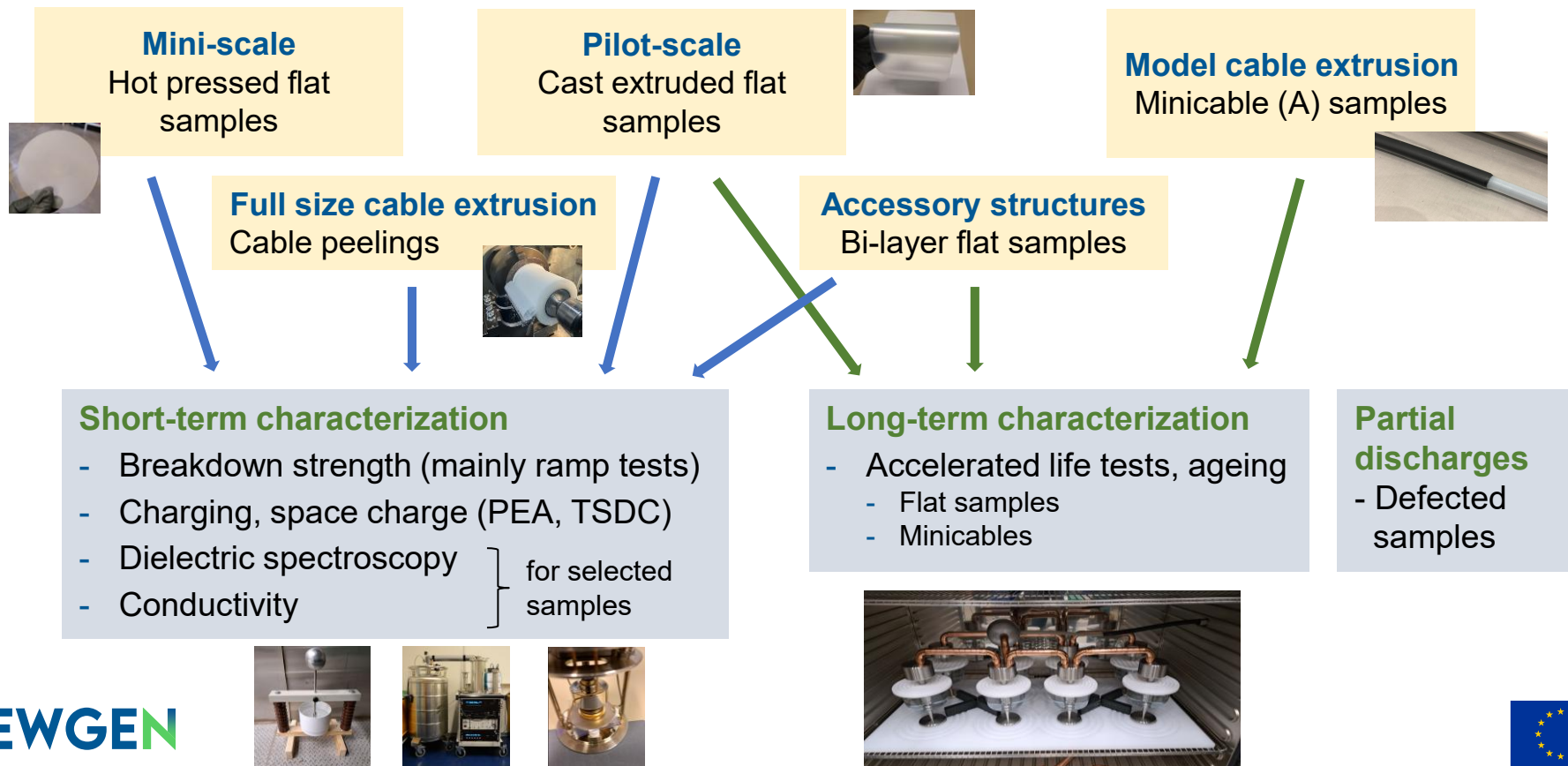


Dielectric characterization of insulation specimens

Kari Lahti, Minna Niittymäki (TAU)

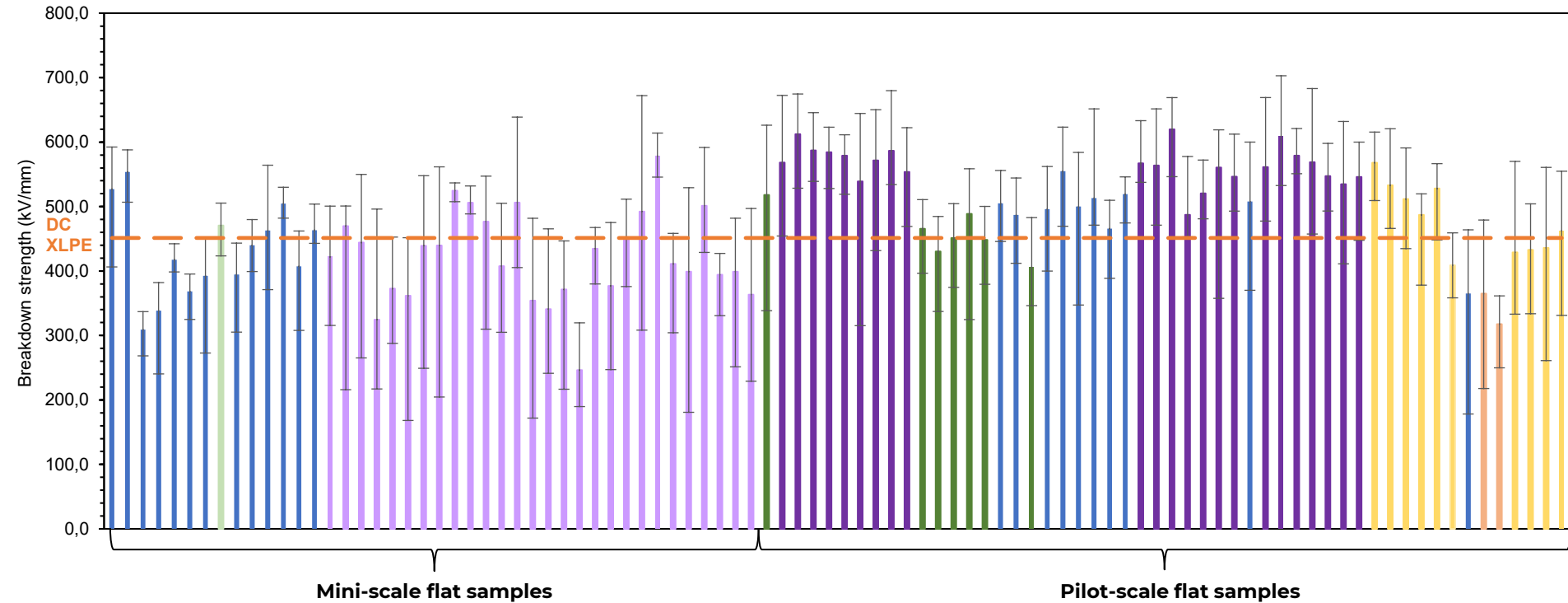


Introduction – Dielectric characterization in NEWGEN



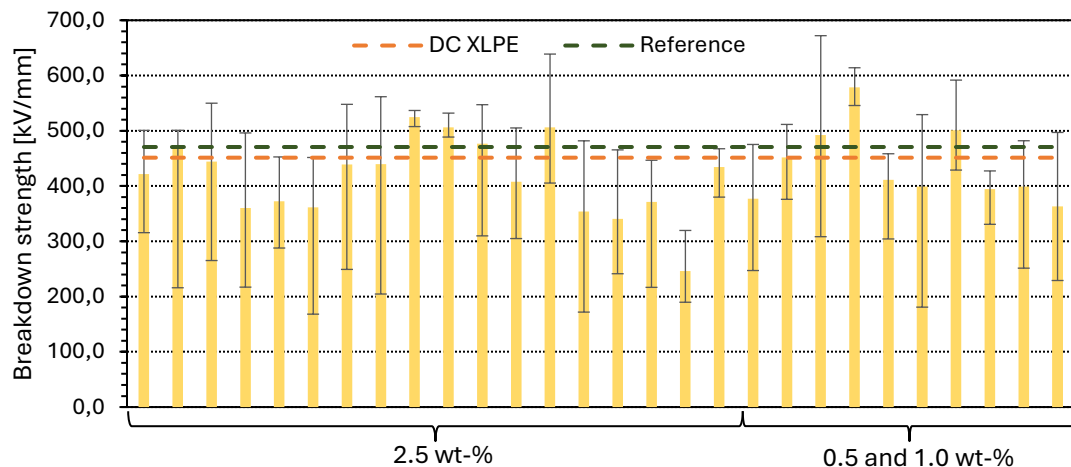
Breakdown strength of various PP blends

Outlook on the development in breakdown strength



Results – Dielectric characterization in NEWGEN

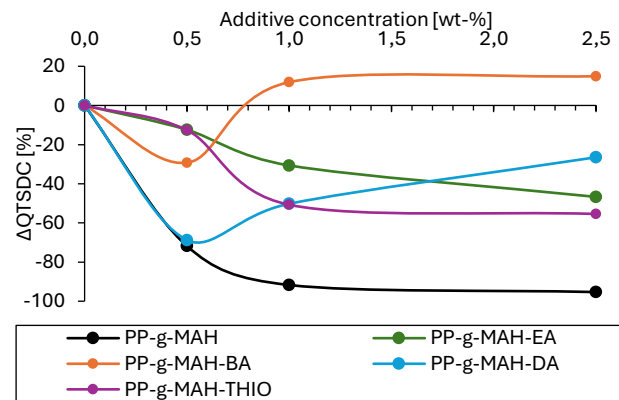
Mini-scale PP blends with and without additives



Especially, PP-g-MAH & PP-g-MAH-THIO have good performance in comparison to the reference.



Promising additives are studied more in the **pilot-scale materials**.



MAH = Maleic anhydride ($C_2H_2(CO_2O)_2$)

BA = Benzylamine (C_7H_9N)

EA = Ethanolamine (C_2H_7NO)

DA = Dodecylamine ($CH_3(CH_2)_{11}NH_2$)

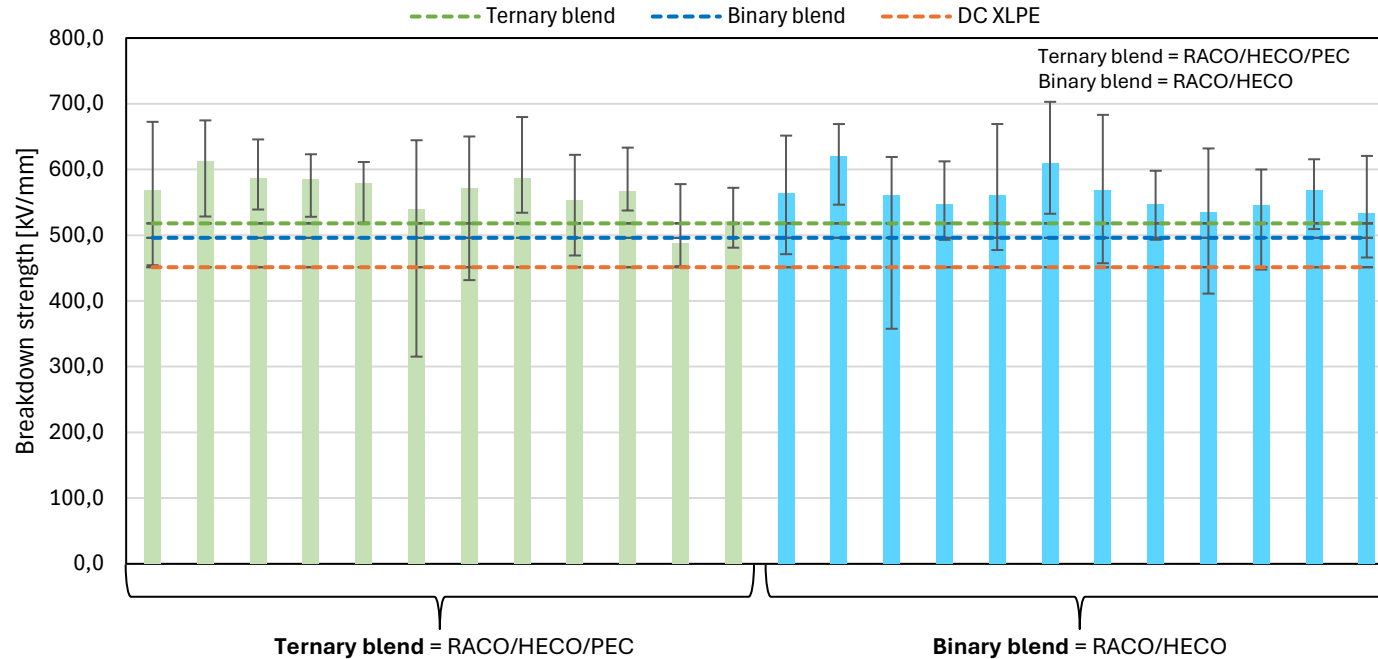
THIO = Thiophene methylamine (C_5H_7NS)

More information available in publications:

- DOI: [10.1109/ceidp61707.2025.11218281](https://doi.org/10.1109/ceidp61707.2025.11218281)
- DOI: [10.1109/ICD59037.2024.10613125](https://doi.org/10.1109/ICD59037.2024.10613125)
- DOI: [10.1109/ICD59037.2024.10613139](https://doi.org/10.1109/ICD59037.2024.10613139)

Results – Dielectric characterization in NEWGEN

Breakdown strength of pilot-scale PP blends

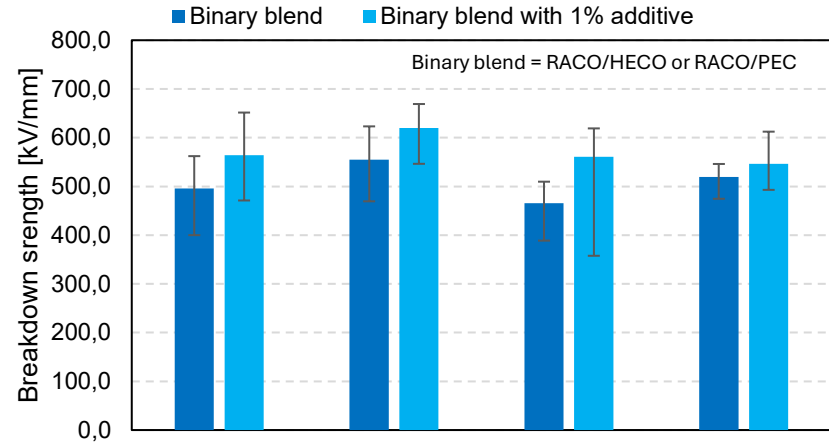
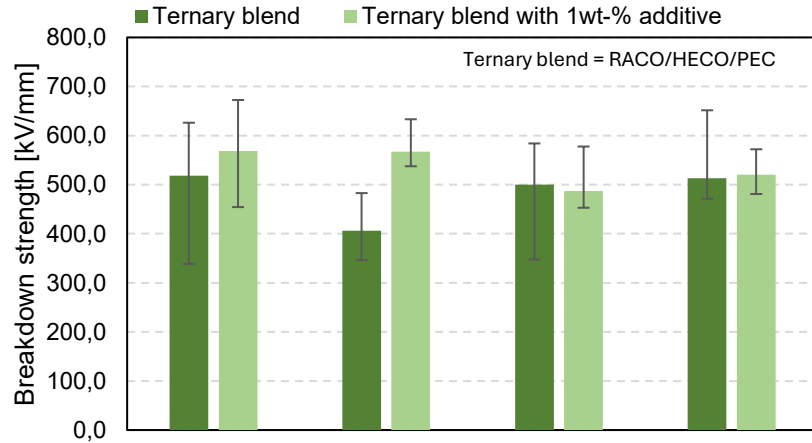


Studied additives:

PP-g-MAH = Maleic anhydride
PP-g-MAH-Apy = Aminopyrene
PP-g-MAH-PyMA = Pyrenemethylamine

Results – Dielectric characterization in NEWGEN

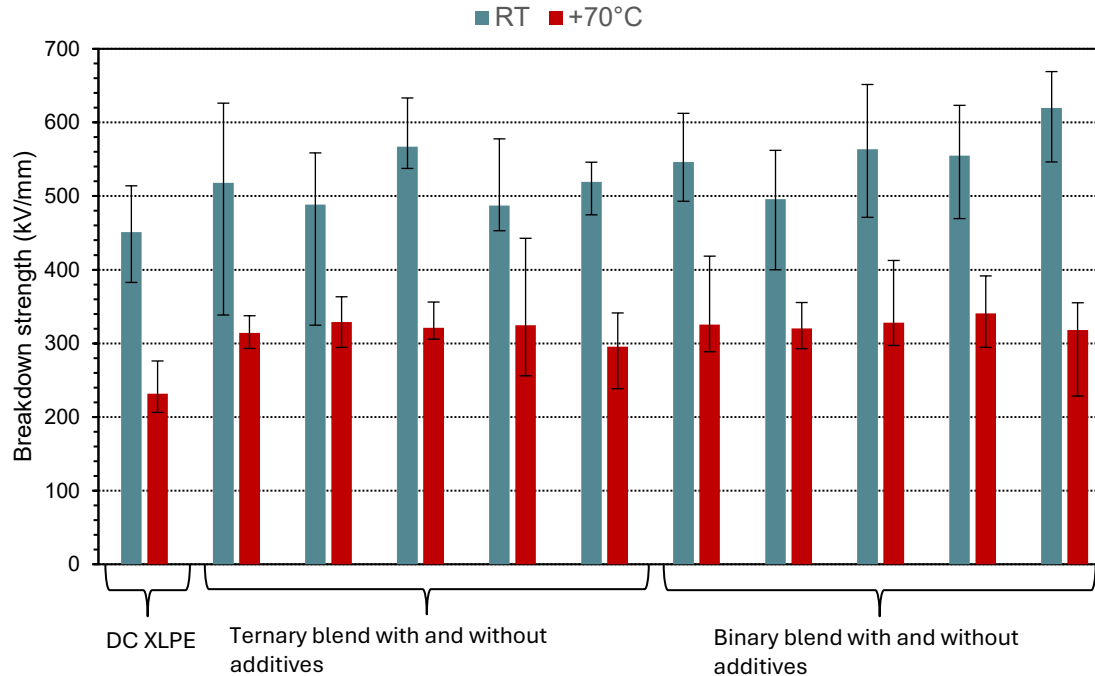
Breakdown strength of pilot-scale PP blends



- In **ternary blends**, difference between reference PP blends and additivated blends is either **very small** or **even 40%**.
- In **binary blends**, the **additivated** PP blends have **higher breakdown strength**, **5–20 %**.

Results – Dielectric characterization in NEWGEN

Breakdown strength of pilot-scale PP blends



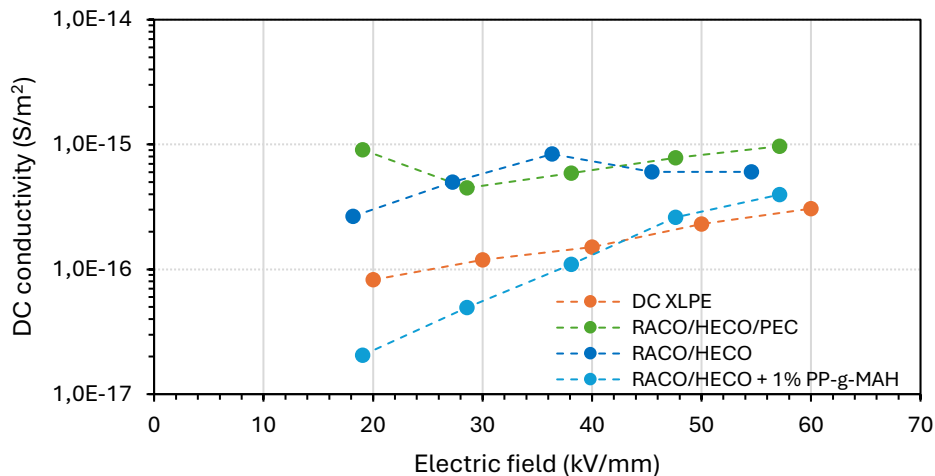
Next
phase

Long-term testing, e.g. accelerated life tests (ALT) have been made for ternary and binary blends.

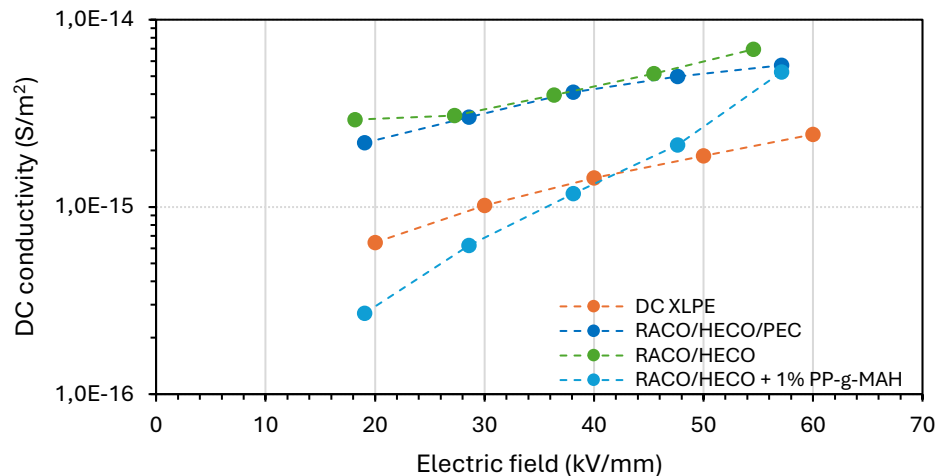
Results – Dielectric characterization in NEWGEN

DC conductivity of pilot-scale PP blends

+30°C



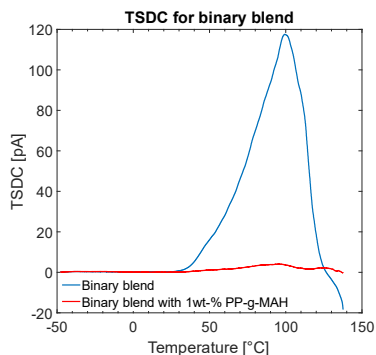
+50°C



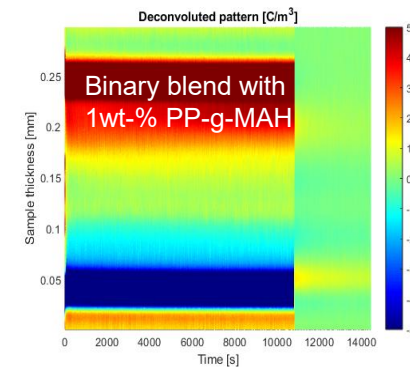
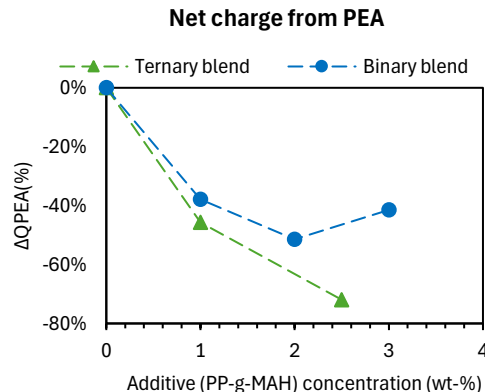
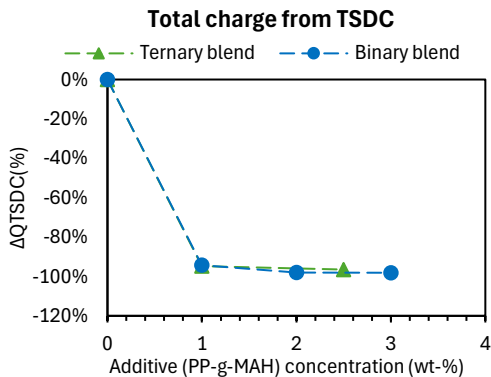
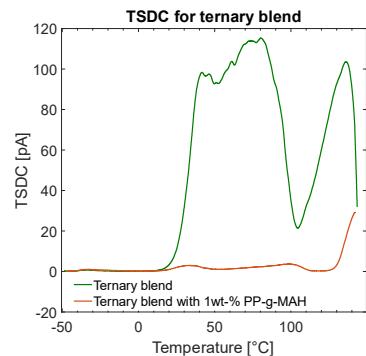
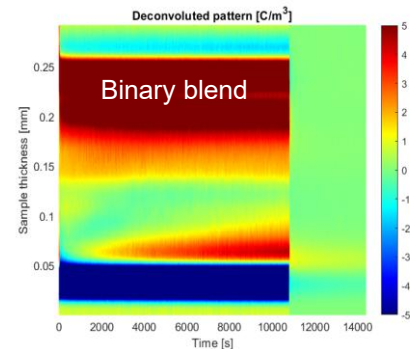
- Binary and ternary PP blends without additive exhibit higher conductivity than DC XLPE.
- Adding 1 wt-% PP-g-MAH to PP blend decreases the conductivity to similar level with DC XLPE or even lower level (E = 10–30 kV/mm).

Results – Dielectric characterization in NEWGEN

Charge trapping properties of pilot-scale PP blends



- Charge trapping properties were studied:
 - Thermally stimulated depolarization (**TSDC**) –method
 - Space charge measurement (**PEA**)
- Even **small amount additive**, e.g. 1 wt-%, decreased the amount charges → **space charge mitigation** can be observed.
- Decreasing additive effect can be seen all PP blends as well as PP homopolymer.

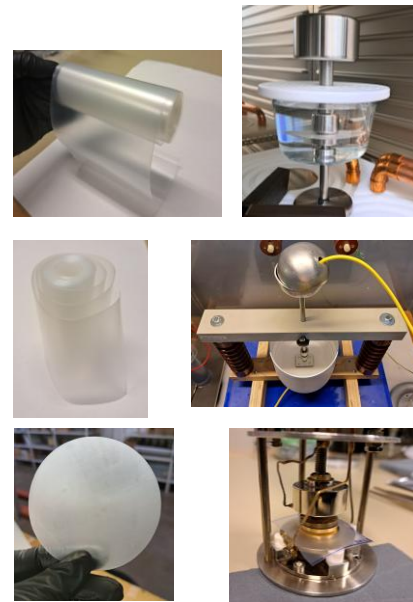


Conclusions – Dielectric characterization in NEWGEN

Mini- and pilot-scale flat samples

- At room temperature, **breakdown strength** of the studied PP blends increased **10–20%** in comparison to the state-of-art DC XLPE.
- At **+70°C**, the **breakdown strengths** of the PP blends are almost **40%** higher than DC XLPE.
- Space charge mitigating **additives improves** the electrical performance of PP blends:
 - **Breakdown strength increases 20–30%** compared to DC XLPE.
 - **DC conductivity** at service stress levels **are lower** than DC XLPE.
 - **Smaller amount of charges** are trapped into PP matrix than in DC XLPE.

 Space charge mitigation can be achieved with additivated PP blends!



Publications of dielectric characterization in NEWGEN

- M. Niittymäki et al., 2026, “Effect of Additive Concentration on the Dielectric Properties of Extruded HVDC Cable Insulation”, 2026 IEEE 6th International Conference on Dielectrics, Southampton, UK, 2026, IEEE.
- B. Diban et al., “Characterization of Bi-Layer XLPE/EPDM and PP-blend/EPDM Insulations for HVDC Cable Accessories”, 2026 IEEE 6th International Conference on Dielectrics, Southampton, UK, 2026, IEEE.
- S. Lähtenmäki et al., “Evaluating Space Charge Behavior of Polypropylene Blends Using TSDC Measurements”, 2026 IEEE 6th International Conference on Dielectrics, Southampton, UK, 2026, IEEE.
- M. Niittymäki et al., “Novel Grafted Additives for Space Charge Mitigation in Extruded HVDC Cable Insulation”, 2025 IEEE Conference on Electrical Insulation and Dielectric Phenomena (CEIDP), Manchester, UK, pp. 1-4. DOI:10.1109/ceidp61707.2025.11218281
- B. Diban et al., “Polypropylene Copolymers and Blends for HVDC Cable Insulation: Initial Characterization and Pilot-scale Production”, 2024 IEEE Conference on Electrical Insulation and Dielectric Phenomena (CEIDP 2024), Auburn, AL, USA, pp. 1-5. DOI: 10.1109/CEIDP61745.2024.10907748.
- G. Mazzanti et al. “The Horizon Europe NEWGEN Research Project: For a New Generation of High-Voltage DC Insulation Materials, Cables, and Systems after 24 Months since the Start of the Project”, IEEE Industry Applications Magazine, vol. 31, pp. 72-82. DOI: [10.1109/MIAS.2025.3559863](https://doi.org/10.1109/MIAS.2025.3559863)
- G. Mazzanti et al., “Updates About the Horizon Europe NEWGEN Research Project for a New Generation of HVDC Insulation Materials, Cables and Systems”, 2024 IEEE International Conference on Environment and Electrical Engineering and 2024 IEEE Industrial and Commercial Power Systems Europe, Rome, Italy, pp. 1-6, DOI: 10.1109/EEEIC/ICPSEurope61470.2024.10751490
- M. Niittymäki et al., “Screening of Suitable Random Copolymer Polypropylene Blends for HVDC Cable Insulation,” 2024 IEEE 5th International Conference on Dielectrics (ICD), Toulouse, France, 2024, pp. 1-4, DOI: 10.1109/ICD59037.2024.10613125.
- B. Diban et al., “Characterization of Isotactic-Polypropylene-Based Compounds for HVDC Cable Insulation,” 2024 IEEE 5th International Conference on Dielectrics (ICD), Toulouse, France, 2024, pp. 1-4, DOI:10.1109/ICD59037.2024.10613139.

NEWGEN

Q&A Session 1

Moderator: Merie Kannampuzha (CLI)



NEWGEN

Session 2: Reliable-by-design manufacturing of HVDC cables

14:10-14:55





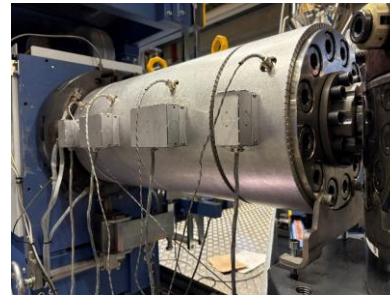
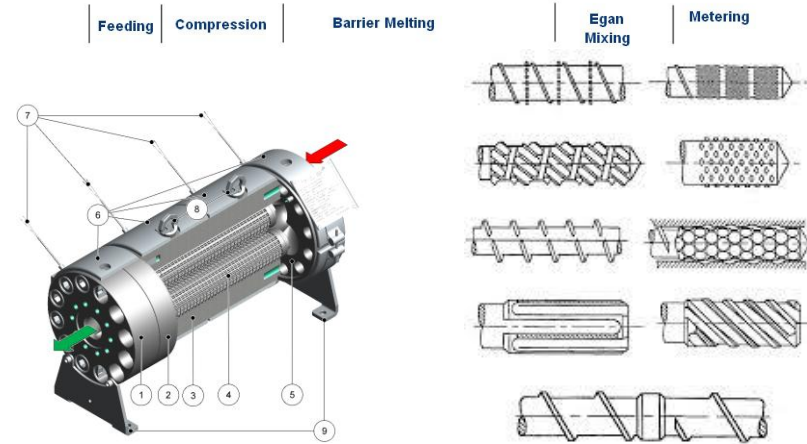
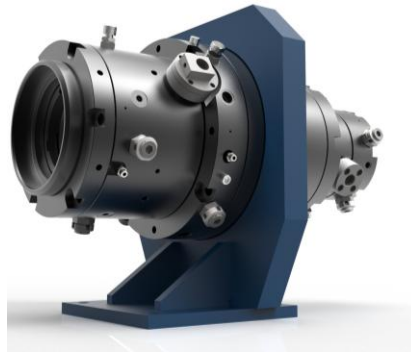
Advancements in HVDC cable extrusion machinery optimized for PP insulated cables and their characterization

Anders Nordström (MAI)



Objectives

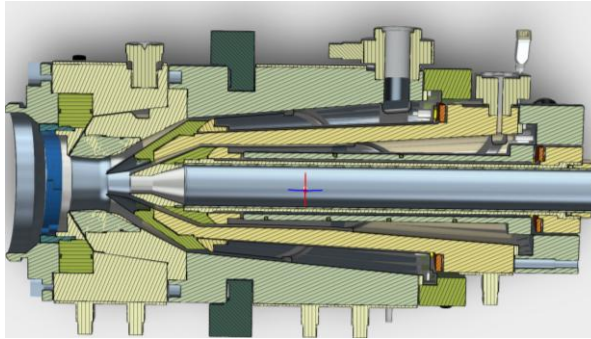
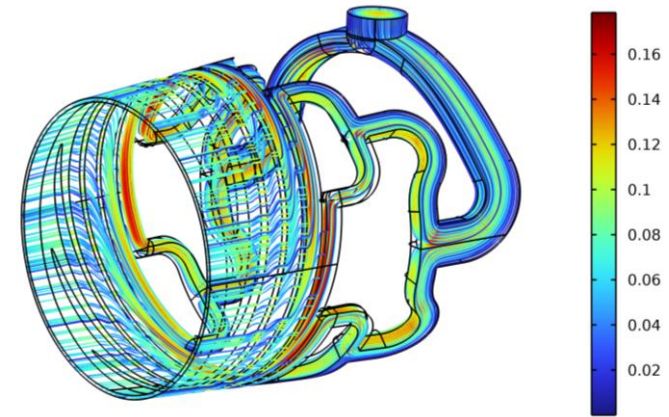
Develop new extrusion equipment solutions to improve HVDC cable properties



Crosshead

- Design target
 - PP dedicated EHV size triple crosshead
 - Conical, Size 70/150
- Flow simulations done with multiple softwares
 - Comsol Multiphysics
 - Compuplast
 - Maillefer proprietary Heliflow

Streamline: Velocity field

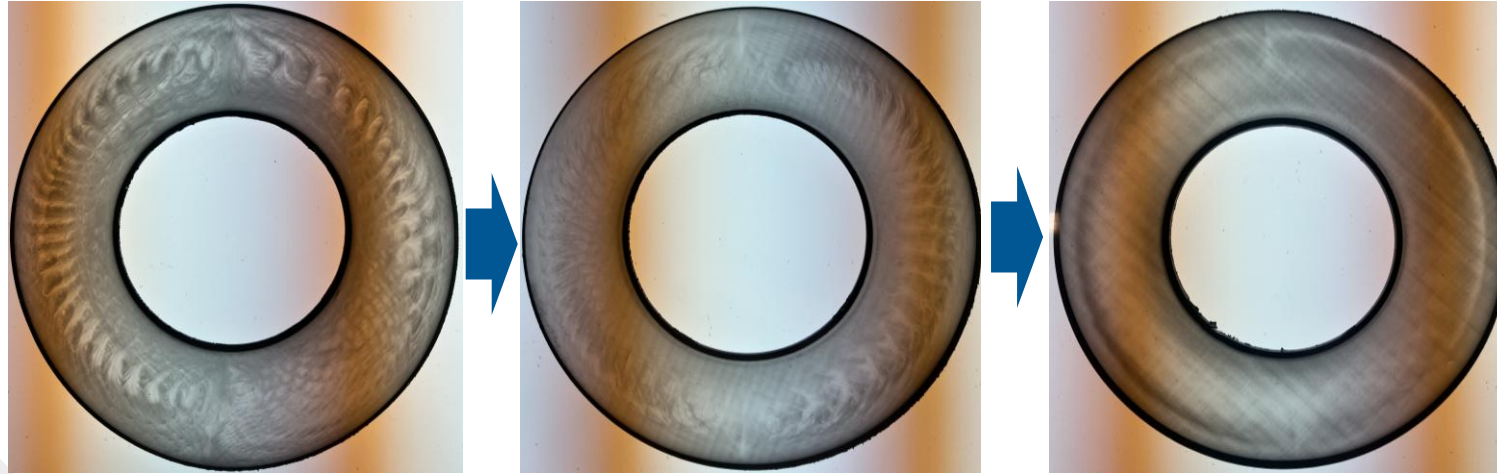


Extrusion development

Step 1:

Step 2:

Optimal NEWGEN PP screw



Clear reduction of heterogenous areas due to improved processing in extrusion



HVDC prototype manufacturing

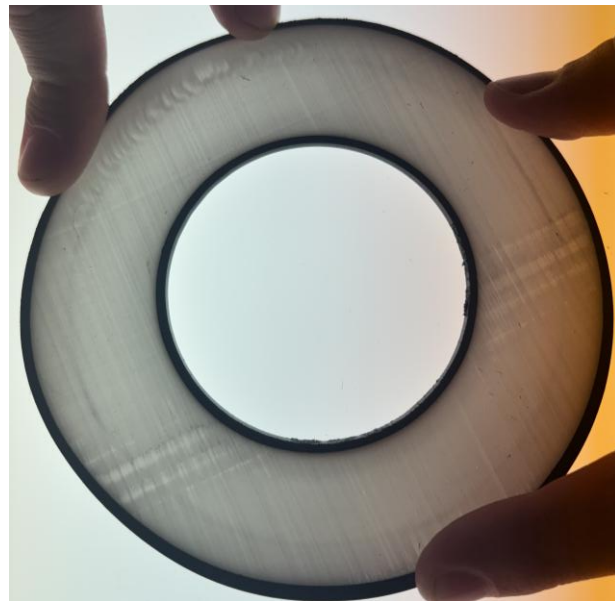
Voids with binary blend and water cooling



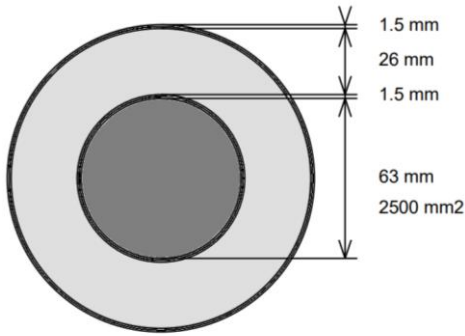
Gas cooling upgrade
commisisoned



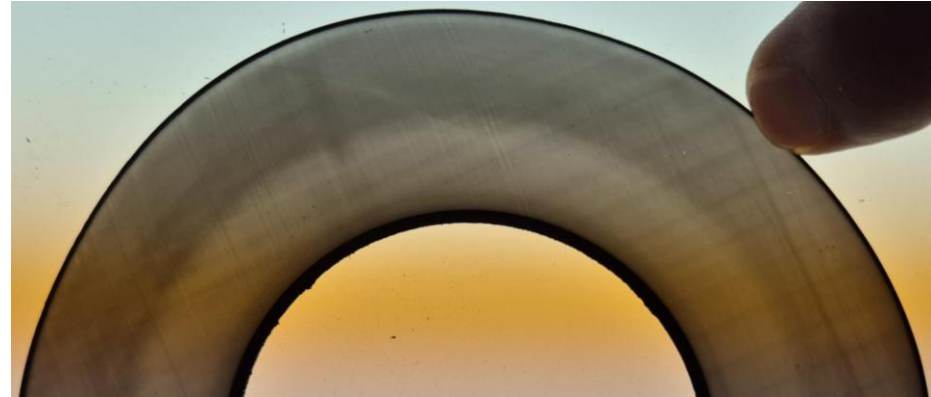
Defect free cables with optimized
cooling rate



THC70/150 HE crosshead type testing

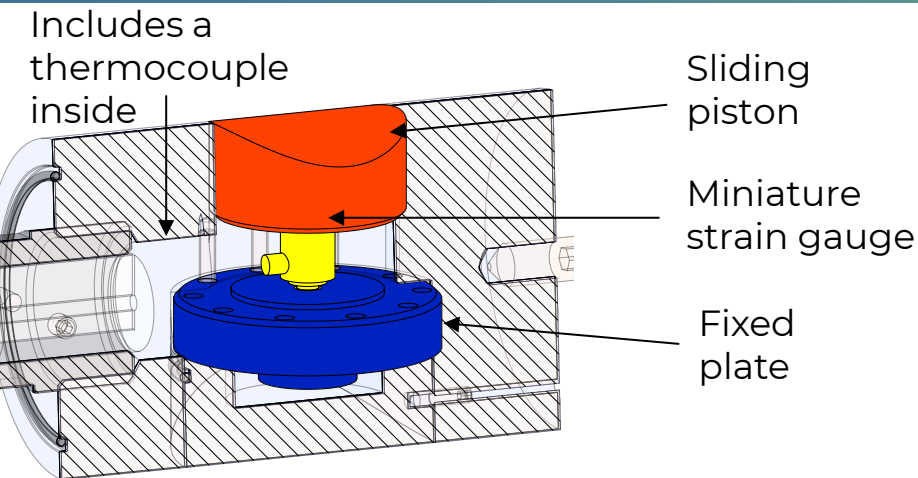


THC 70/150 HE
2-spiral design using NG1-152
NEWGEN PP screw with saxton
mixer



- Seamlines are curving as modelled and observed in color tests previously. NEWGEN insulation screw provided more homogenous material with less flow patterns compared to standard PP insulation screw.
- Designs free of voids as expected when using stiffness optimized NG1-152 and slow cooling gradient with gas (80°C) cooling

Internal stress measurements



Sensor

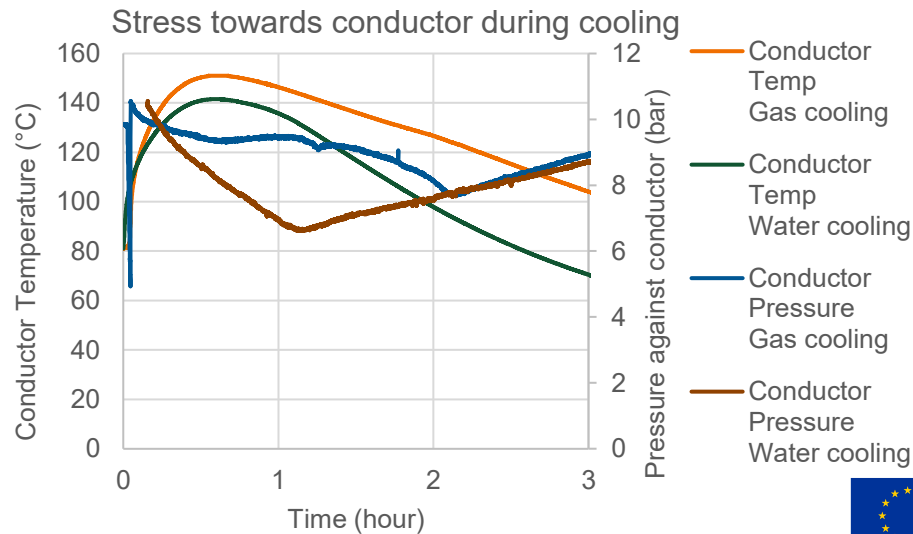


Assembled
inside the
conductor



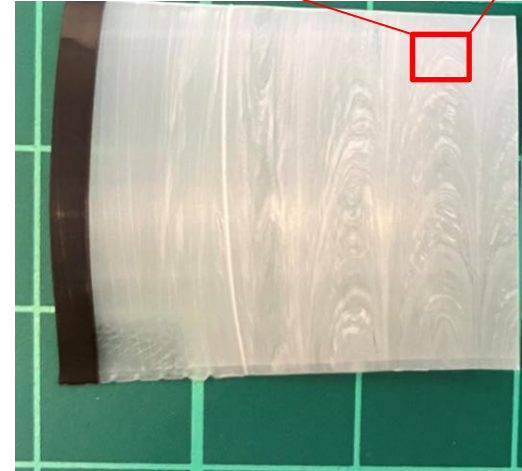
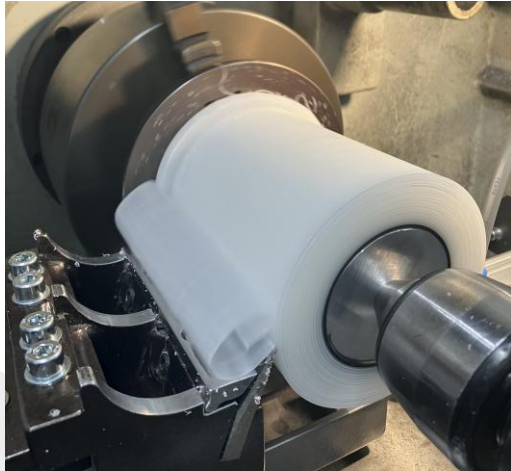
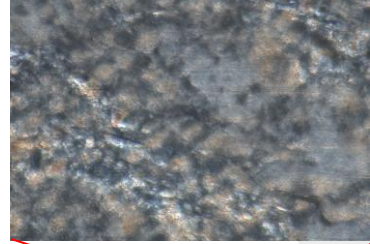
Embedded
in the cable

- Comparison of the cooling process and what happens inside the cable
 - Wiring through hollow conductors
- Internal stress simulation made with inhouse software
 - Good correlation with theory and novel measurements

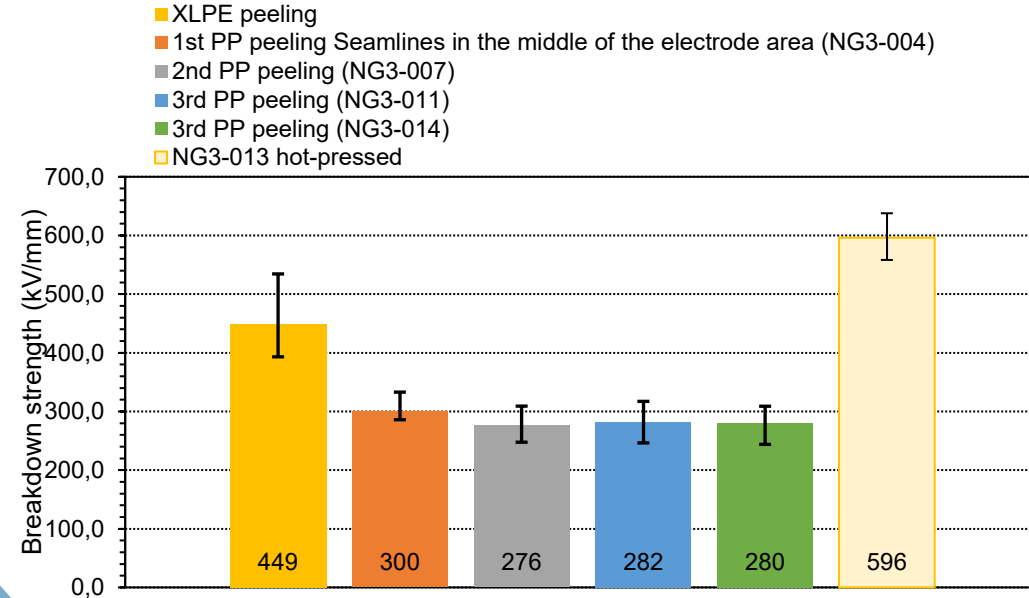


Cable peelings from HVDC prototypes

- Thin cable peelings for electrical characterization such as:
 - DC breakdown
 - DC conductivity
 - Thermally stimulated depolarization current (TSDC)
- Visual analysis of insulation homogeneity as function of process settings



Analysis of cable peelings



- Thin cable peelings for electrical characterization such as:
 - DC breakdown
 - DC conductivity
 - Thermally stimulated depolarization current (TSDC)
- All PP cable peeling samples have had consistently lower breakdown strength than films
 - Strong relationship between morphology and electrical performance
 - Reproducible behaviour between cable peelings and as slowly cooled down films

Summary



WP2 focused on how to make the best cables using novel materials

Key results:

- Extruder upgrades with NEWGEN insulation screw design
- THC 70/150 HE crosshead
- Optimization of thermoplastic PP cable manufacturing process
- PP thermoplastics prototyping experience





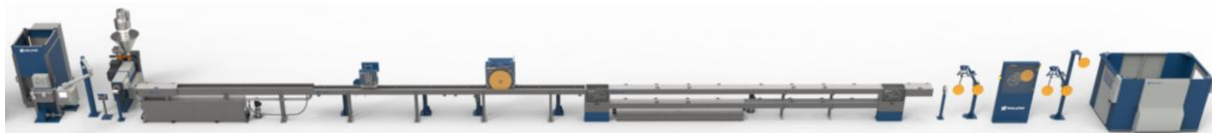
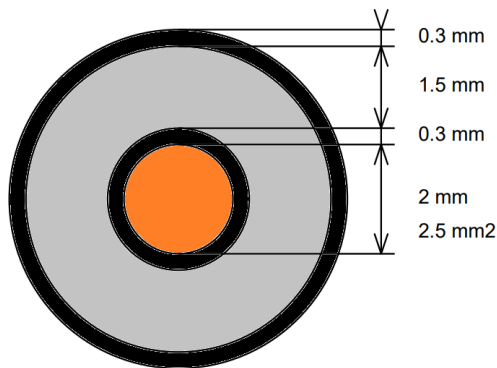
Manufacturing and characterization of model “A” cables

Ludovic Boyer (SGI)

Anders Nordström (MAI)

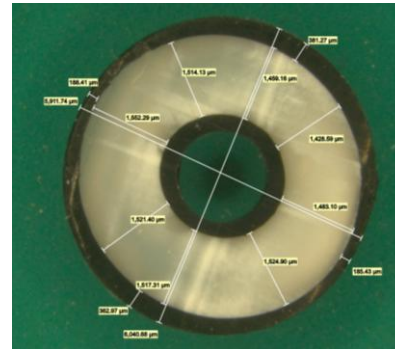


Task 2.3 - Cable model “A” samples (MAI, supported by VTT, TAU, SGI & UBO)



Task 2.3 - Cable model “A” samples (MAI, supported by VTT, TAU, SGI & UBO)

Material	Code	Material description	Semiconducting material description	Sample type	Comments
NG1-048	NG3-003	Ternary PP blend	Same semiconducting material for all cables	1000 m cable	Used for test setup development and testing
NG1-063	NG3-005	Ternary PP blend		800 m of cable	Poor diameter stability and lumps found
NG1-064	NG3-006	Ternary PP blend with additive A		800 m of cable done	Poor diameter stability and lumps found
NG1-064	NG3-006B	Ternary PP blend with additive A		800 m remanufacturing of NG1-064 with new helper caterpillar	Good quality
NG1-078	NG3-008	Binary PP blend		800 m of cable done	Good quality
NG1-079	NG3-009	Binary PP blend with additive A		800 m of cable done	Good quality
NG1-120	NG3-016	Binary PP blend with additive A 2.5 %		800 m of cable done	Good quality
NG1-121	NG3-017	Binary PP blend with additive B		800 m of cable done	Good quality
NG1-134	NG3-018	Binary PP blend (same as NG3-008)		800 m of cable done	Good quality



Task 2.3 - Cable model “A” tests

Breakdown strength

Compare different formulations performances in a short period of time
Test results also serve as an output of Accelerated Life Test

Electrical conductivity

Check if prone to high dielectric losses and thermal instability
Compare field grading effect (if E field will be greatly inverted with thermal gradient, for instance)

Ageing

Evaluate effect of thermoelectrical stress on space charge accumulation

Accelerated life test

Provide lifetime input for the work package "Tools and models for reliable and resilient HVDC cable systems"

Task 2.3 - Cable model “A” - Preparation

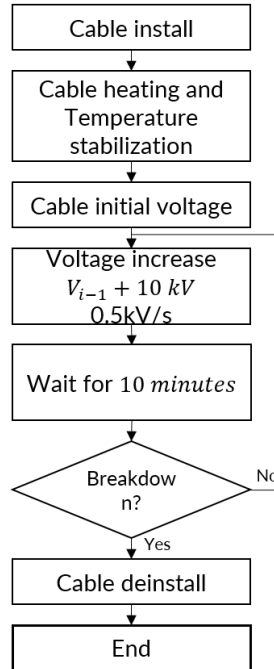


Motorized cutting tool Guiding rails



Cable preparation setup upgraded to accommodate for the 120+ samples prepared

Task 2.3 - Cable model “A” – Breakdown



Aim:

Compare different insulation formulations in a short period of time

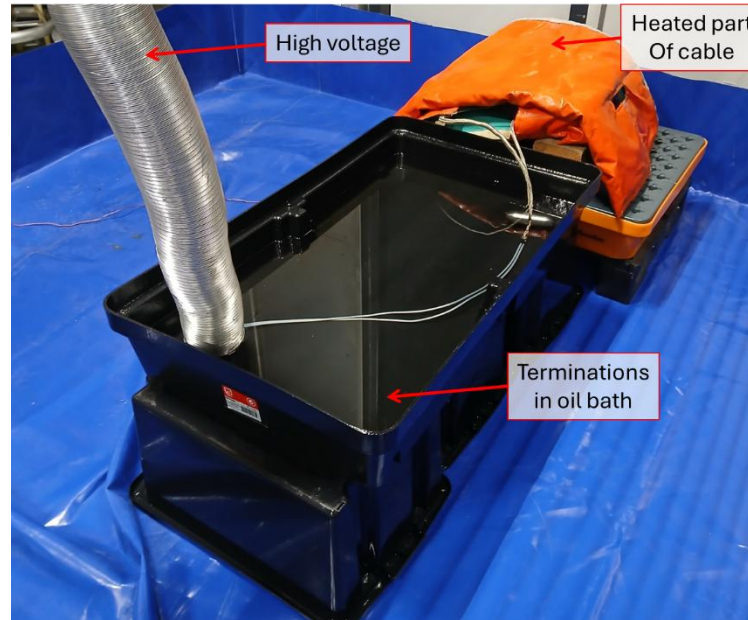
Test results may also serve as an Accelerated Life Test

Parameters:

Heating temperature 90 °C

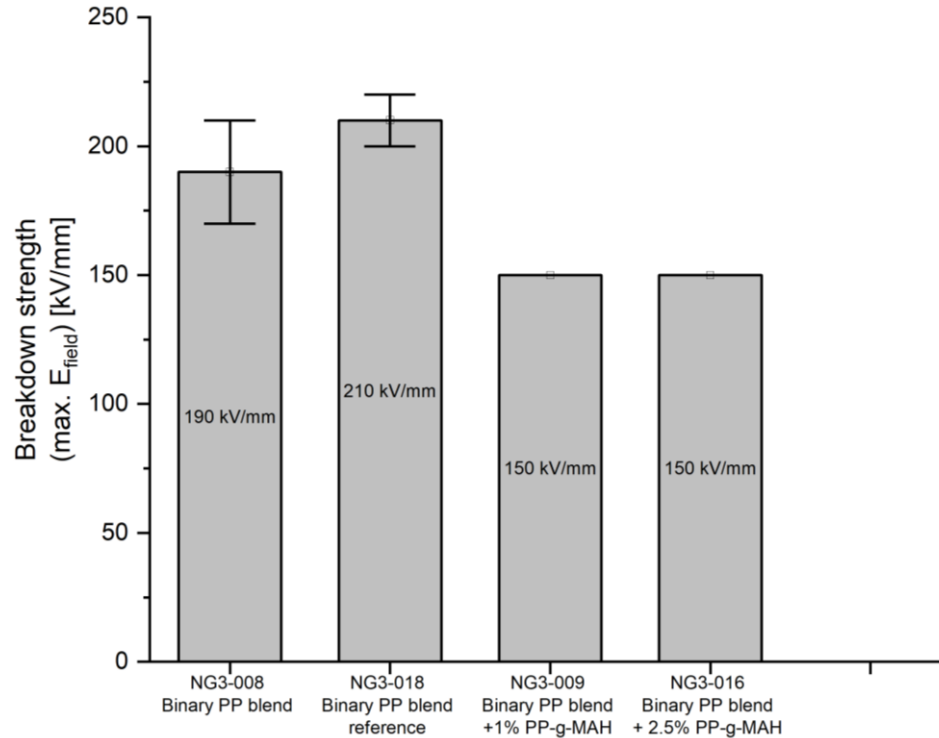
3 cable references per campaign

Task 2.3 - Cable model “A” – Breakdown



Terminations at room temperature to optimize their strength

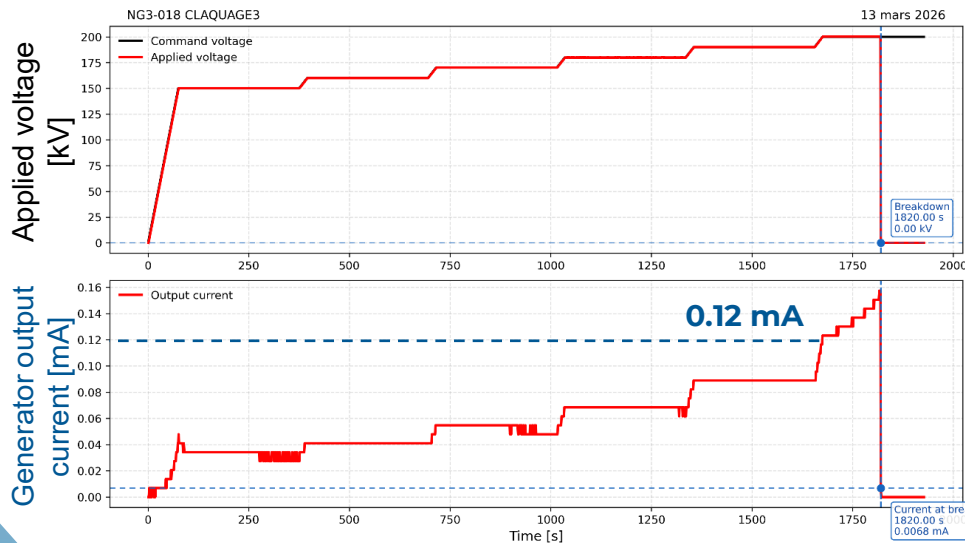
Task 2.3 - Cable model “A” – Breakdown of binary PP blend without and with additives



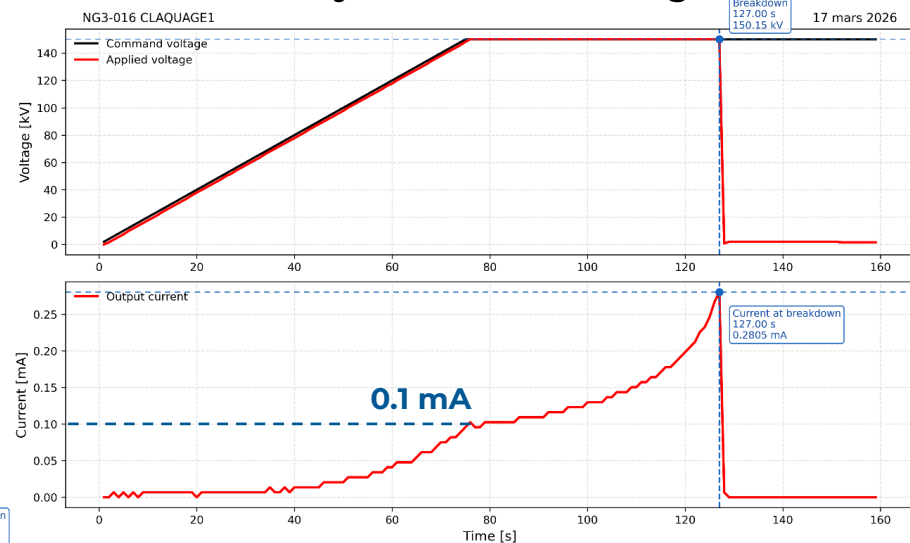
Modification of crystallization properties caused by additives might be the root cause of BD strength decrease

Task 2.3 - Cable model “A” – Breakdown of binary PP blend without and with additives

PP binary blend

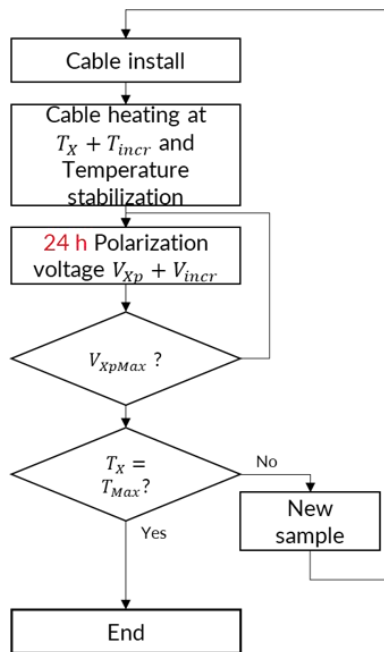


PP binary blend + 2wt-% PP-g-MAH



All tested samples show runaway before breakdown

Task 2.3 - Cable model “A” - Conductivity



Aim:

Get electrical conductivity versus electric field and temperature of tested cable

Parameters:

Maximum heating temperature 90 °C

Tested temperatures : 30, 50, 90°C

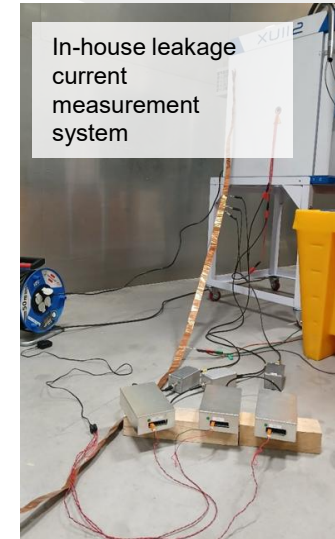
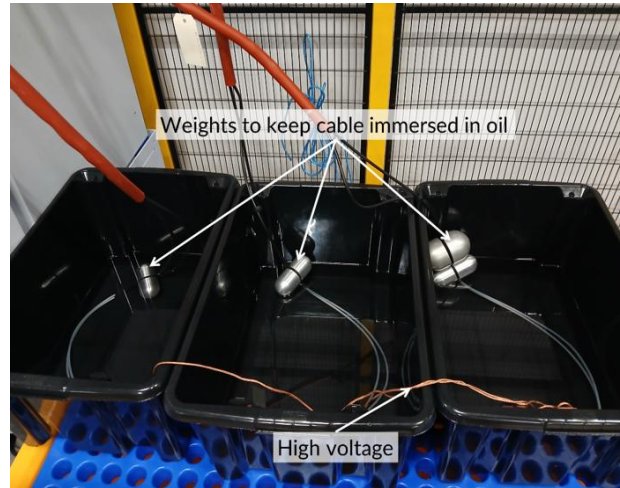
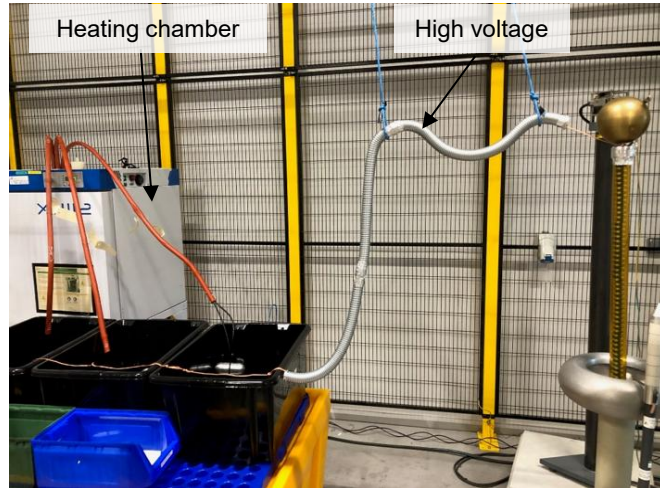
3 samples in parallel to measure conductivity for 1 temperature for 1 week

Average Electric field [kV/mm]		
S1	S2	S3
13	13	13
20	20	20
30	30	30
40	40	40

Applied voltage [kV]		
S1	S2	S3
20	20	20
30	30	30
45	45	45
60	60	60

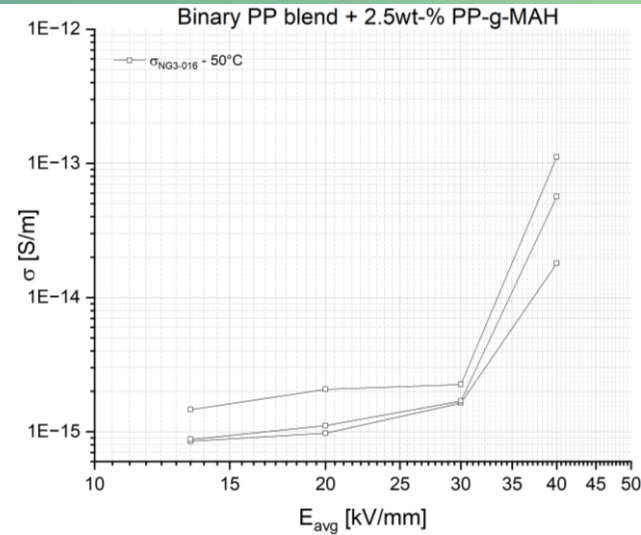
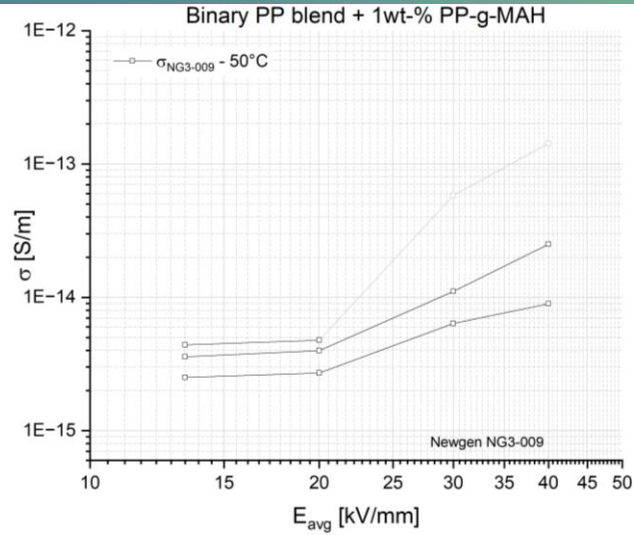
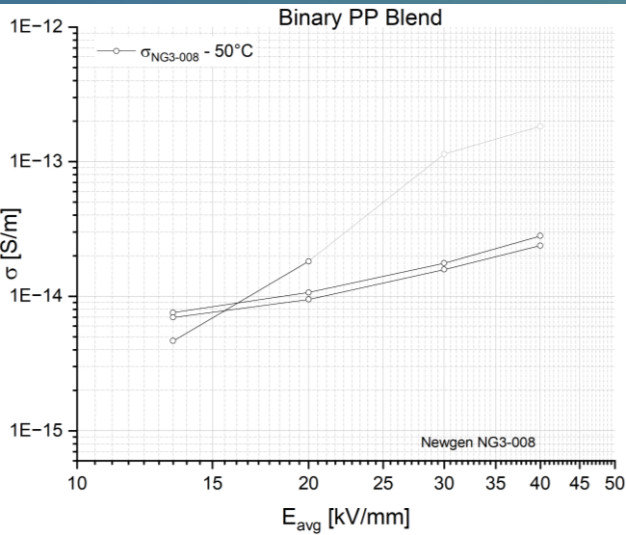
3 samples of same reference characterized in parallel

Task 2.3 - Cable model “A” - Conductivity



Leakage current measurements are processed to extract the apparent electrical conductivity of cable triplex (semicon+insulation+semicon)

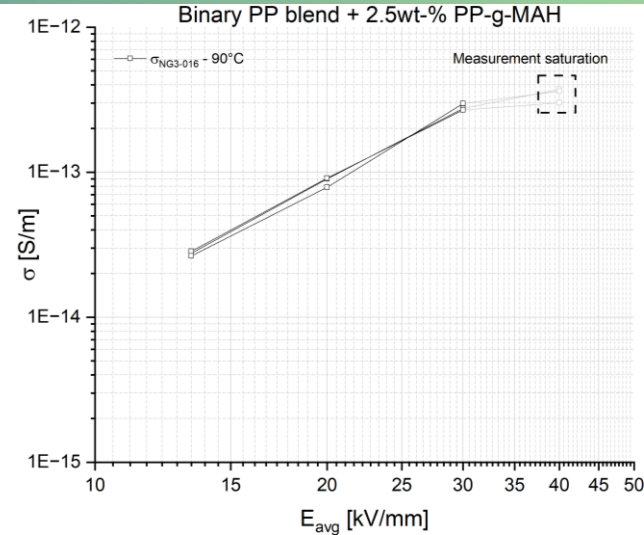
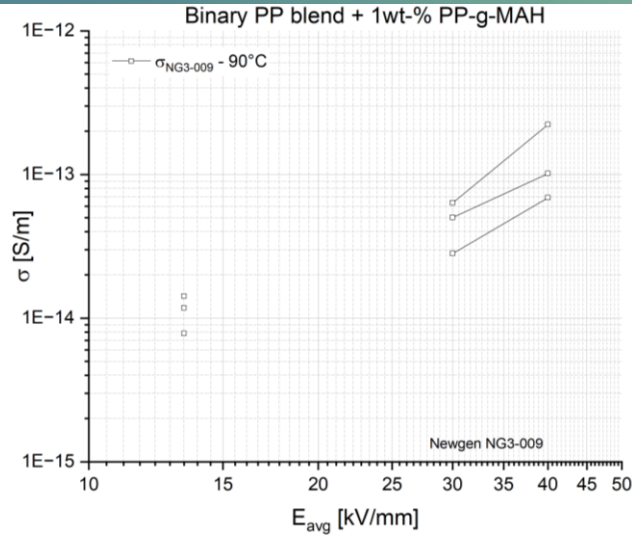
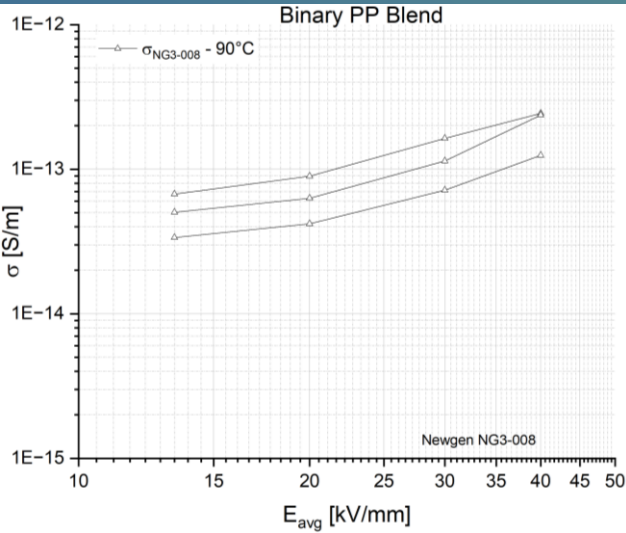
Task 2.3 - Cable model “A” - Conductivity of binary PP blend without and with additives



Increasing concentration of additive:

- Increases the nonlinearity threshold
- Decreases the conductivity below nonlinearity threshold
- Has no noticeable effect at higher electric fields

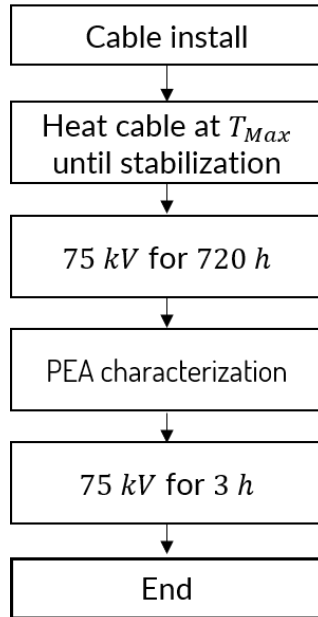
Task 2.3 - Cable model “A” - Conductivity of binary PP blend without and with additives



Increasing concentration of additive:

- Decreases the conductivity at low electric fields
- Has no noticeable effect at higher electric fields

Task 2.3 - Cable model “A” - Ageing



Aim:

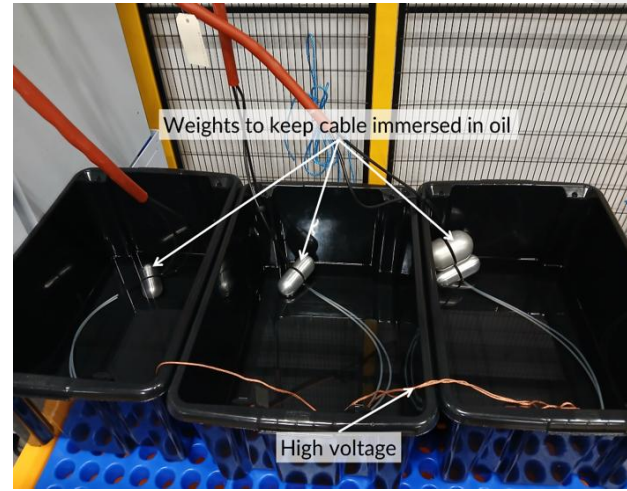
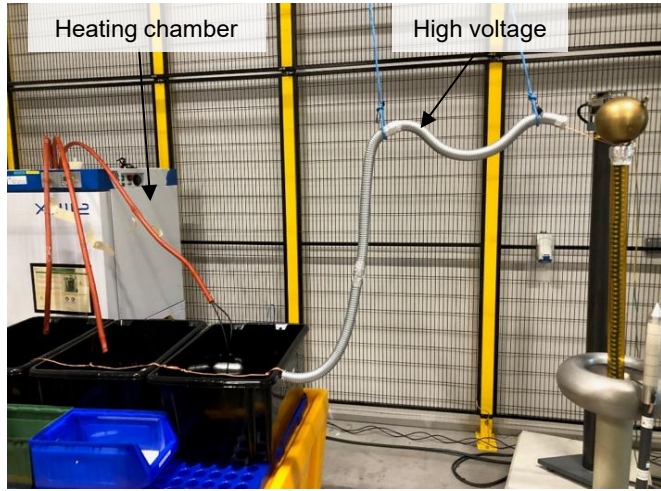
Follow up of insulation parameters due to stress application

Parameters:

Heating temperature 30°C and 90 °C.

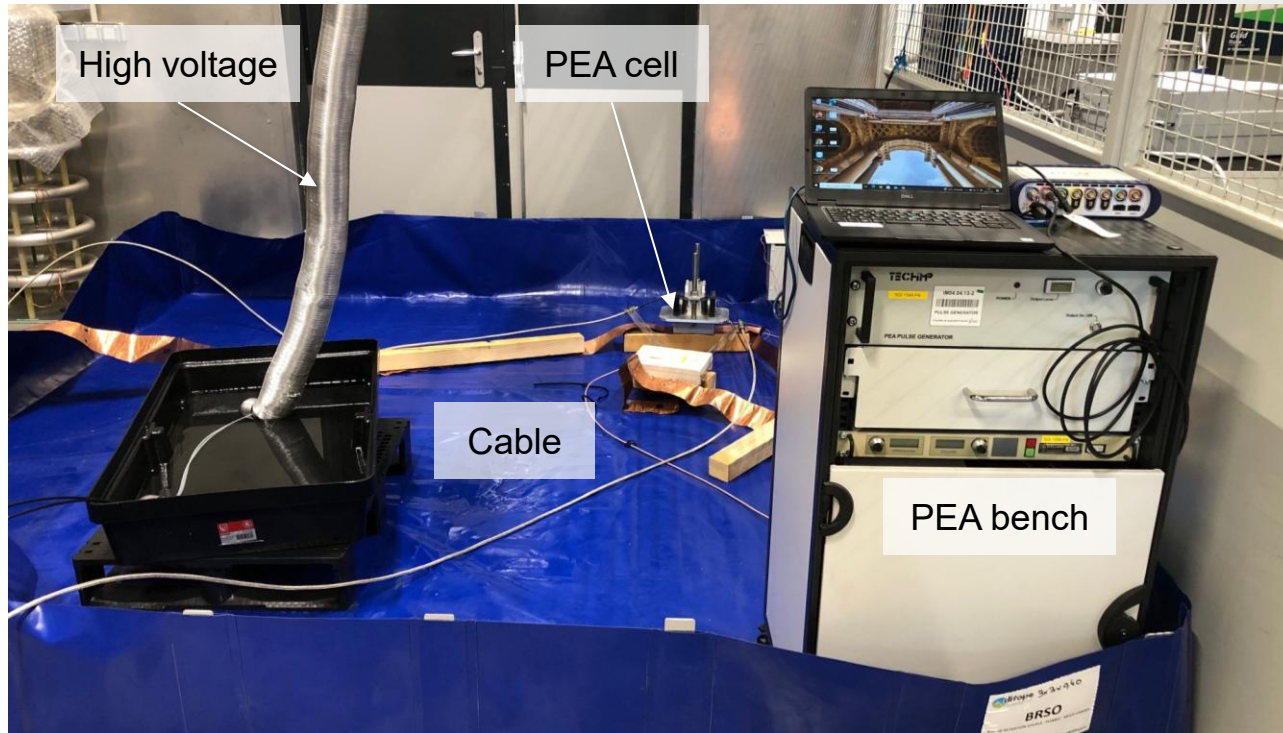
PEA characterization done after ageing and compared to PEA characterization on fresh sample

Task 2.3 - Cable model “A” - Ageing



Same test setup as for conductivity

Task 2.3 - Cable model “A” – Ageing, PEA characterization

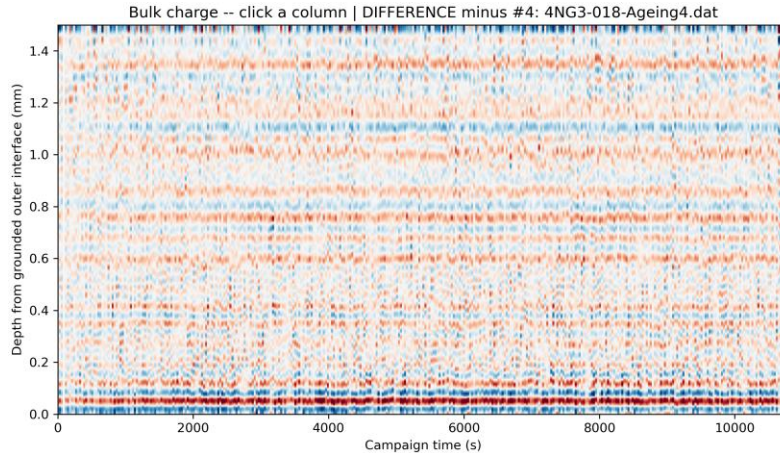


Evolution of space charge evaluated during polarization: $SC(t_x) - SC(t_0)$

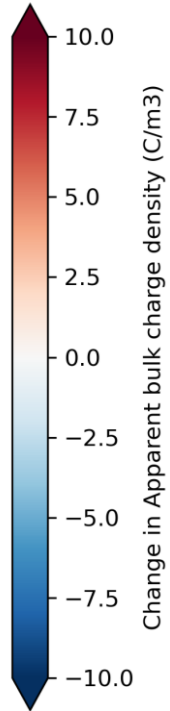
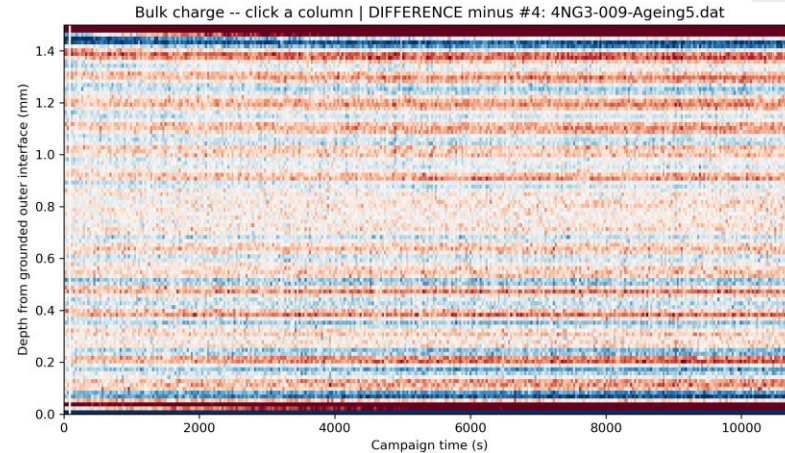
Task 2.3 - Cable model “A” – Ageing, PEA characterization

Fresh sample

PP binary blend



PP binary blend + 1wt-% PP-g-MAH



No noticeable space charge evolution for sample PP binary blend

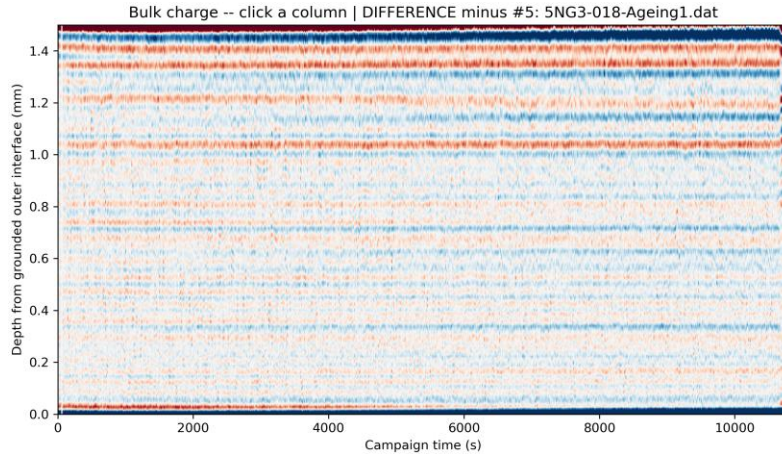
No noticeable space charge evolution for sample with additive

Similar behaviour noticed for samples aged at 30 °C

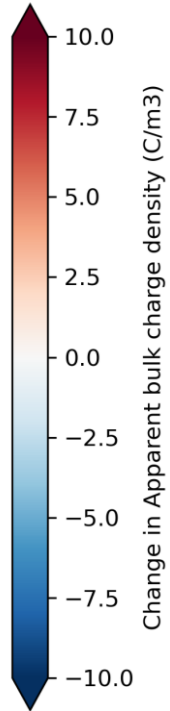
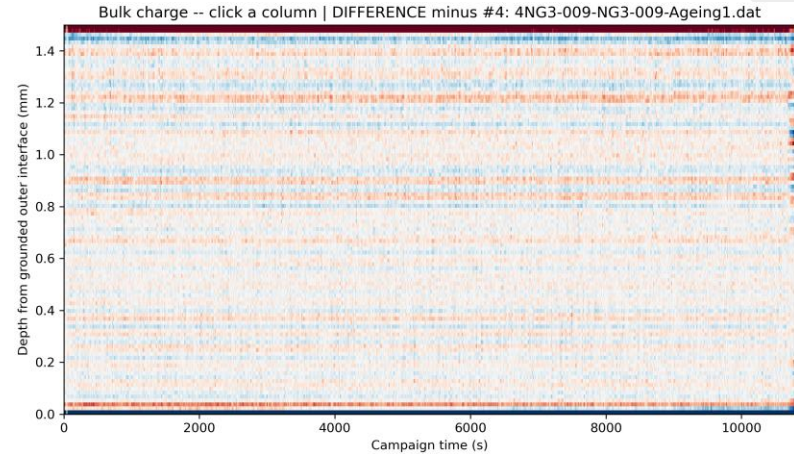
Task 2.3 - Cable model “A” – Ageing, PEA characterization

Sample aged at 90 °C

PP binary blend



PP binary blend + 1wt-% PP-g-MAH



Slight heterocharge increase in PP binary blend at high voltage electrode but trapped charges noticed at t_0 (not shown)

No noticeable space charge evolution for sample with additive, no trapped charges noticed at t_0

1wt-% PP-g-MAH prevent charge trapping when aged at 90 °C



LCA and sustainability

Kirill Maister (GD)

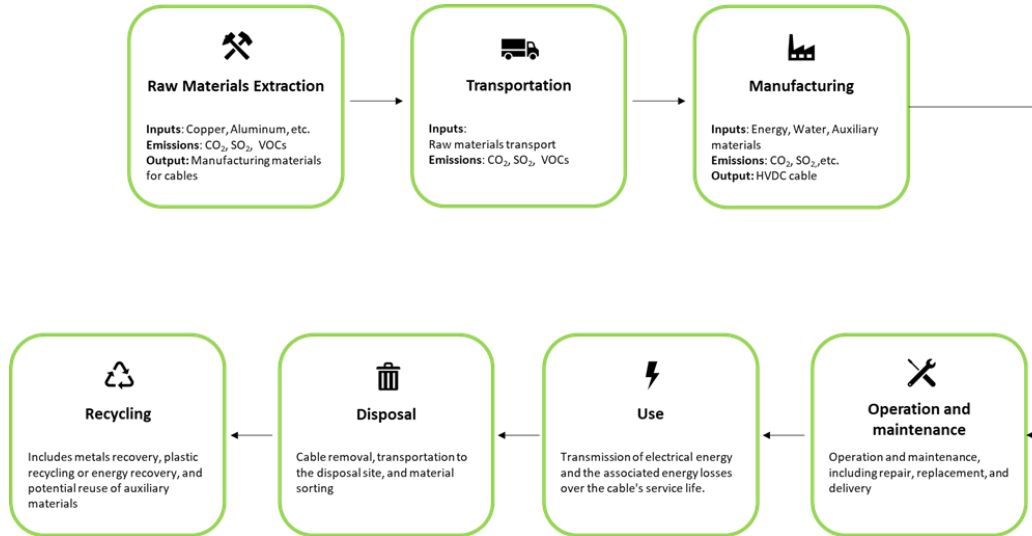
greenDELTA



Environmental LCA, Goal and Scope

- Does NEWGEN outperform the XLPE benchmark environmentally?
- What drives the main environmental and cost differences?
- What are the key economic and social-risk hotspots?

Environmental LCA, Goal and Scope



Environmental LCA, Goal and Scope



FU= 1 MWh of electricity delivered through the HVDC cable system over a reference service life of 25 years.



Environmental LCA, Results

Benchmark XLPE vs NEWGEN PP cable
80% common load (1960 Am 525 kV)

Benchmark

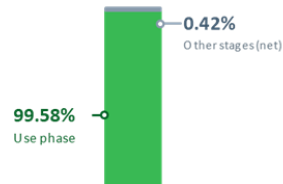
Total climate-change impact

0.01091 kg CO₂e / FU

Use phase

99.58%

0.01086 kg CO₂e / FU



NEWGEN

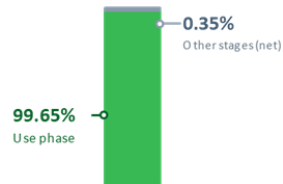
Total climate-change impact

0.01117 kg CO₂e / FU

Use phase

99.65%

0.01113 kg CO₂e / FU



● Use phase ● Other stages (net)

Raw materials

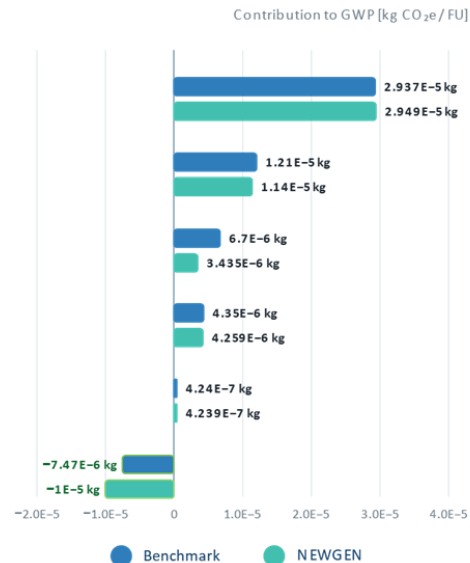
O&M

Manufacturing

Transportation

Installation

EoL recycling



Environmental LCA, results

Benchmark XLPE vs NEWGEN PP cable
80% load cable-specific ampacity (70°C)

Benchmark

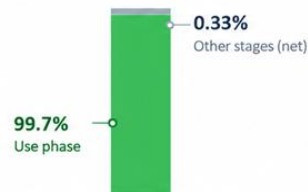
Total climate-change impact

0.01253 kg CO₂e / FU

Use phase

99.7%

0.01249 kg CO₂e / FU



● Use phase

● Other stages (net)

NEWGEN

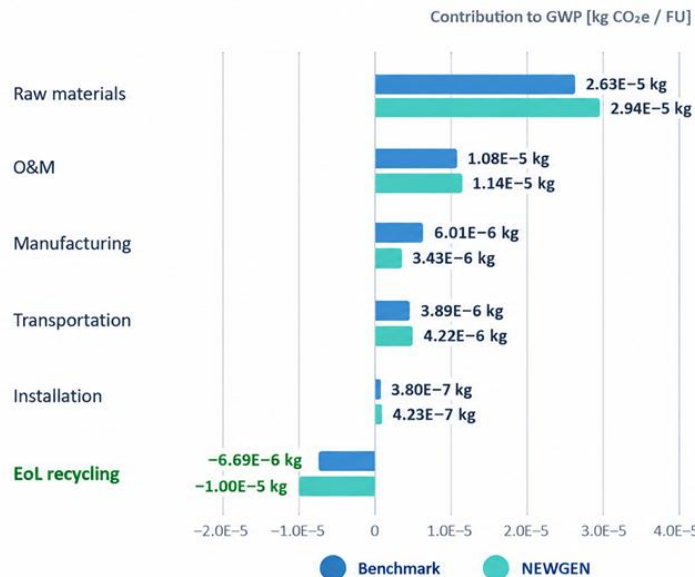
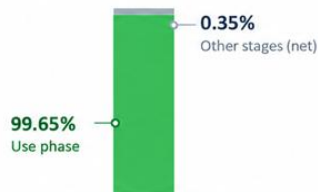
Total climate-change impact

0.01122 kg CO₂e / FU

Use phase

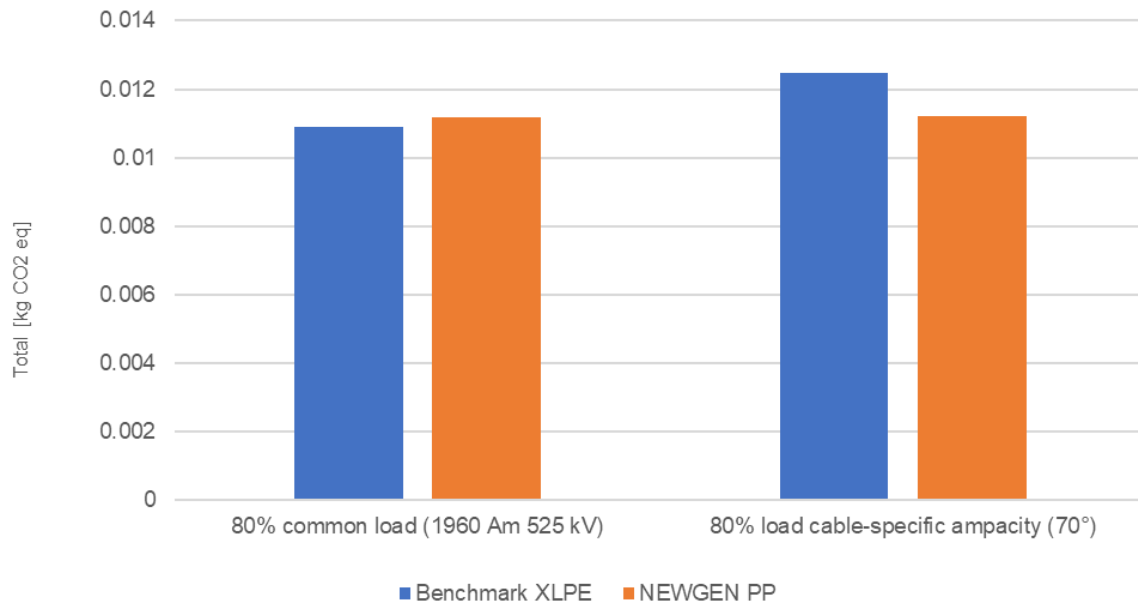
99.65%

0.01119 kg CO₂e / FU

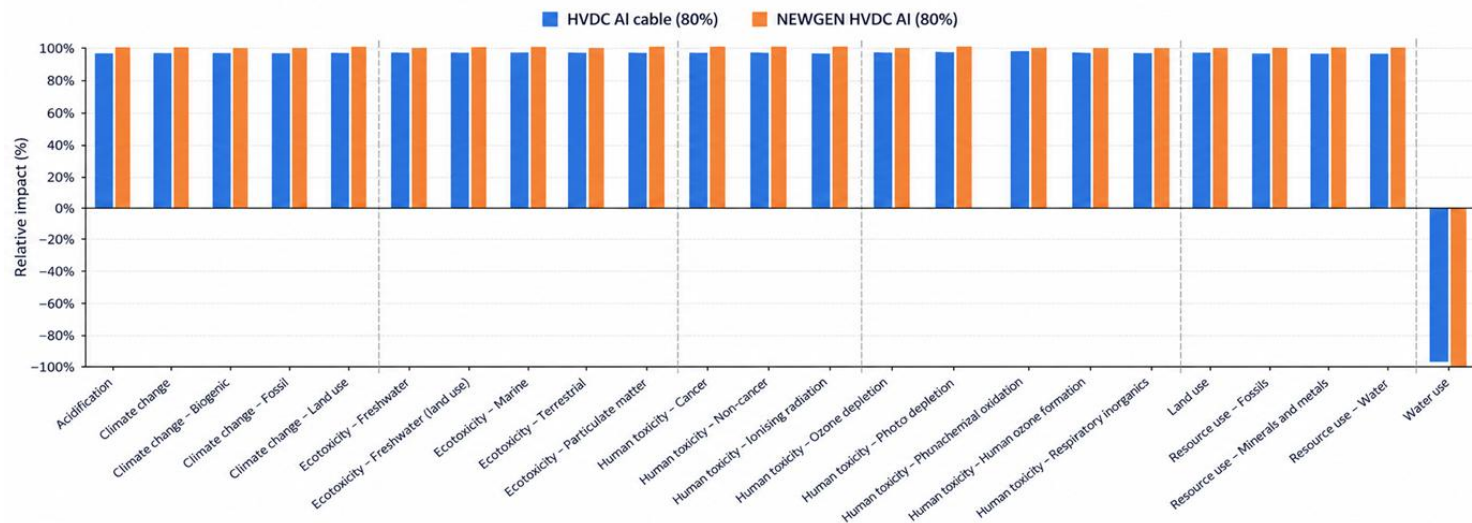


Environmental LCA, Climate Change

Benchmark vs NEWGEN cable • Scenarios



Under the 80% common-load scenario, NEWGEN shows 2.39% higher impacts, while under the cable-specific ampacity scenario it shows 10.5% lower climate-change impacts.



NEWGEN shows slightly higher average environmental impacts than the benchmark (+2.4%).

Baseline cost inventory

Material, production, transport, installation, use-phase, O&M and end-of-life costs.

Time allocation

Upfront costs in Year 0; use-phase and O&M in Years 1–25; end-of-life in Year 25.

Discounting

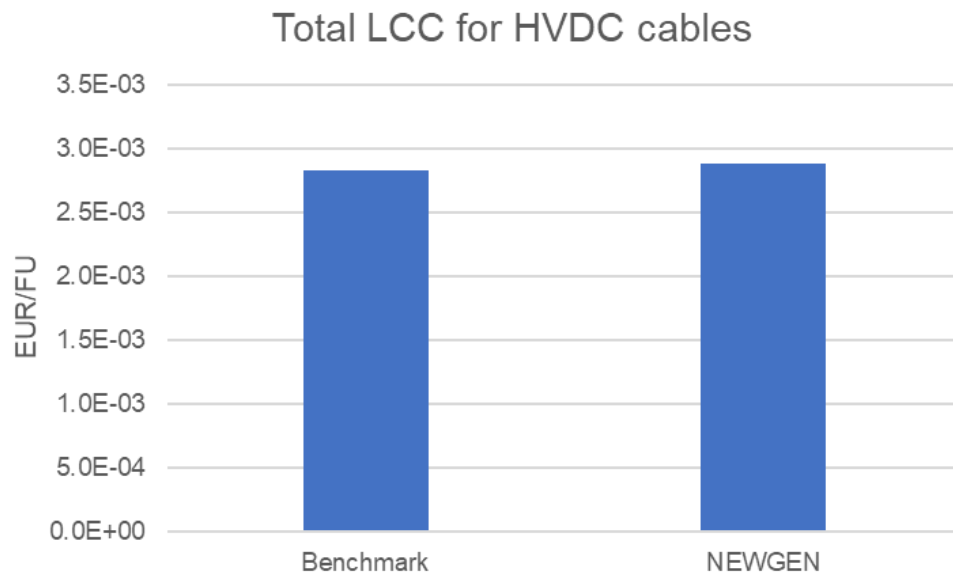
Future costs converted to present value using 2% inflation and a 6% nominal discount rate.

LCC

LCC

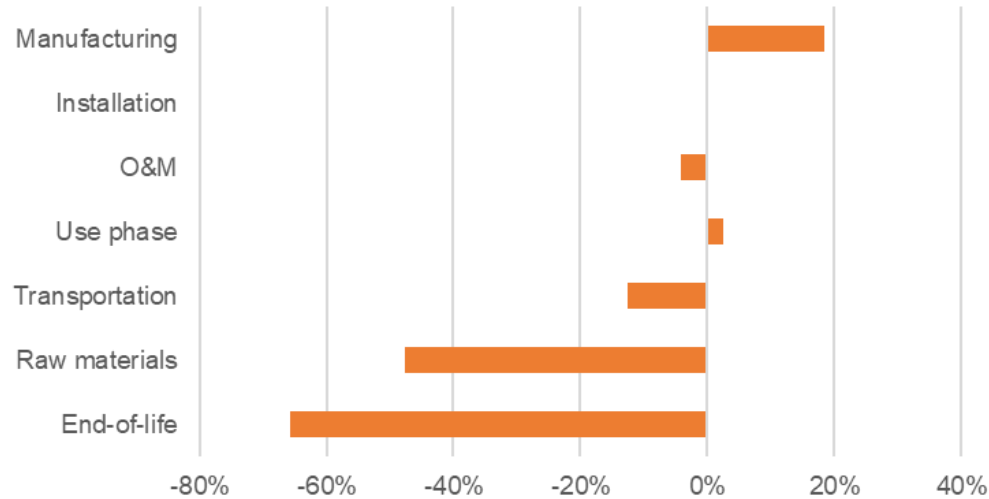
NEWGEN





Total LCC for NEWGEN is about 2.1% higher than for the benchmark.

NEWGEN vs Benchmark



Percentages show the relative difference within each stage, not the contribution to total LCC

LCC, Temporal modelling and discounting

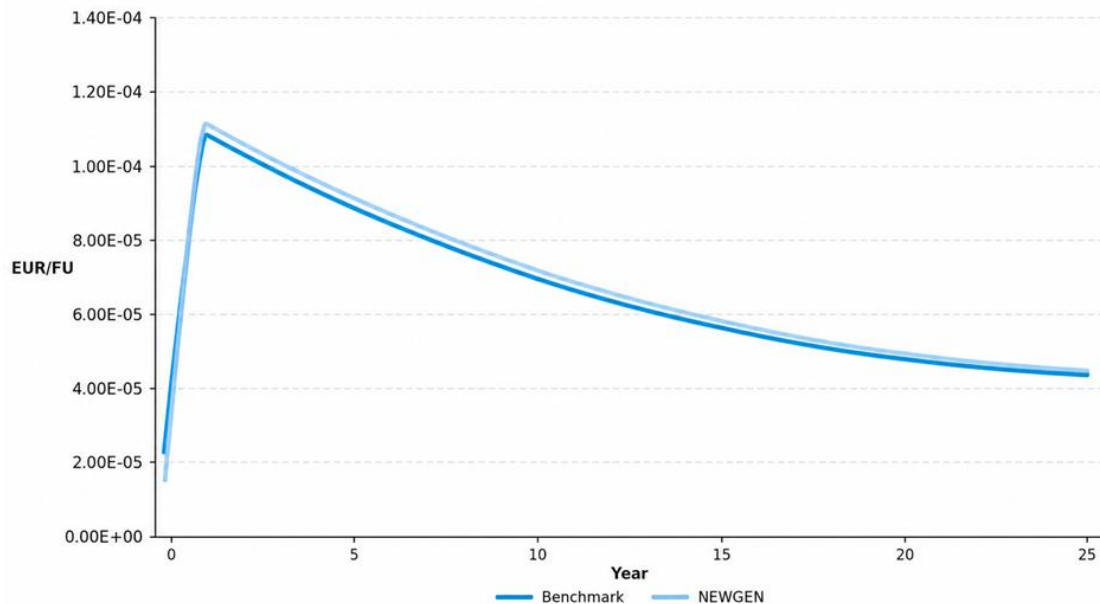
Reference period	25 years
Inflation	2.0%
Nominal discount rate	6.0%
Effective real discount rate	3.92%

$$DF_t = \left(\frac{1 + 0.02}{1 + 0.06} \right)^t$$

t - year in the 25-year reference period.

The same assumptions are applied to both cable systems.

LCC, Temporal modelling and discounting



After the initial Year 0 costs, annual LCC peaks when recurring operating costs start and then gradually declines due to discounting. NEWGEN remains lower throughout the 25-year period

S-LCA

Purpose

Identify potential social-risk hotspots and compare the NEWGEN cable with the benchmark.

Assessment scope

Same functional unit as LCA and LCC: 1 MWh delivered. Major life-cycle stages are included; the use phase is excluded.

Method

Screening-level assessment using the Social Guidelines and PSILCA 4

Workers

Child labour · Forced labour · Fair salary · Health & safety · Freedom of association

Local community

Access to material resources

Value chain actors

Corruption

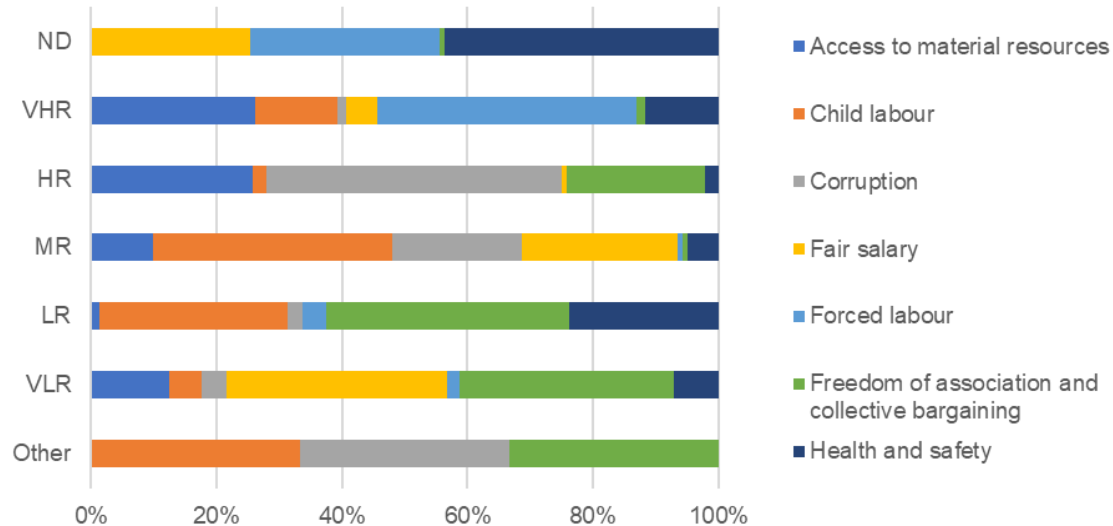
7 indicators selected

Indicators were selected using the UNEP S-LCA Guidelines (2020) and Methodological Sheets (2021), with focus on relevance to the cable supply chain and availability in PSILCA 4.

Foreground components linked to PSILCA country-sector activities through monetary inputs.

Component	PSILCA activity	Geography	Monetary value
Aluminium conductor	Manufacture of basic metals	Norway	EUR
Lead jacketing	Manufacture of basic metals	Sweden	EUR
Steel wire	Manufacture of fabricated metal products	Sweden	EUR

S-LCA, Benchmark and Newgen Social Risks



VLR – very low risk, LR – low risk, MR – medium risk, HR – high risk and VHR – very high risk, ND-No data

S-LCA, Benchmark and Newgen Social Risks

Life-cycle hotspots

- O&M dominates several indicators: 74–77%, such as: Child labour, Forced labour, Health and safety, Corruption.
- Access to material resources: O&M 54%, raw materials 25%, recycling 14%.
- Living wage remains material-driven: raw materials 71%.
- Trade union density is split across raw materials, recycling and O&M.



Key upstream drivers

- Finnish petroleum-sector activity is the main foreground gateway for O&M risks.
- Several high-risk contributions originate further upstream in Russian energy and industrial sectors.

NEWGEN

Q&A Session 2

Moderator: Merie Kannampuzha (CLI)



NEWGEN

Break

14:55-15:05



NEWGEN

Session 3: Novel pre-fault monitoring solutions for HVDC cables and accessories

15:05-15:40



NEWGEN

Detection and acquisition of partial discharges under HVDC and development of global monitoring system

Andrea Caprara (TAG)



Can we predict a HVDC failure before it fails?

Objective:

- From detection of failure to prediction and prevention of failure

How did we do it?

- Through Partial Discharge Analysis under DC stress conditions

Steps for understanding PD behavior in HVDC:

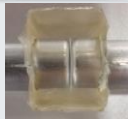
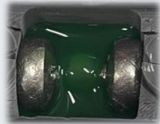
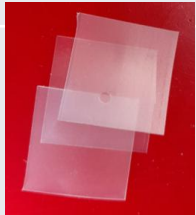
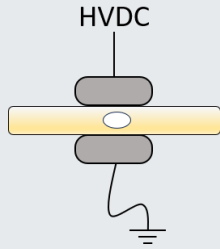
- Investigate adaptation of HVAC PD techniques to HVDC: sensitivity, noise rejection, sensors, bandwidth.
- Manufacturing of representative PD defects
- Validation and characterization of defects under AC voltage
- PD acquisition and measurements under DC voltage
- Analysis of PD behavior in HVDC conditions

Why did we do it?

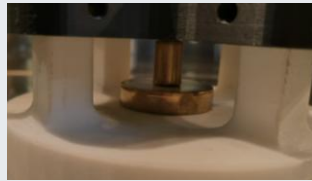
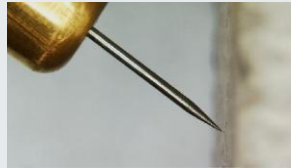
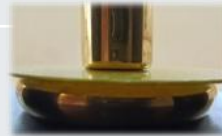
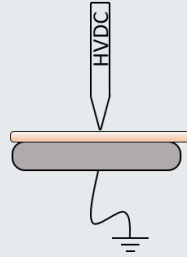
- HVDC assets are critical and difficult to inspect. Predictive maintenance can reduce outages and costs.

Manufacturing of PD defects

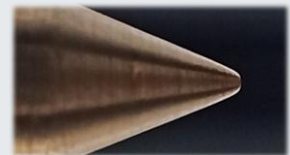
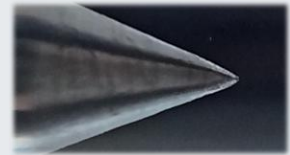
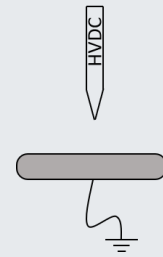
Internal



Surface



Corona



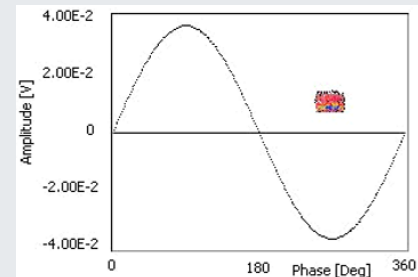
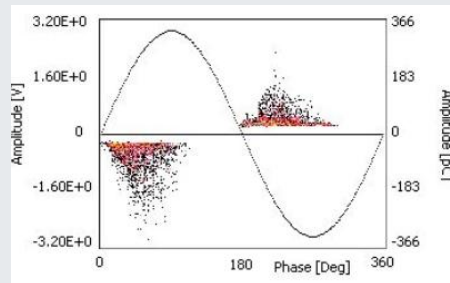
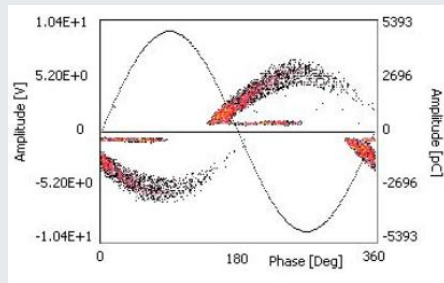
Validation and characterization of defects AC/DC

Internal

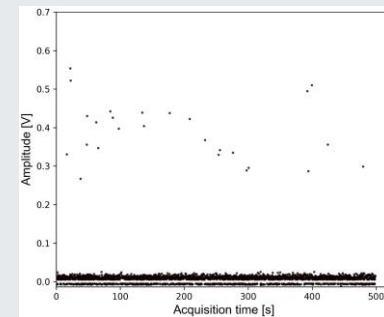
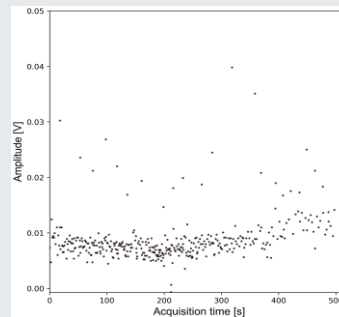
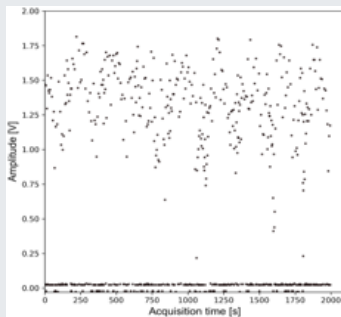
Surface

Corona

AC



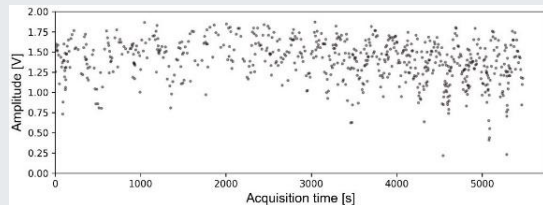
DC



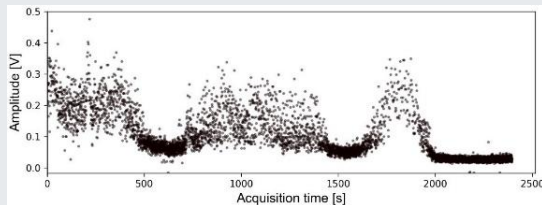
TRPD pattern & TBD pattern in DC

TRPD

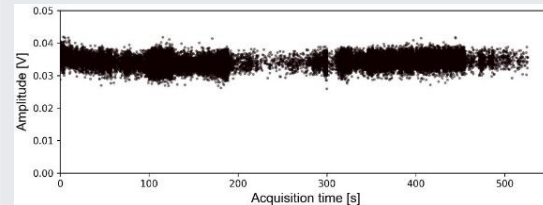
Internal



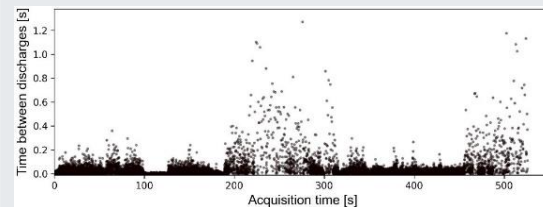
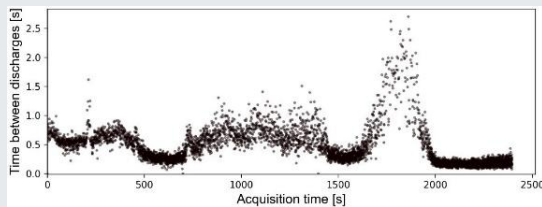
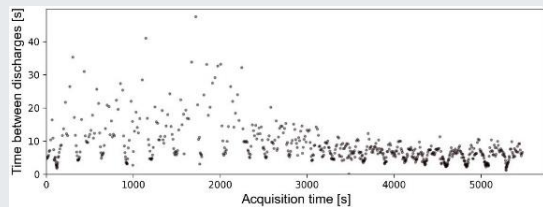
Surface



Corona



TBD



Data analysis under DC stress conditions

Main characteristics for DC PD:

- Method of discharge (Townsend -> streamer) similar to PD in AC;
- No phase correlation;
- Very low repetition rate;
- Correlation with discharge time and amplitude;
- Space charge plays an important role in the electric field distribution;

How did we do it?

- Thousands of PD acquisitions on hundreds of artificially defected specimens;
- Long acquisitions to understand the effect of the charge behaviour for different defects (internal, surface, corona);
- Correlation of the datasets from homogeneous defects;
- Use of Weibull distribution for data analysis.

But:

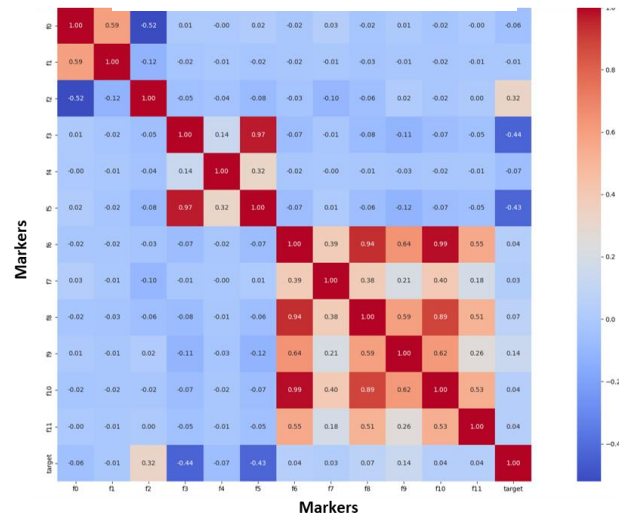
In stress conditions close to the insulation system design electric field, defects rarely incept.

Data analysis under DC stress conditions

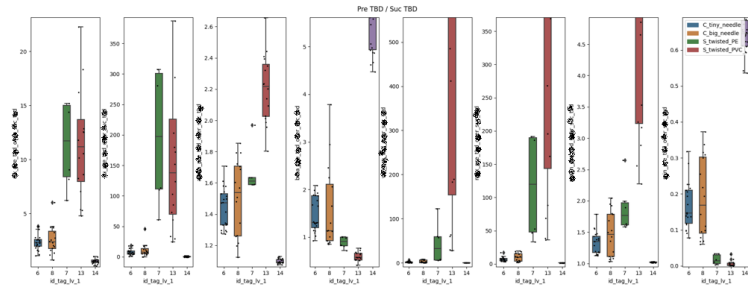
Data analysis tool



Confusion matrix



Parameters extraction



Relation of measurement with the life model

$$\begin{cases} K_{PD} = 0 \text{ if } 0 < N_{PD} < 10 \text{ [n/min]} \\ 0 < K_{PD} < 1 \propto 10 < N_{PD} < 20 \text{ [n/min]} \\ K_{PD} = 1 \text{ if } N_{PD} > 20 \text{ [n/min]} \end{cases}$$

Where:

N_{PD} is the number of discharges acquired per minute at a certain aging time, t_{aging} .

K_{PD} is passed to the life model to confirm or worsen (no improvement is expected) the life indication.

$$L_{PD} = t_{aging} K_{PD} + L_{NO_PD} (1 - K_{PD})$$

Where:

L_{PD} = life of the defected specimen on which PD are recorded during aging

L_{NO_PD} = life provided by the life model for a non-defected specimen where PD are theoretically absent, subjected to the same aging stresses as the monitored defected specimen.

Online condition monitoring

Objective:

- Strengthen the predictive analysis through combined diagnostics.

How did we do it?

- Online Condition Monitoring of multiple parameters:
 - Partial Discharge
 - Leakage current
 - DTS
 - Environmental and operational parameters

Steps for developing the integrated monitoring system:

- Development of the monitoring architecture
- Development of the data visualization platform
- Final monitoring tests on the integrated setup

Why did we do it?

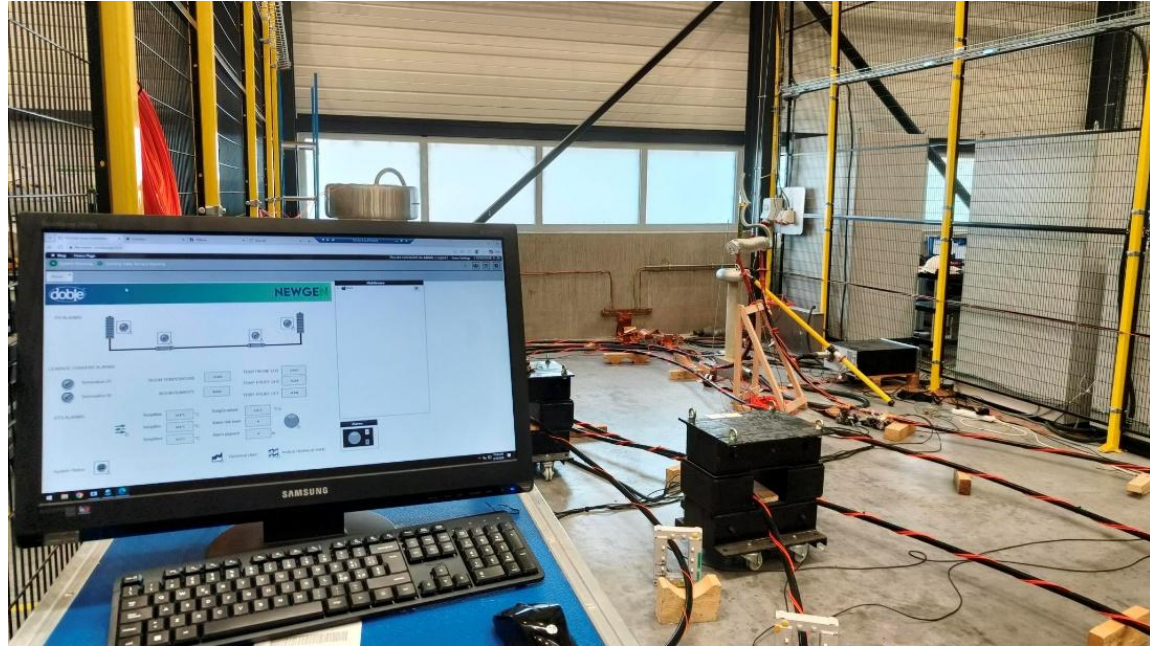
- Different technologies capture different aspects allowing a better correlation of the cause/effect physical behaviour.

Online condition monitoring platform

Development of an integrated monitoring platform for HVDC cable systems.

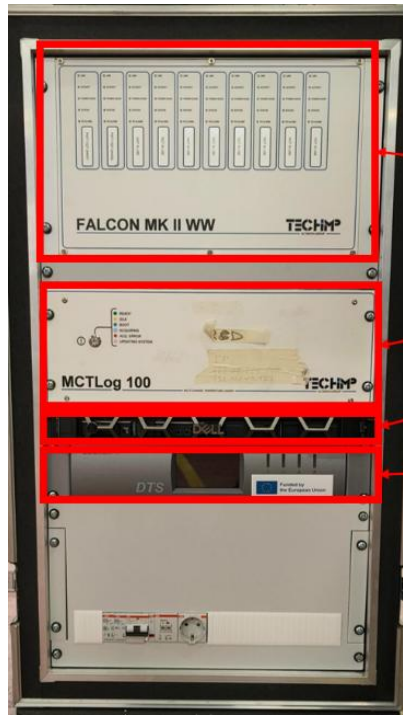
Continuous acquisition of electrical, thermal, and environmental parameters.

Platform designed to support condition monitoring and future predictive maintenance strategies. Strengthen the predictive analysis through combined diagnostics.



Online condition monitoring prototype

Doble system rack



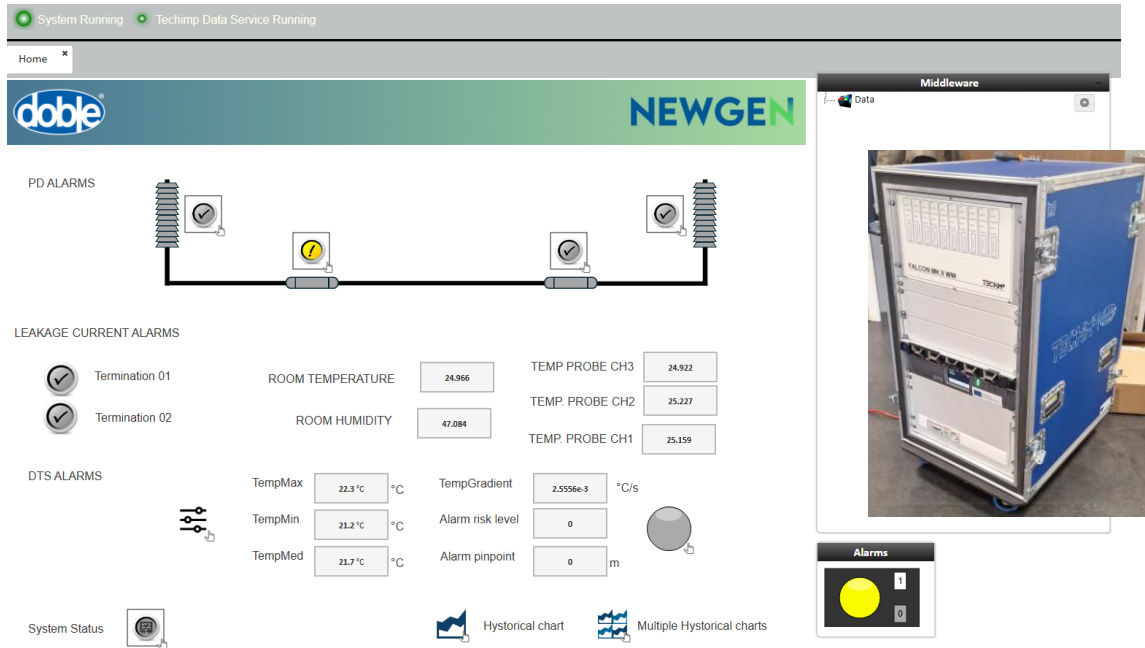
PDNova

MCTLog

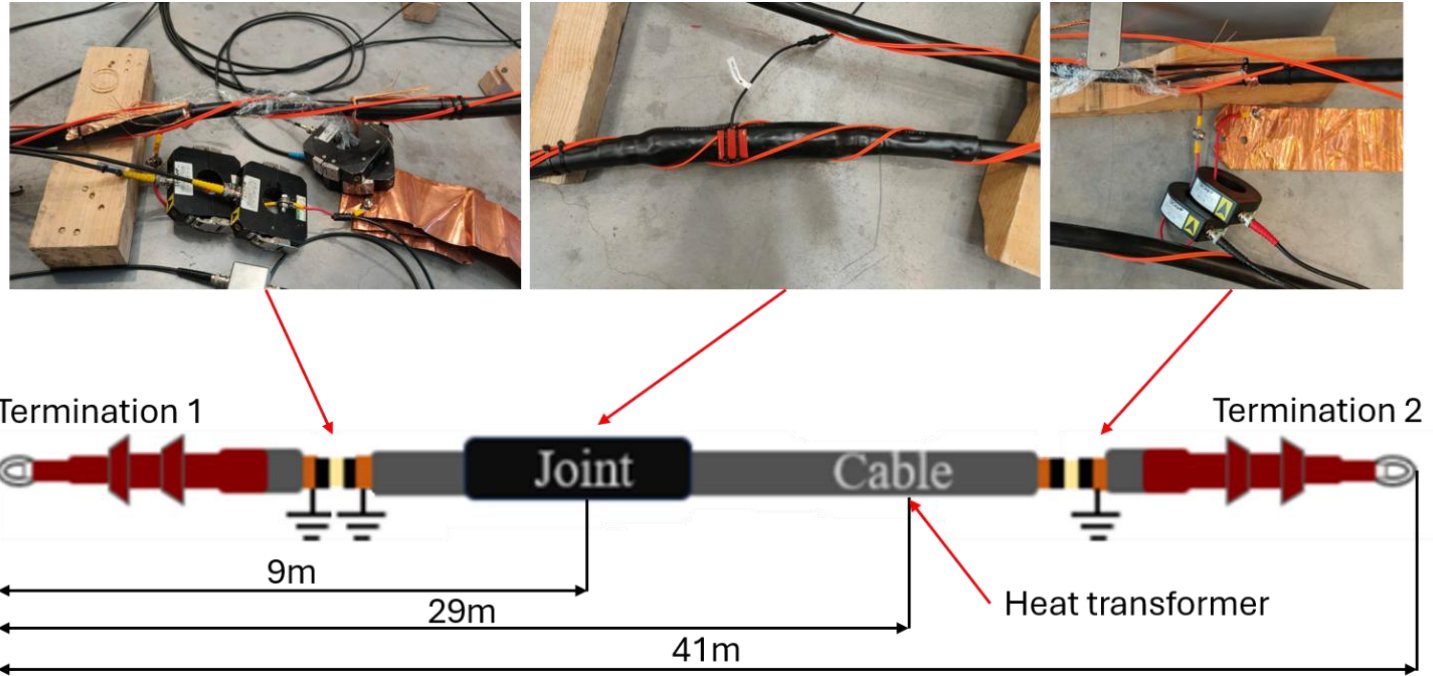
Server

DTS

TiSCADA HMI

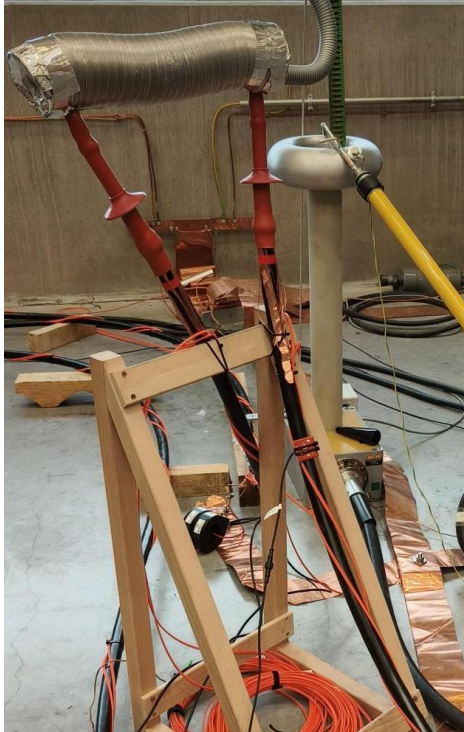


Laboratory testing to TRL 6



Laboratory testing to TRL 6

**PT1000 on cable
termination**



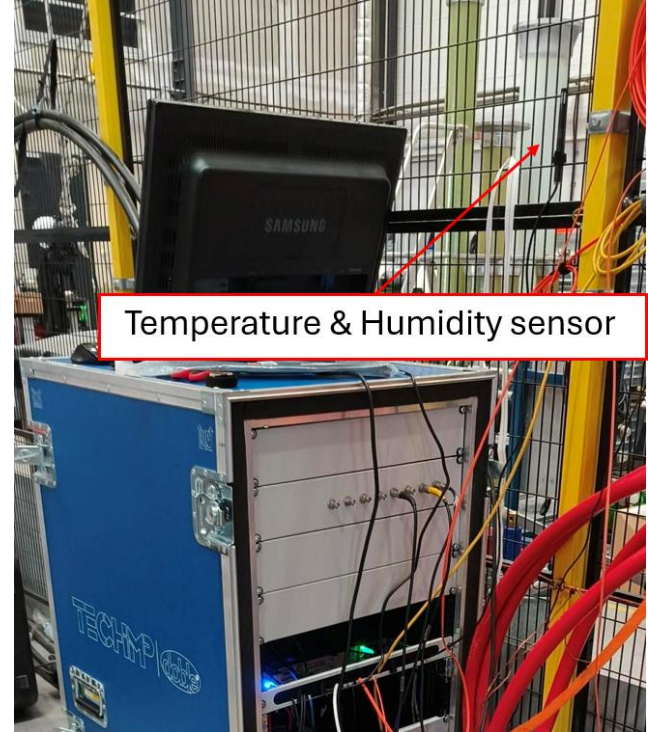
PT1000 on joint



Fiber installed around the cable

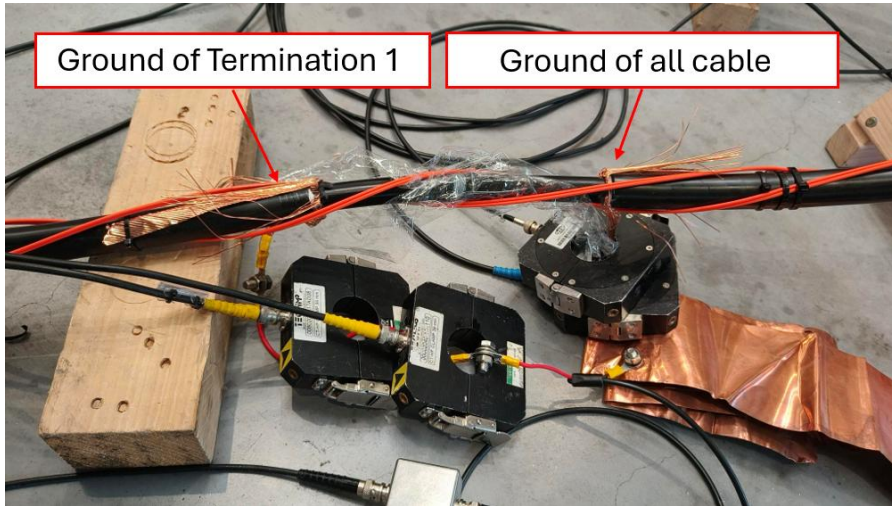


**Temperature and humidity
sensor**



Laboratory testing to TRL 6

First termination and cable ground with HFCT39 connection

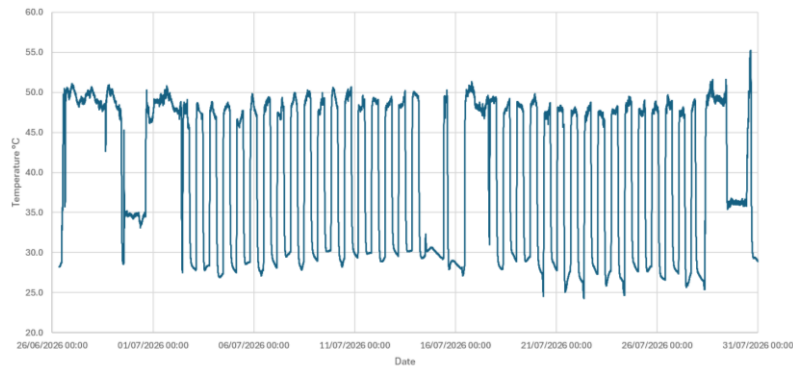


Second termination ground with HFCT50 connection

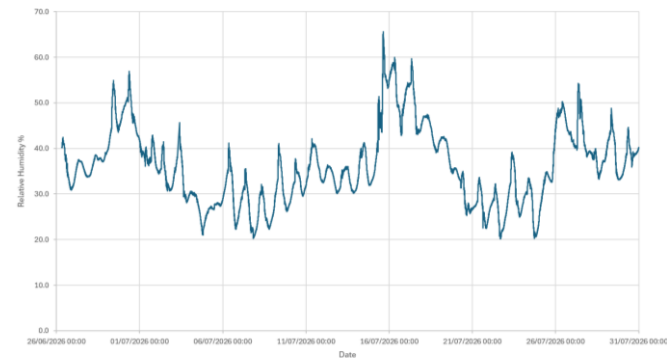


Laboratory testing to TRL 6

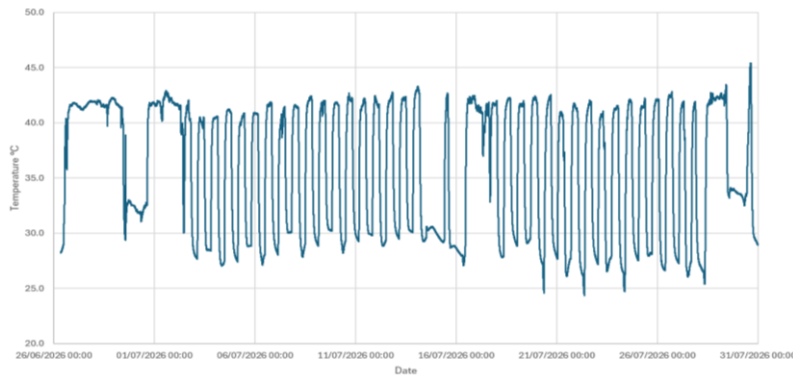
Termination 1 spot temperature



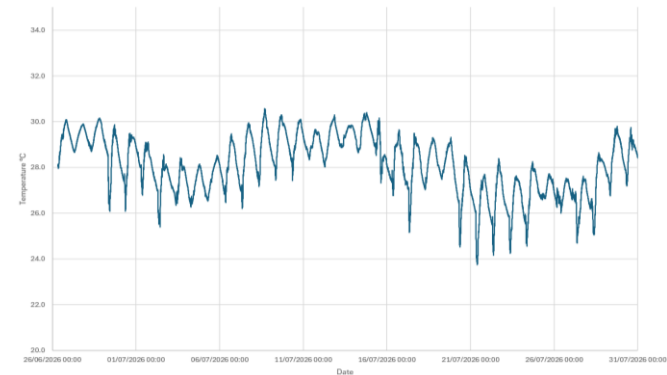
Environment relative humidity



Joint Spot Temperature

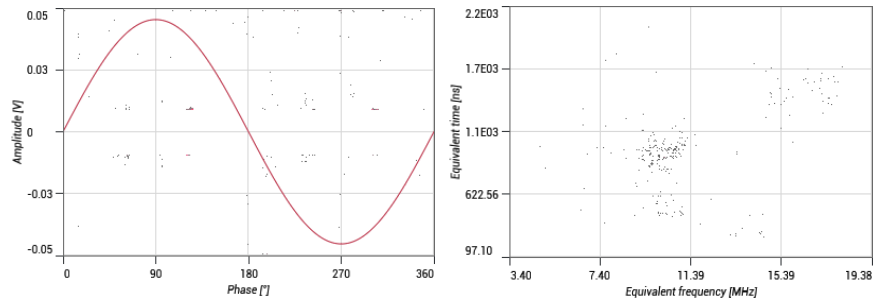


Environment Temperature

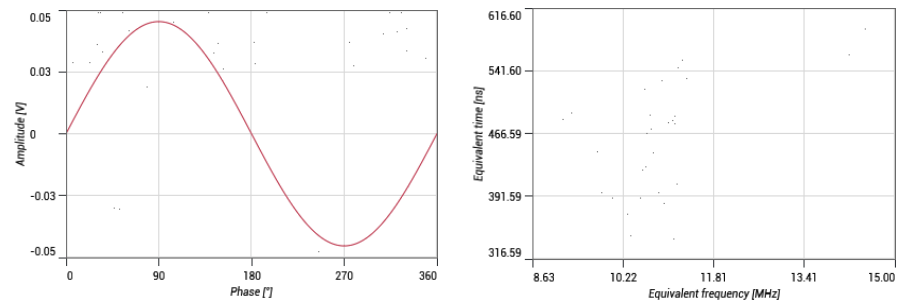


Laboratory testing to TRL 6

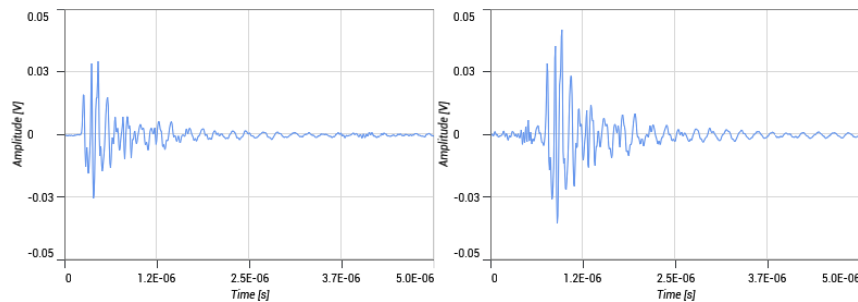
PRPD pattern & TF Map without filter



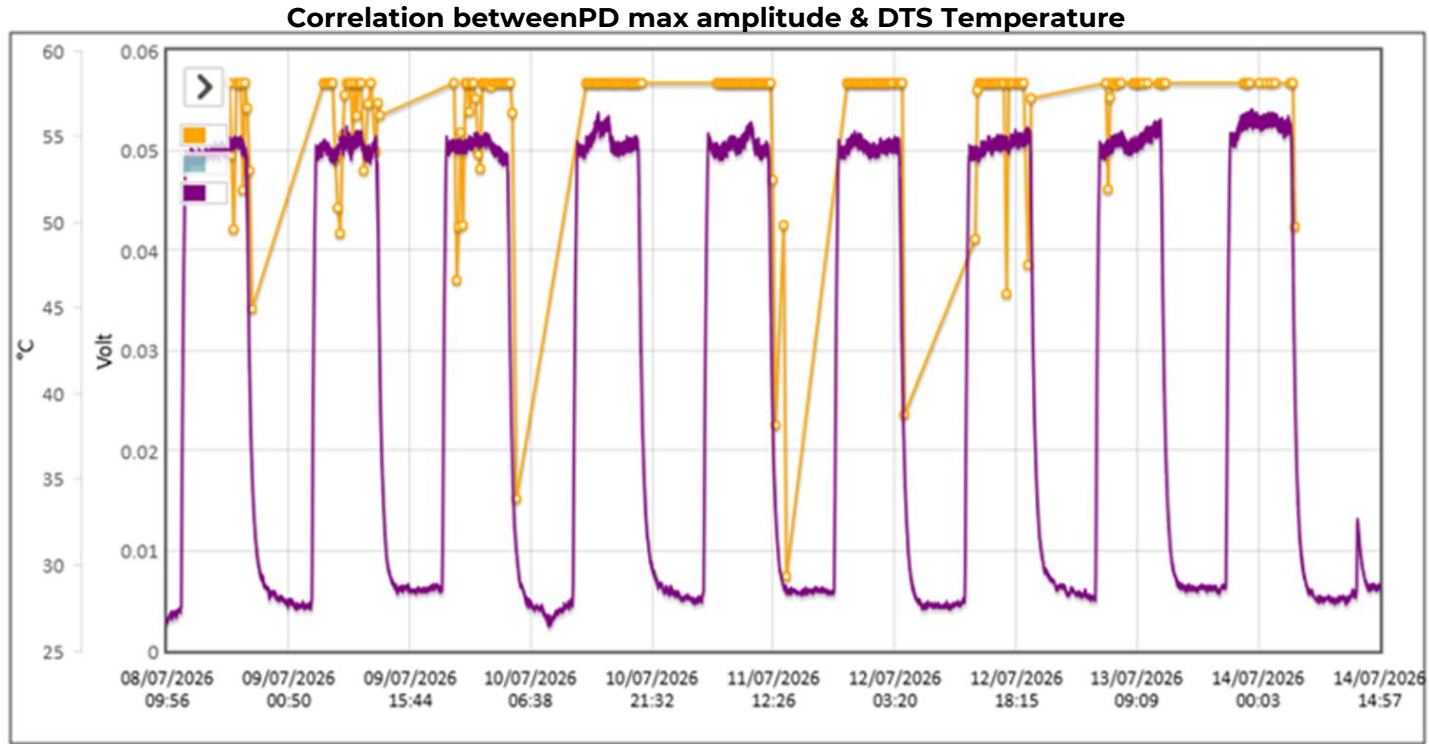
PRPD pattern & TF Map with filter



PD Waveform



Laboratory testing to TRL 6



Main achievements and takeaways

Main objectives achieved during NEWGEN:

- Validated commercial PD devices for the acquisition of signals under DC conditions;
- Correlated the PD measurements to the life model of WP4 through ALTs
- Obtained better understanding of the physics behind PD and the relation with the electric field and space charge;
- Extended the measurements to online condition monitoring of various parameters affecting the diagnostics
- Validated the online condition monitoring device prototype in lab conditions;
- Demonstrated the correlation of different parameters (leakage currents, temperature, voltage) with the PD defects;

Takeaways from NEWGEN:

- Online condition monitoring can be effective on relatively short cables (<10 km) with the current architecture;
- A huge expertise gathered in the acquisition, configuration and analysis of PD signals under DC conditions;

Activities beyond NEWGEN:

- Testing, testing, testing!!!
- Characterization of the various insulating materials
- Describe the strong dependency of the PD inception with the space charge (PD signals create space charge!);
- Find ways to extend the coverage for offshore cables >10 km.

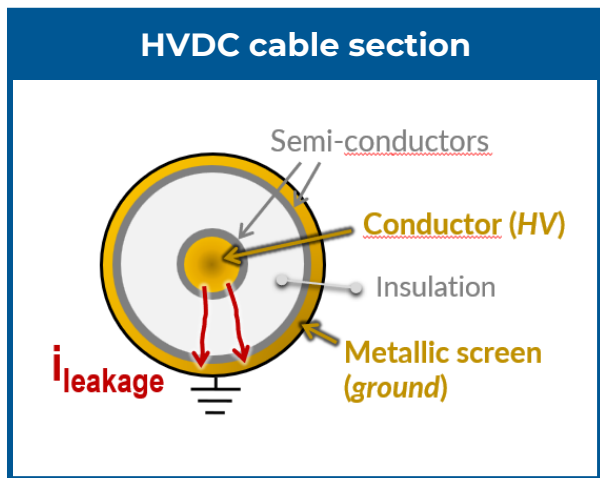


Novel optical method for leakage current monitoring of cable systems

Anais Leproux (SGI)



Leakage current: a metrics for electrical insulation state of HVDC cable systems



L. Boyer, 2022, "Current measurements on HVDC XLPE model cable during type test", Proceedings IEEE 4th ICD

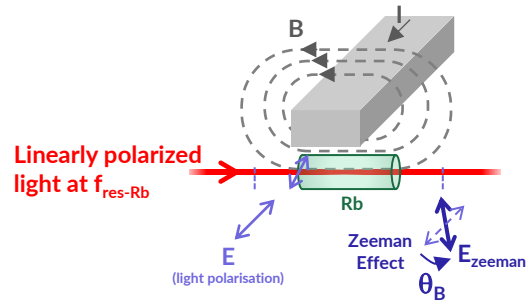
Leakage current + cable temperature
⇒ **Operational state of HVDC cable**

→ **Development of a leakage current sensor**

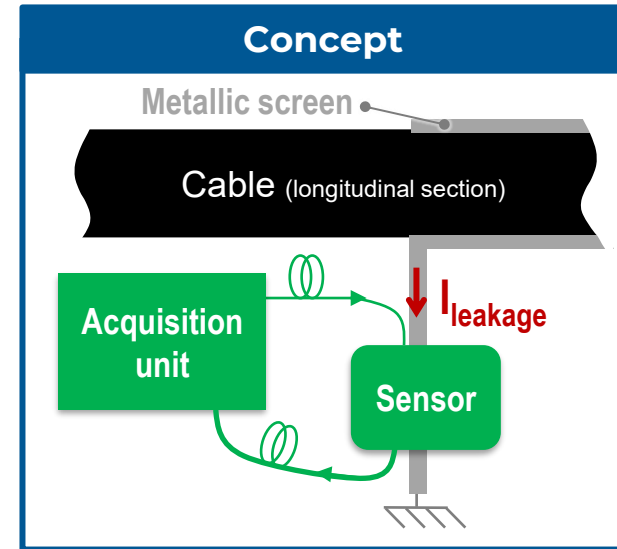
→ Magneto-optical based technique

Specs	The Zeeman Effect
✓ Non-intrusive	
✓ Immune to high current transient	
✓ Low power consumption	
✓ High sensitivity (1 mA near DC)	

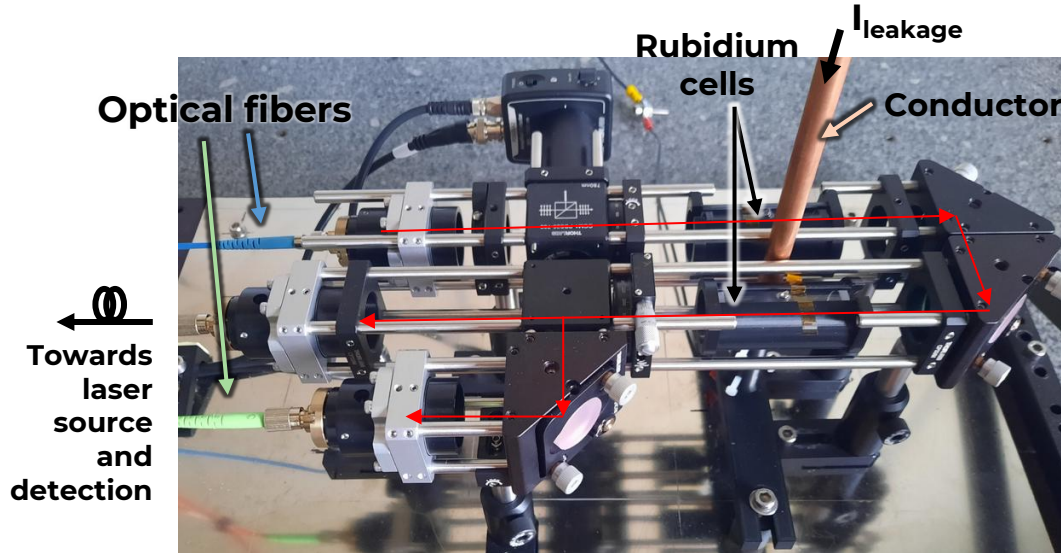
Zeeman Effect - For high sensitivity contact-free non-intrusive current measurements



- I Conductor current (conductor=metallic sheath grounding)
- B Magnetic field induced by conductor current
- Rb Rubidium cell
- E_B Electric field vector (induced by B) $\equiv$ light polarisation
- θ_B Birefringent rotation of polarisation vector due to Zeeman Effect



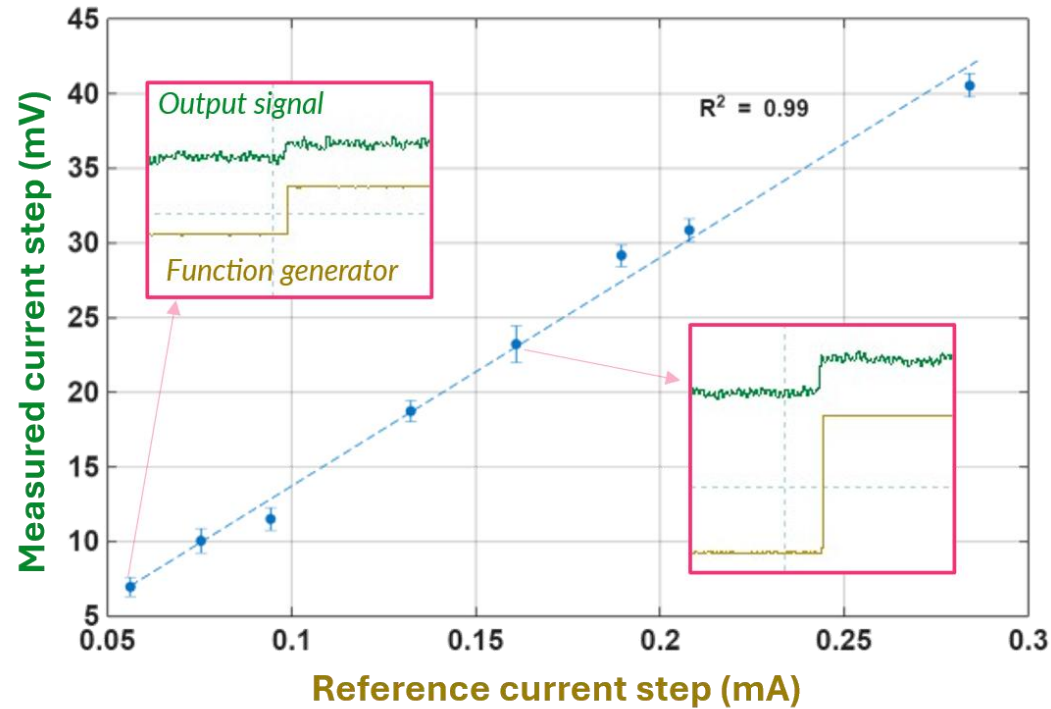
Laboratory prototype



Technical aspects investigated:

- **Laser** light source frequency lock
- **Light polarization** stability
- Geometrical **alignment**
- **Optical path design**
- **Rb cells** design
- **Fiber** coupling
- **Detection** photodiodes
- **Noise** characterization
- **Temperature** dependance
- etc

Main results



→ Sensitivity of 0.05 mA

Main achievements and takeaways

▪ **Main objectives achieved during NEWGEN**

- Proof of concept of an optical technique based on the Zeeman Effect to measure 1 mA current was validated
- A working prototype was developed
- Alignment and calibration procedures were established

▪ **Takeaways from NEWGEN**

- Numerous technical barriers were overcome during the project
- Further technical development is needed for operational use

▪ **Activities beyond NEWGEN**

- Testing, testing, testing!!!
- Patterns of leakage current behaviour during in-lab measurements should be established
- Comprehensive studies to interpretate the leakage current amplitude and dynamics will be conducted with various cable materials

NEWGEN

Q&A Session 3

Moderator: Merie Kannampuzha (CLI)



NEWGEN

Session 4: Tools and models for reliable and resilient HVDC cable systems

15:40-16:10



NEWGEN

Session 4: Tools and models for reliable and resilient HVDC cable systems (30 min)

15:40-15:55	Life and reliability model of the HVDC cable, accessories and of the whole HVDC cable system	Giovanni Mazzanti (UBO)	15 min
15:55-16:05	Effects and resilience to faults of the HVDC cable connection in the AC network	Rolando Ezequiel Diaz (UBO) Sayantani Maiti (UBO)	10 min
16:05-16:10	Q&A	Moderator, all	5 min





Life and reliability model of the HVDC cable, accessories and of the whole HVDC cable system

Giovanni Mazzanti (UBO)



ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA



WP4 – Results on Task 4.1

➤ Task 4.1: Development and validation of a dedicated algorithm for life and reliability modelling of HVDC cables

➤ Task 4.1.1: algorithm **development** (UBO)

$L(E, T) = L_0(E/E_0)^{-(n_0 - b_{ET}T')} \exp(-BT')$ **IPM-Arrhenius** life model: **E, T** const.

$L(E, T) = L_H(T)(E/E_H)^{-n_H(T)}$ **T-dependent IPM**: validation, ALTs at various T

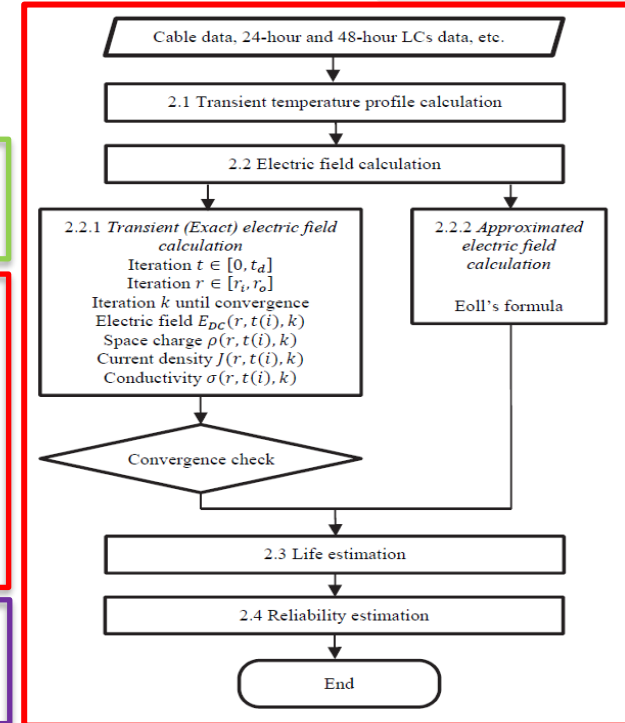
$L_{cycle}^* = \min\{L_{cycle}(r), r \in [r_i, r_o]\}$ Life with **load cycles at most stressed point**

$L_{cycle}(r) = t_{cycle} \times K_{cycle}(r)$ Life with **load cycles within insulation**

$K_{cycle}(r) = 1/LF_{cycle}(r)$ Number of **cycles to failure**

$LF_{cycle}(r) = \int_0^{t_{cycle}} \frac{dt}{L[E(r, t), T(r, t)]}$ Loss-of-life-fraction in 1 **load current cycle**

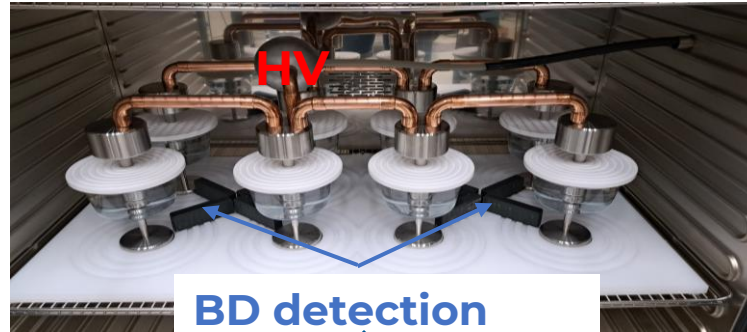
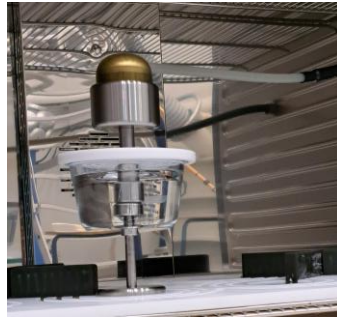
$\Delta LF_{Trans}(r) = \int_{\Delta t_{Trans}} \frac{dt}{L[E(r, t), T(r, t)]}$ Loss-of-life-fraction in 1 **voltage transient** (e.g. **TOV**)



WP4 – Results on Task 4.1

➤ Task 4.1.2: algorithm validation

- via **ALTs** at **TAU** on **NEWGEN PP-ternary & binary blend flat specimens** (2 IEEE TDEI papers)
 - test chambers (ovens) → 4 different temperatures can be tested at the same time
 - 8 sample cells can be placed in one oven → 8 parallel specimens tested in 1 oven
 - 3 power supplies → 3 different fields tested at same time



One test chamber where 8 parallel specimens are placed: 1 sample in one glass bowl →

- Additional ALTs at **SGI**: flat specimens, model A cables



WP4 – Results on Task 4.1

➤ Task 4.1.2: algorithm validation

- Processing of ALTs at UBO: Weibull statistics with censoring (2 IEEE TDEI papers)
- High values of test fields and life exponent: excellent voltage endurance of NEWGEN PP

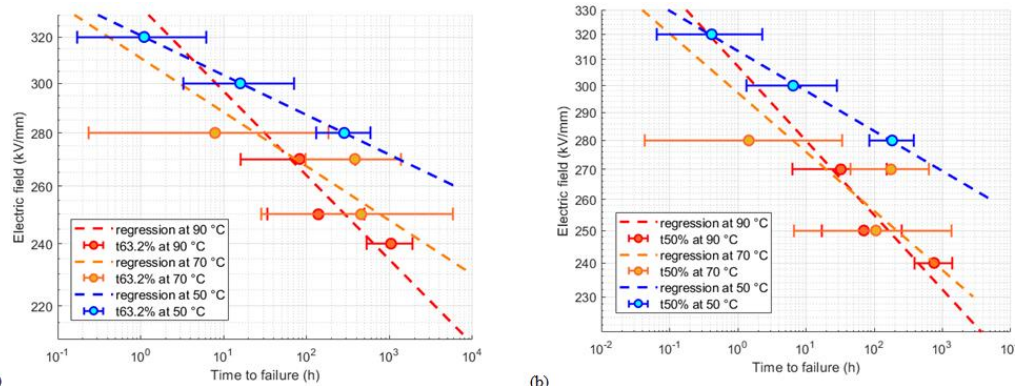


Fig. 2. ALT plot in $\log(E)$ - $\log(t_p)$ scale of: (a) $t_{63.2\%}$ at 90°C, 70°C, 50°C with 90% confidence bounds of ALT points and IPM LSR fitting of $y=\log(t_p)$ vs. $x=\log(E)$; (b) same as previous for $t_{50\%}$. Binary blend with additive

Table V

LIFE EXPONENT n AND CORRELATION COEFFICIENT $|R|$ FROM IPM FITTING OF $\alpha=t_{63.2\%}$ AND MEDIAN LIFETIME= $t_{50\%}$ FROM ALTs ON BINARY BLEND WITH SPACE CHARGE SUPPRESSING ADDITIVE AT 90, 70, 50°C. SINGLE CENSORING BY MEASURED QUANTITY (CMQ).

T (°C)	n ($t_{63.2\%}$)	n ($t_{50\%}$)	$ R $ ($t_{63.2\%}$)	$ R $ ($t_{50\%}$)
90	19.63	24.58	0.876	0.896
70	30.57	30.94	0.771	0.679
50	41.59	45.67	≈ 1.000	0.999

WP4 – Results on Task 4.2

- **Task 4.2: Development and validation of a dedicated algorithm for life and reliability modelling of HVDC cable systems**
- **Algorithm development at UBO** (series reliability + enlargement law)

cable life with time-varying E,T
(cycles, V-trans.)

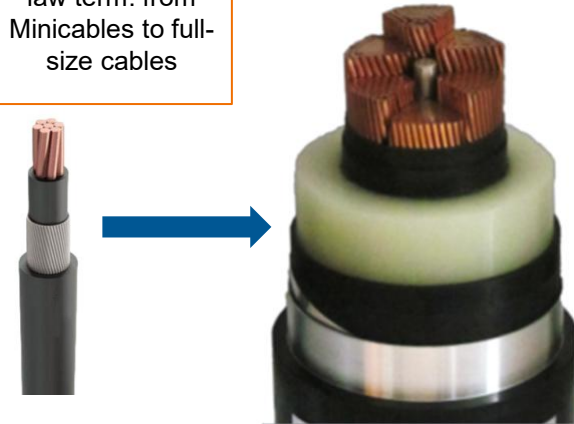
joint life with time-varying E,T
(cycles, V-trans.)

termination life with time-varying E,T
(cycles, V-trans.)

Enlargement law term: from Minicables to full-size cables

Time-varying E, T

$$\begin{aligned}
 \ln(R_{sys,cycle}) &= \ln(1 - P_{sys,cycle}) \approx \\
 &\approx - \left[\frac{t_{F,cycle}}{L_{cycle,D} / [-\ln(1 - P_D)]^{1/\beta_t}} \right]^{\beta_t} \left[\frac{GH(\Delta T_{mean})}{k_{P,E}} \right]^{n\beta_t} + \\
 &+ N_{joi} \left\{ - \left[\frac{t_{F,cycle,joi}}{L_{cycle,D,joi} / [-\ln(1 - P_{D,joi})]^{1/\beta_{t,joi}}} \right]^{\beta_{t,joi}} \right\} + \\
 &+ N_{ter} \left\{ - \left[\frac{t_{F,cycle,ter}}{L_{cycle,D,ter} / [-\ln(1 - P_{D,ter})]^{1/\beta_{t,ter}}} \right]^{\beta_{t,ter}} \right\}
 \end{aligned}$$



WP4 – Results on Task 4.2 (UBO)

➤ Task 4.2: Development and validation of a dedicated algorithm for life and reliability modelling of HVDC cable systems

• Algorithm **validation**

- via ALTs on bi-layer XLPE-EPDM flat specimens at TAU
→ processing at UBO: Weibull statistics with censoring (ICD 2026 paper)
- via ALTs on bi-layer PP-EPDM flat specimens at 70°C at TAU

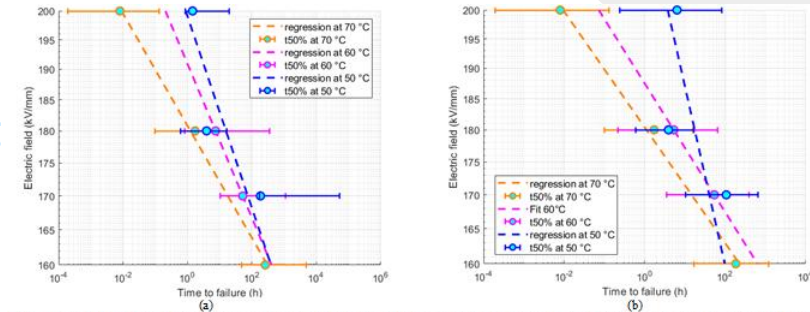


Fig. 1 Accelerated life test plot in log-log scale of $t_{50\%}$ at 70°C, 60°C and 50°C with 90% confidence bounds and a linear regression, obtained with: (a) the SRC scheme; (b) the CMQ scheme.

Schematic structure:

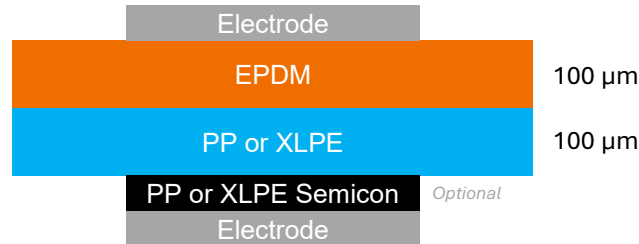


TABLE III

T (°C)	LIFE EXPONENTS WITH CORRELATION COEFFICIENT R FOR α AND $t_{50\%}$ CALCULATED AT 70°C, 60°C AND 50°C WITH BOTH THE SRC AND THE CMQ CENSORING SCHEMES							
	SRC				CMQ			
	n	R	n	R	n	R	n	R
	(α)	(α)	$(t_{50\%})$	$(t_{50\%})$	(α)	(α)	$(t_{50\%})$	$(t_{50\%})$
70	44.6	0.9992	46.8	0.9985	42.6	0.9977	45.2	0.9971
60	22.3	1.0000	34.0	1.0000	31.4	1.0000	40.7	1.0000
50	29.9	0.8771	27.3	0.8791	11.4	0.5230	14.6	0.6748

Summary

Demonstrated in NEWGEN

Life (L) & reliability (R) model of HVDC cable, accessories & whole cable system has been **developed, validated** and is **able to tackle** (see **Deliverables 4.1, 4.2, 4.3** for details):

- ✓ **constant voltage and temperature** (= **design** values of E and T stress)
- ✓ cable current **Load Cycles** (LCs) at constant DC voltage (= periodical cycles of E and T) - focus on **qualification** LCs after **Cigré TB 852:2021**
- ✓ **voltage transients** (VTs) - focus on long Temporary Overvoltages (TOVs) and 0-crossing Damped TOVs
- ✓ **local space charge** (SC) distributions due to charge injection/extraction/transport (= **BCT model**)
- ✓ **optimized life-based geometric HVDC cable design** considering electrical and thermal transients
- ✓ **reliability of whole HVDC cable system** (joints, terminations, cables with insulation enlargement)

Outlook

Outlook beyond NEWGEN

- More ALTs on flat specimens at lower electric fields, e.g. < 200 kV/mm
- More ALTs on flat specimens at different temperatures, e.g. 60°C
- More extensive tests on bi-layer specimens
- Improving the compatibility of PP vs. EPDM coupled layers

Published papers on **Life and reliability model**

- 1) B. Diban, G. Mazzanti, L. Boyer, J. Castellon, "Macroscopic conductivity models fit for HVDC cable insulation", Jicable'23, paper C5-5, Lione (Francia), 18-22 June 2023
- 2) G. Pierotti, A. Popoli, F. Ragazzi, B. Diban, A. Cristofolini, G. Mazzanti, "FEVER - Fem Electrothermal solVER: application to an HVDC joint", 2023 IEEE International Conference on Environment and Electrical Engineering and 2023 IEEE Industrial and Commercial Power Systems Europe (IEEE IC/ICPS Europe), pp. 1-6, Madrid, Spain, 6-9 June 2023
- 3) G. Mazzanti, "Updated review of the life and reliability models for HVDC cables", IEEE Trans. Dielectr. Electr. Insul., Vol. 30, No: 4, pp. 1371-1390, August 2023
- 4) B. Diban, G. Mazzanti, P. Seri, "The effect of superimposed switching impulses on space charge accumulation in XLPE-insulated HVDC cables", atti della IEEE Conference on Electrical Insulation and Dielectric Phenomena (IEEE CEIDP 2023), pp. 654-657, East Rutherford, New Jersey, USA, 14-19 October 2023
- 5) B. Diban, R.E. Diaz, G. Mazzanti, P. Seri, I. Rytöluoto, K. Lahti, M. Niittymäki, A. Perez, A. Leproux, "ALT Data Fitting for PolyPropylene-based HVDC Cable Insulation Developed in the HEU-NEWGEN Project", Proceedings of IEEE Conference on Electrical Insulation and Dielectric Phenomena (IEEE CEIDP 2025), pp. 105-108, Manchester, UK, 13-18 September 2025
- 6) B. Diban, G. Mazzanti, "Life estimation of HVDC cable insulation under load cycles: from macroscopic to microscopic charge conduction modelling", IEEE Trans. Dielectr. Electr. Insul., Volume 33, Issue 3, pp. 2284 – 2293, June 2026
- 7) B. Diban, R.E. Diaz, G. Mazzanti, P. Seri, I. Rytöluoto, K. Lahti, M. Niittymäki, "Characterization of Bi-Layer XLPE/EPDM and PP-blend/EPDM Insulations for HVDC Cable Accessories", Proc. International Conference on Dielectrics (ICD 2026), Southampton, UK, 21-25 Jun. 2026
- 8) B. Diban, R.E. Diaz, G. Mazzanti, P. Seri, I. Rytöluoto, K. Lahti, M. Niittymäki, "Accelerated Life Test Fitting of Bi-Layer Insulations for HVDC Cable Accessories", Proc. International Conference on Dielectrics (ICD 2026), Southampton, UK, 21-25 Jun. 2026
- 9) G. Mazzanti, "Recent Developments in Electro-Thermal Life Modelling of HVDC Cables, 2026 Thomas W. Dakin Distinguished Technical Contributions Award Keynote Lecture, Proc. International Conference on Dielectrics (ICD 2026), Southampton, UK, 21-25 Jun. 2026
- 10) G. Mazzanti, B. Diban, R. E. Diaz, P. Seri, I. Rytöluoto, K. Lahti, M. Niittymäki, A. Perez, A. Leproux, "The influence of space charges on the life exponent derived from accelerated life tests on PP-based HVDC cable insulation. Part 1: ternary blends", IEEE Trans. Dielectr. Electr. Insul., 2026
- 11) G. Mazzanti, B. Diban, R. E. Diaz, P. Seri, I. Rytöluoto, K. Lahti, M. Niittymäki, A. Perez, A. Leproux, A. Bernardi, "The influence of space charges on the life exponent derived from accelerated life tests on PP-based HVDC cable insulation. Part 2: binary blends and final comparison with ternary blends," IEEE Trans. Dielectr. Electr. Insul., 2026



Effects and resilience to faults of the HVDC cable connection in the AC network

Rolando Ezequiel Diaz & Sayantani Maiti (UBO)



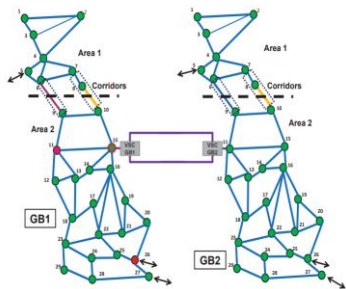
ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA



WP4 – Results on Task 4.3 (1) Literature survey

Task 4.3: **Effects** and resilience to faults of the HVDC cable link in the AC network (TRI, contribution **UBO**)

➤ Literature proves DC cable firewall properties



GB1 and GB2 connected through a VSC HVDC link.

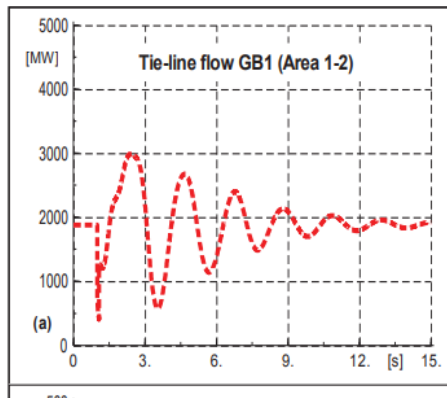


Fig.2.1.a

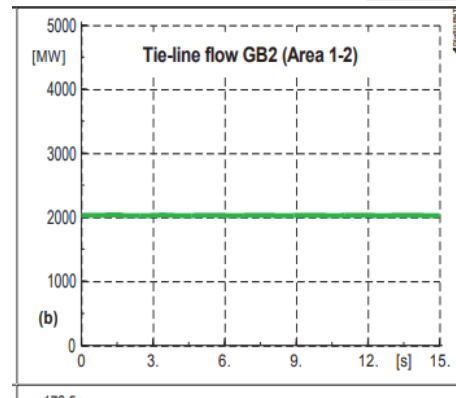


Fig. 2.1.b

- Response of two equivalent AC grids (GB1 and GB2) connected through a VSC-HVDC link under a 3-ph fault applied in GB1.
- Fig. 2.1 highlights the decoupling effect by the VSC-HVDC link: the 3-ph fault causes significant power oscillations in GB1 (Fig. 2.1.a).
- The **flow in GB2 (Fig. 2.1.b) remains ≈constant** ⇒ disturbances are confined within affected AC area.

Adapted from Spallarossa et al., IET ACDC 2012.

WP4 – Results on Task 4.3 (1) Literature survey

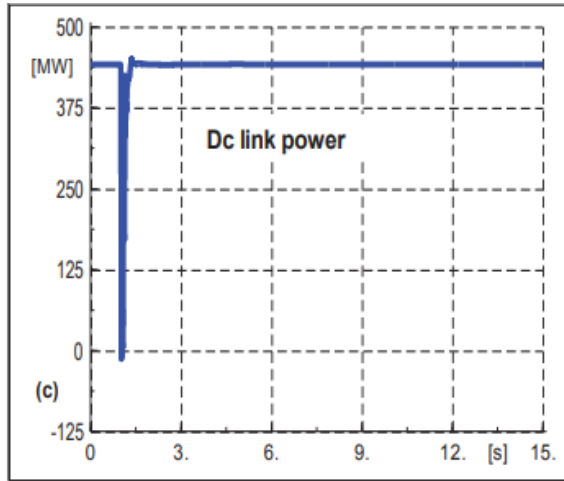


Fig. 2.1.c

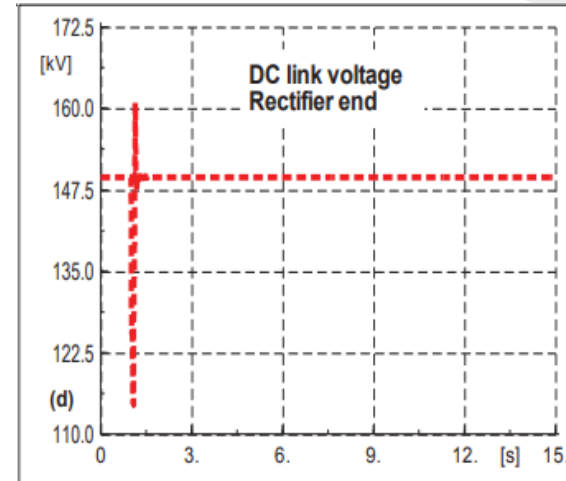


Fig. 2.1.d

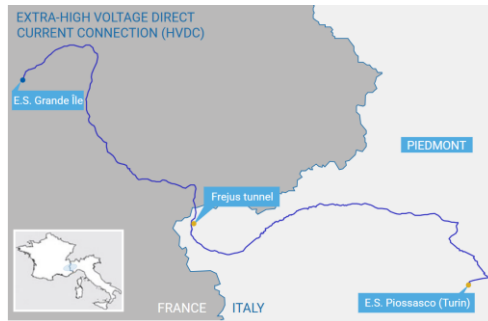
- Limited variations of DC-link power and voltage (Fig. 2.1.c, 2.1.d) $\Rightarrow$ converter maintains stable operation and controlled power transfer during network contingencies

Task 4.3 (1) TRI simulations - Background

- A 2030 reference network scenario and grid configuration
- Estimated system demand of approximately **37 GW**
- Objective is to **enhance both the robustness** and the transfer capability of the Italian transmission system while facilitating the **integration of increasing renewable generation** capacity.

Simulations were performed on two links based on the projected 2030 grid scenario :

- HVDC Italy – France Link
- The HVDC Adriatic Link in Italy (referred to as *HVDC Centro Sud / Centro Nord*), consisting of a 1,000 MW Voltage Source Converter (VSC)-based HVDC connection between the Villanova and Fano substations.



Task 4.3 (1) TRI simulations - Effects

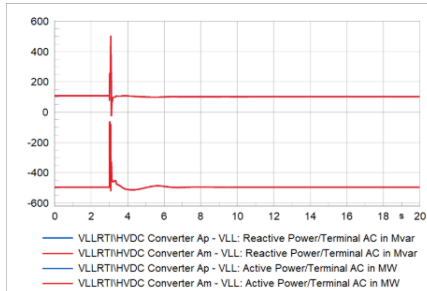


Fig. 2.5.a

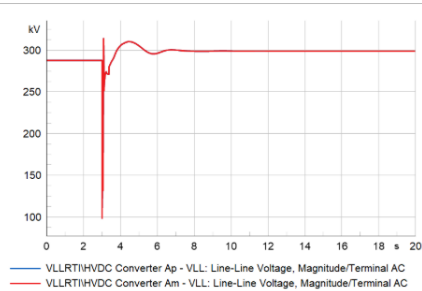


Fig. 2.5.b

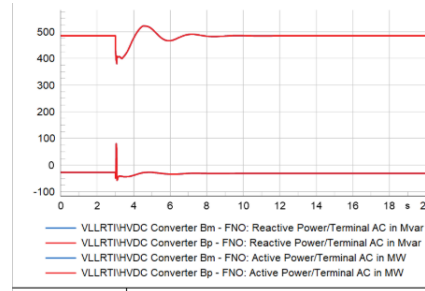


Fig. 2.5.c

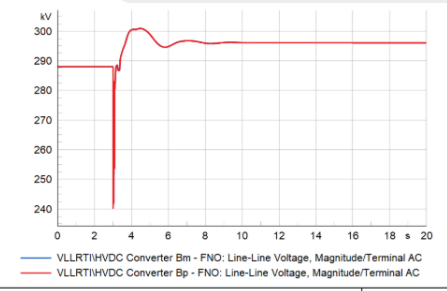


Fig. 2.5.d

Simulated AC parameters (Active Power, Reactive Power, and Voltage) on the positive (Ap, Bp) and negative (Am, Bm) poles of the HVDC Ita-Fra link (Italian Side FRI, French Side GRA) in case of a fault on the EHVAC double circuit Rondissone-Albertville line.

- Severe AC fault on the VLL terminal side causes strong power (Fig. 2.5.a) and voltage (Fig. 2.5.b) transient: converter transformer voltage drops abruptly to 100 kV at t=3 seconds, undergoing a post-fault voltage overshoot up to 310 kV around t = 4.5 s before settling (Fig.2.5.b). Despite this, the DC link utilizes VSC technology to successfully ride through the fault without tripping or triggering a total black-out: see FNO terminal (Fig. 2.5.c,2.5.d)

Task 4.3 (1) TRI simulations - Effects

- Fig 2.5.a - Severe AC fault on the VLL terminal side causes strong power
- Fig. 2.5.b - Voltage transient - converter transformer voltage drops abruptly to 100 kV at $t=3$ seconds, undergoing a post-fault voltage overshoot up to 310 kV around $t = 4.5$ s before settling.
- the DC link utilizes VSC technology to successfully ride through the fault without tripping or triggering a total black-out: see FNO terminal (Fig. 2.5.c,2.5.d)

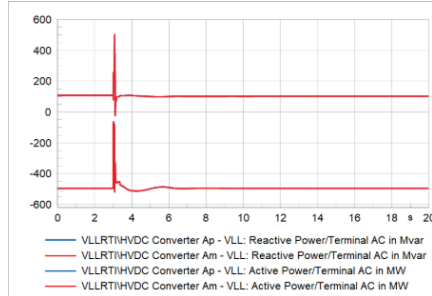


Fig. 2.5.a

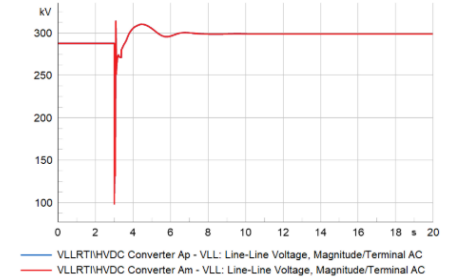


Fig. 2.5.b

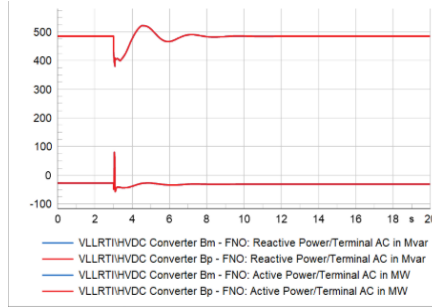


Fig. 2.5.c

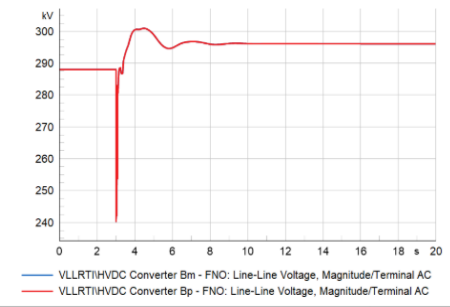


Fig. 2.5.d

WP4 – Results on Task 4.3 (2)

Task 4.3: Effects and **resilience to faults** of the HVDC cable link in the AC network

- Simulations at UBO with algorithm for **loss-of-life-fraction (LF)** estimation under **voltage transients** → LF negligible →

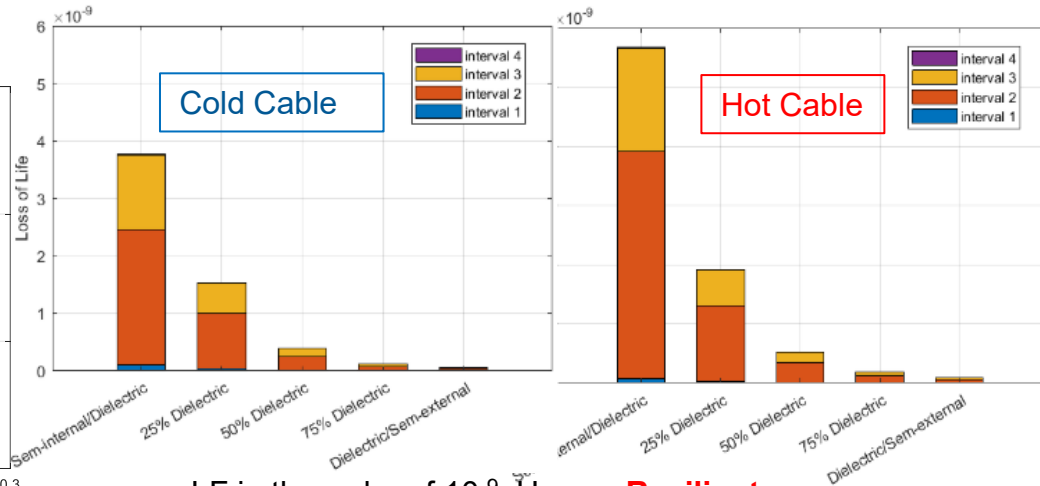
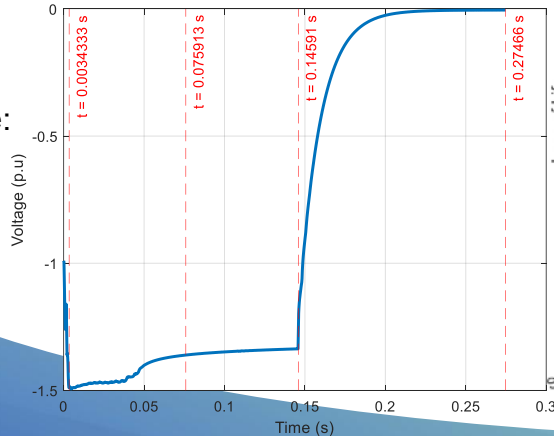
Loss-of-life-fraction in 1 voltage transient
(e.g. TOV)

$$\Delta LF_{Trans}(r) = \int_{\Delta t_{Trans}} \frac{dt}{L[E(r, t), T(r, t)]}$$

Cable resilience proved for various CASE STUDIES:

1) DC – TOV in TERNA's HVDC
Cable Link

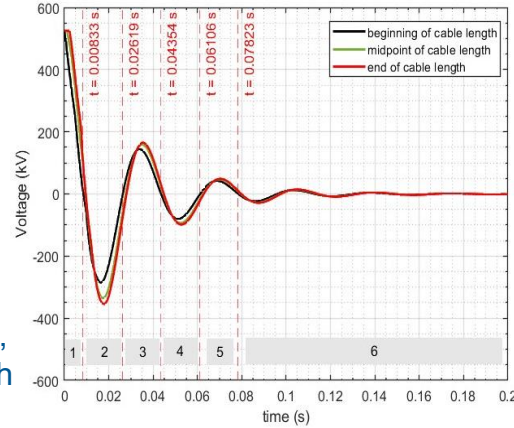
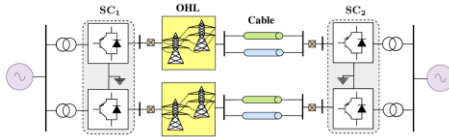
525 kV-DC PP cable:



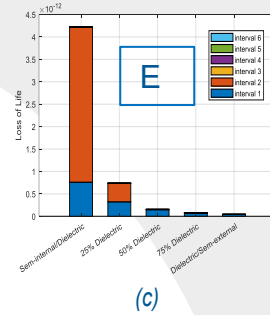
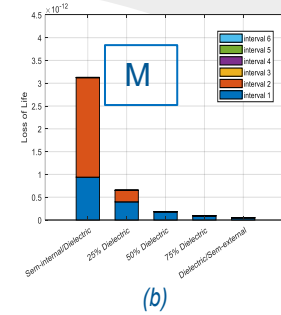
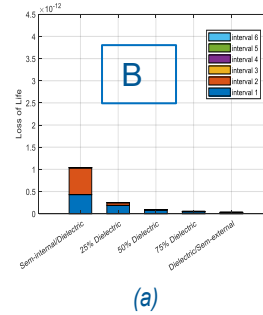
- LF in the order of 10⁻⁹. Hence, **Resilient**

WP4 – Results on Task 4.3 (2)

2) SOV due to DCCB switching voltage transient simulated at Sapienza Univ. Rome



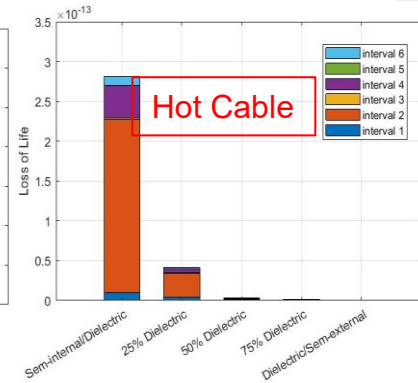
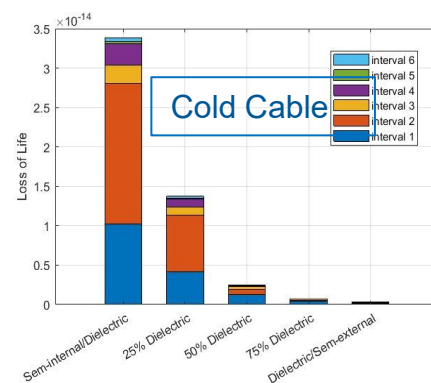
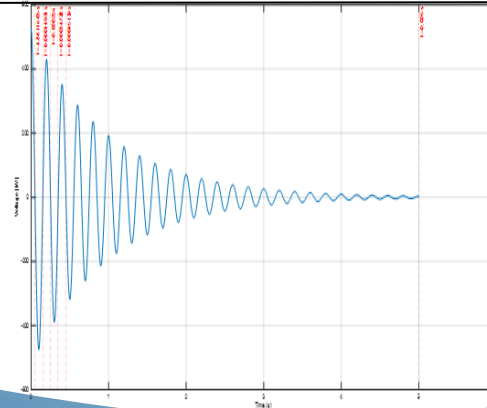
525 kV DC-PP cable: (a) beginning, (b) midpoint, (c) end of cable length



- LF in the order of 10^{-12} . Hence, **Resilient**

3) Zero crossing DTOV associated with fast oscillating damped grounding of cables simulated at 5 kHz

525 kV DC-PP cable: (a) Cold cable, (b) Hot cable



- LF in the order of 10^{-13} . Hence, **Resilient**

Summary and outlook **Effects and resilience**

Summary

- Firewall properties of HVDC cable links have been proven by literature and TRI simulations
- Resilience of HVDC cable links in the presence of contingencies has been proved for
 - long Temporary Overvoltages (TOVs)
 - Switching overvoltages due to DCCB
 - zero-crossing Damped TOVs

Outlook

- More grid simulations to model
 - contingencies in addition to TOVs, DTOVs, SOV
 - a greater penetration of RES

Published papers on **Resilience**

- 1) G. Mazzanti, B. Diban, R.E. Diaz, S. Lauria, R. Sgriscia, "Preliminary evaluation of the challenge set to HVDC extruded cables by switching overvoltages due to the operation of Direct Current Circuit Breakers", Proc. International Conference on Dielectrics (ICD 2026), Southampton, UK, 21-25 Jun. 2026
- 2) G. Mazzanti, B. Diban, R.E. Diaz, B. Aluisio, M. Vedovato, "Loss-of-life fraction estimation for HVDC Extruded Cables in the presence of long Temporary Overvoltages recorded in the field", Proc. International Conference on Dielectrics (ICD 2026), Southampton, UK, 21-25 Jun. 2026

N.B. Effects and resilience to faults of the HVDC cable connection in the AC network have been reported in the Deliverable 4.3 in section 3.

NEWGEN

Q&A Session 4

Moderator: Merie Kannampuzha (CLI)



NEWGEN

Session 5: Project impact and exploitation of the results

16:10-16:30



NEWGEN

Exploitation & Impact

Merie Kannampuzha (CLI)



UNIVERSITY
OF TWENTE.



NEWGEN project, Grant Agreement N° 101075592





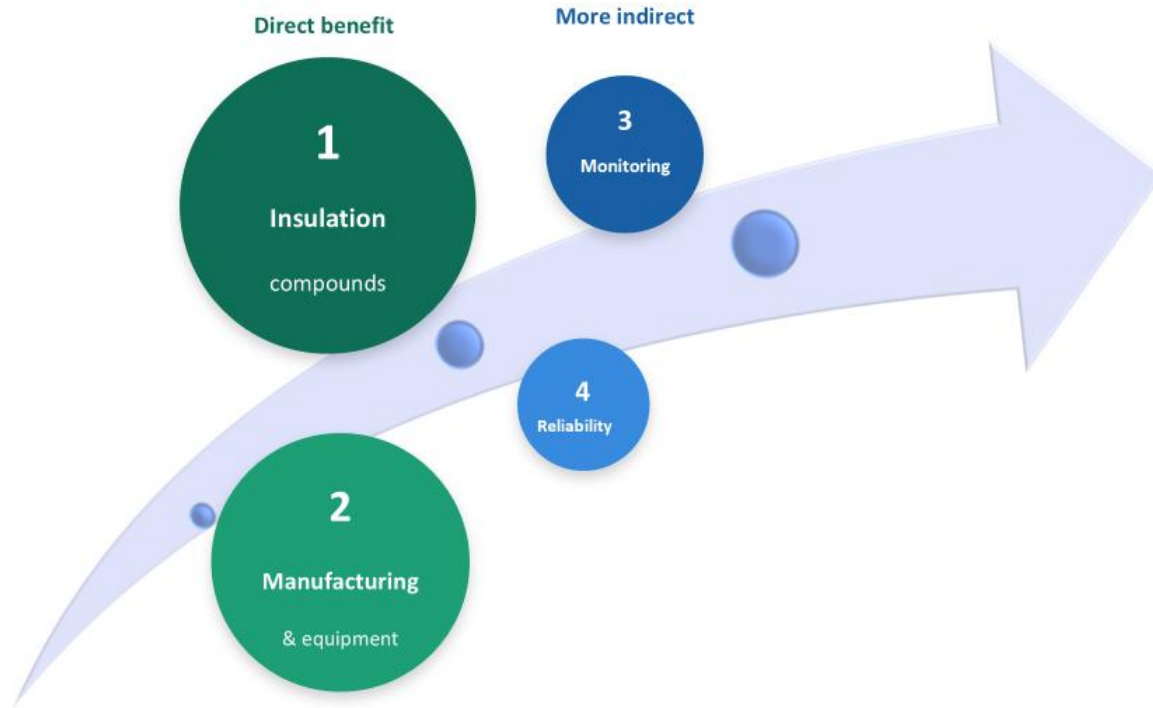
From innovation to impact

Market potential and exploitation routes
for NEWGEN results

Merie Kannampuzha | CLIC Innovation
NEWGEN Public Webinar | 24 September 2026



NEWGEN work in the context of growing cable market



Growing HVDC cable market →

Conceptual illustration - bubble size reflects how directly each result benefits from market growth, not a measured value.

HVDC market characters

01

Growing demand

Offshore wind
Cross-border interconnectors
Grid reinforcement

03

Technology pull

Faster manufacturing
Improved insulation
Digital monitoring

02

Supply pressure

Long procurement lead times
Capacity constraints
Rising asset criticality

04

Adoption hurdle

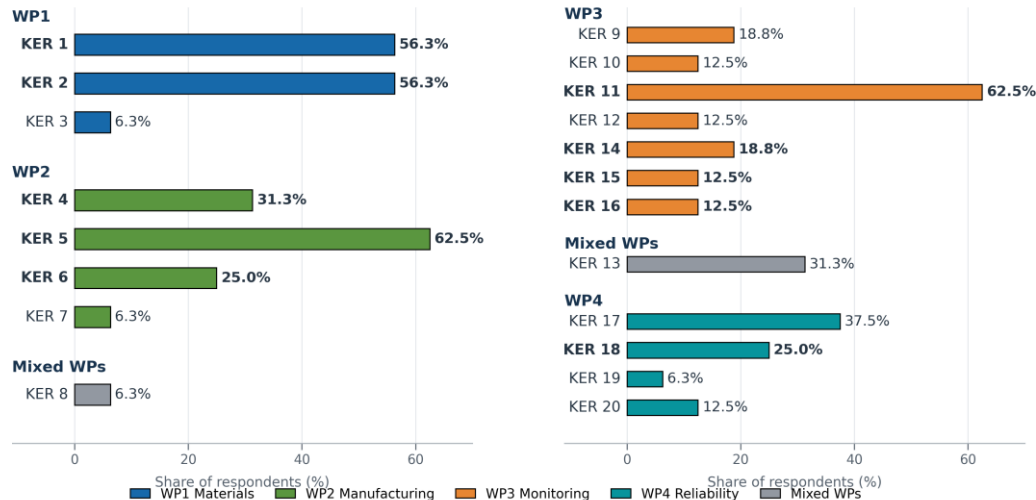
Qualification
Industrial readiness
Reference projects

Market opportunity and execution challenge

NEWGEN from 20 KERs to 4 priorities

KER prioritisation survey results (% of respondents)

Bold = included in selected KER groupings



Consortium evidence and market relevance guided the selection

4 selected KER groups

Advanced insulation

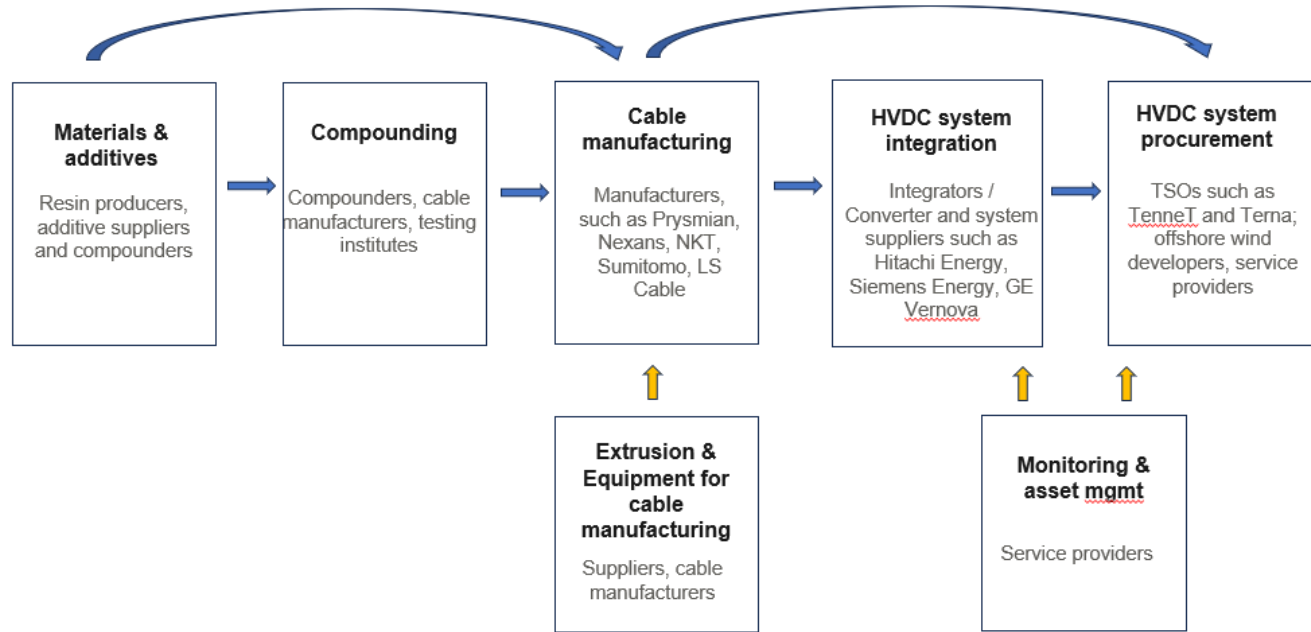
Extrusion technology

Monitoring & diagnostics

Life & reliability model

Selection combined original KERs where this created a clearer market offer.

HVDC cable value chain & NEWGEN KERs



KER 1 Materials & additives

KER 2 Manufacturing equipment

KER 3 Monitoring & diagnostics

KER 4 Reliability decisions

KER 1: Advanced insulation compounds & additives

TRL 5–6

Faster thermoplastic processing, with space-charge mitigation as the technical differentiator

Value proposition

- PP-based thermoplastic insulation avoids long degassing steps
- Tailored additive to mitigate space charge
- Electrical performance and long term reliability of PP over XLPE
- Bio based raw material options & elimination of peroxides in the final product
- Ready to be recycled as it is not crosslinked

Critical proof: long-term reliability, cleanliness, thermal performance and secure supply.

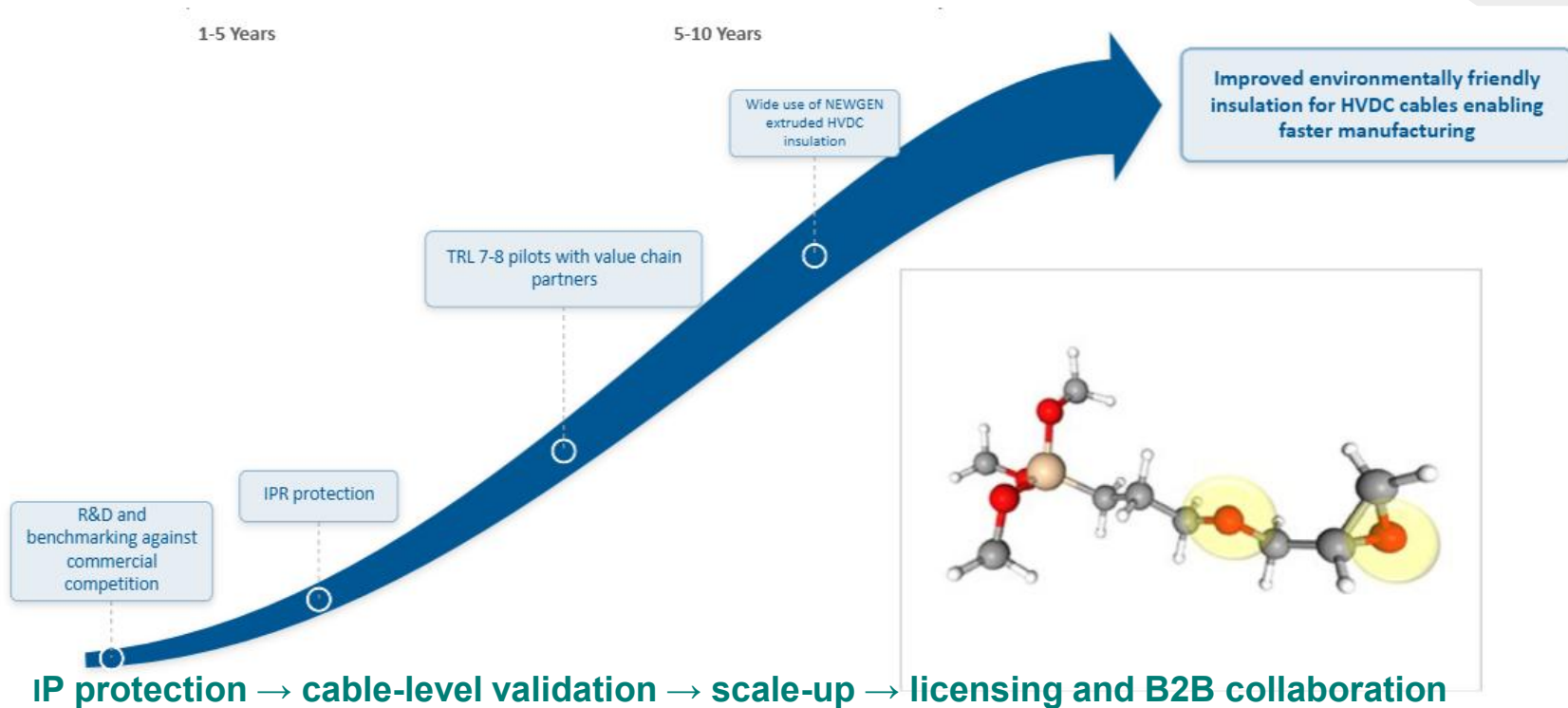
Owners

VTT and UTwente

Target customers

- Resin manufacturers
- Additive manufacturers
- Compounders
- Cable manufacturers

KER 1: Impact pathway



KER 1: Barriers, risks and mitigation

The route to impact depends on proving performance, scaling clean production and securing industry adoption.

BARRIER	RISK	MITIGATION
1 Performance evidence	Uncertain long-term reliability and thermal performance	→ Extended ageing, XLPE benchmarking and cable-level validation
2 Industrial scale-up	Clean, consistent production at commercial volumes is not yet proven	→ Scale compounding with material suppliers and cable manufacturers
3 Market adoption	Long qualification cycles and established XLPE systems slow uptake	→ Pilot projects, prequalification and reference installations
4 Supply security	Few qualified suppliers for clean compounds and specialised additives	→ Develop multi-partner, long-term supply and quality-assurance routes

PROVE → SCALE → QUALIFY → PARTNER → MARKET UPTAKE

KER 2: Advanced extrusion technology and Process Optimisation for HVDC Cables

TRL 6

A future-proof manufacturing route for both XLPE and thermoplastic cables

Value proposition

- Enabling cable manufacturers to manufacture and test thermoplastic insulated cable
- Upgraded screws, extrusion systems and crossheads
- Fine filtering and controlled cooling for PP
- Hybrid multipurpose manufacturing line maintaining XLPE compatibility

Owner

Maillefer

Target customers

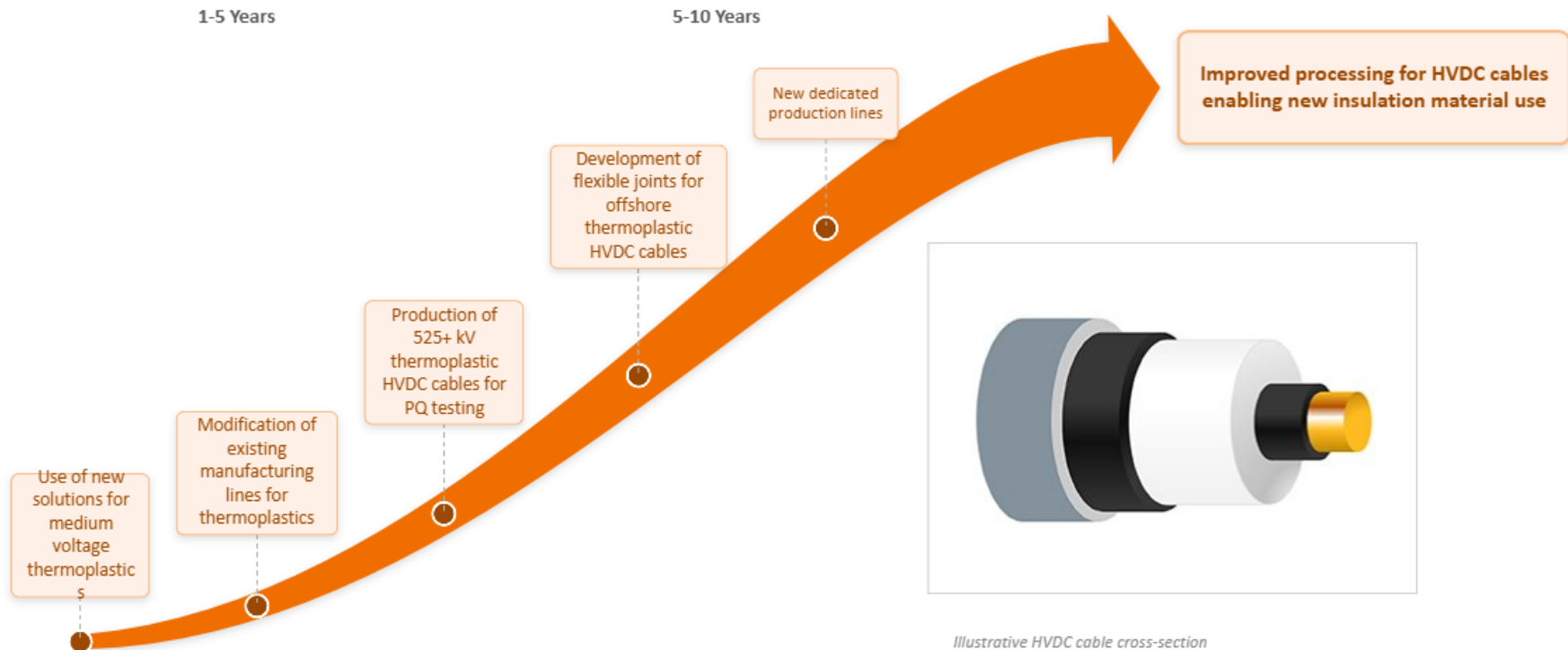
Cable manufacturers

Commercial advantage

Cable manufacturers can invest incrementally: retrofit now, test thermoplastics, and preserve incumbent production.

Near-term entry: test lines, retrofits and medium-voltage applications.

KER 2: Impact pathway



Retrofit existing line to manufacture test cables → Application in MV cable production → Hybrid line for XLPE& PP

KER 2: Barriers, risks and mitigation

Advanced extrusion technology and process optimisation for thermoplastic HVDC cable manufacturing

BARRIER	RISK	MITIGATION
1 Market uncertainty and burden of proof	Low market pull and cautious investment until superior performance is demonstrated	→ Showcase the technology; partner with cable manufacturers for MV testing, full-size HVDC development and qualification
2 Resource bottlenecks for high growth	Scaling production and installation capacity may be constrained by availability of people	→ Use flexible hybrid XLPE/PP lines and upgrades while progressing through customer testing and commercial deployment

SHOWCASE → TEST MV CABLES → DEVELOP FULL-SIZE HVDC → QUALIFY → COMMERCIALISE

KER 3: HVDC Cable Monitoring and Diagnostics

TRL 5–6

From periodic inspection towards earlier warning and predictive maintenance

Combined signals Partial discharge + temperature + leakage current

Value proposition

- Improved visibility of cable condition
- Earlier indication of insulation degradation, partial discharges and leakage currents
- Support for predictive maintenance
- Thermal runaway risk detection avoids catastrophic failure
- Asset-life extension

**First credible market: land-based and short offshore connections.
Submarine use needs further validation and marinisation.**

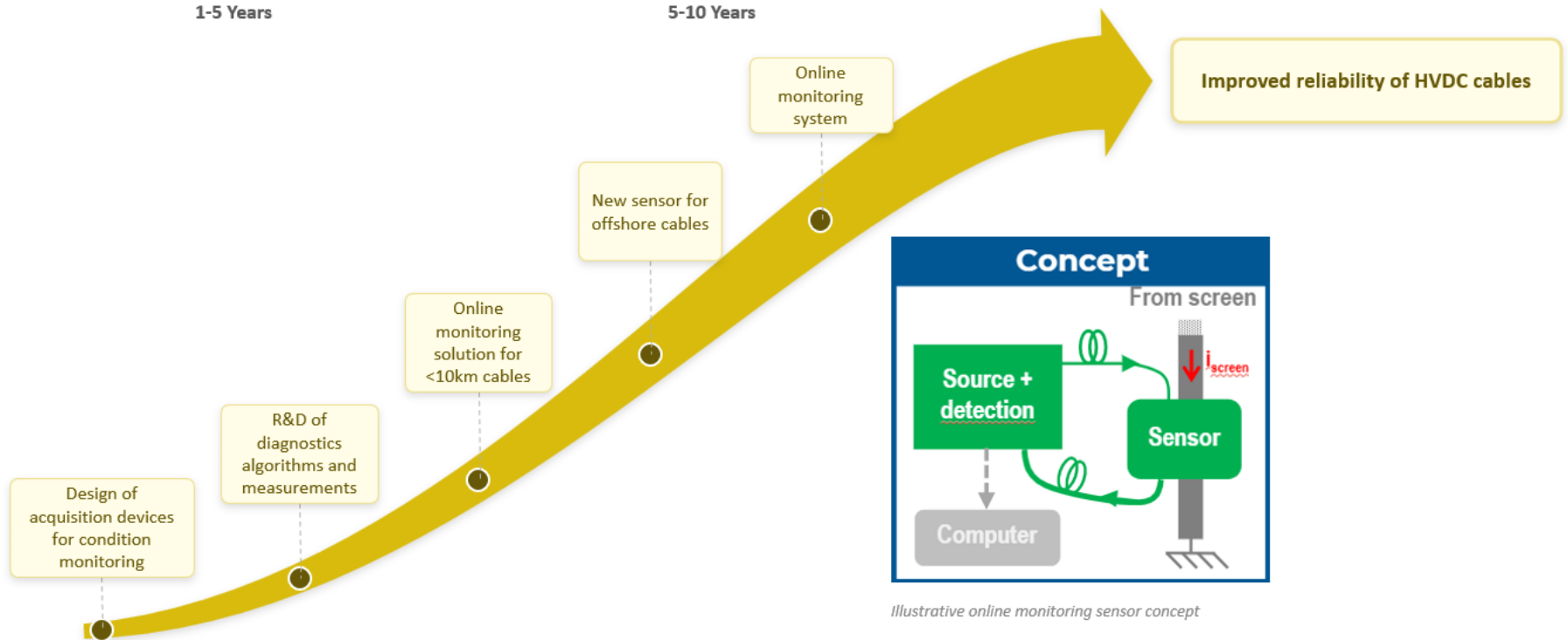
Owners

Doble, Supergrid Institute

Target customers

- Contractors selling and installing cables & accessories
- HVDC operators /TSOs)

KER 3: Impact pathway



Publish and disseminate → Engage with TSOs → Validate concepts → Participate in testing → Licensing

KER 3: Barriers, risks and mitigation

Integrated online monitoring and health assessment for HVDC cable systems

BARRIER	RISK	MITIGATION
1 Technical uncertainty	Benefits and value are not yet demonstrated at system level or in sub-sea environments	→ Validate with cable manufacturers and TSOs under real operating conditions
2 Leakage-current measurement	Very small currents and stray-current effects can distort measurements	→ Test the sensor prototype at a representative site and in realistic environmental conditions
3 Limited site data and unclear requirements	Restricted operating data makes sensor and system specification difficult	→ Work with TSOs, cable operators and diagnostics communities to define requirements and access data
4 Submarine applicability	Limited range, harsh conditions and lack of suitable testing constrain deep-offshore deployment	→ Focus first on land and short offshore use; adapt and marinise solutions for submarine applications

DEFINE REQUIREMENTS → ACCESS DATA → VALIDATE IN FIELD → PILOT → STANDARDISE

KER 4: Life and Reliability Modelling of HVDC Cable Systems

TRL 5-6

Turning test and monitoring data into decision support

Value proposition

- Quantitative tool
- Estimate residual life and reliability under realistic load cycles
- Support maintenance and replacement planning for TSOs
- Research services and consulting applicable for XLPE as well as PP systems
- Inform cable design optimisation

Credibility depends on representative datasets and continued validation with TSOs and manufacturers.

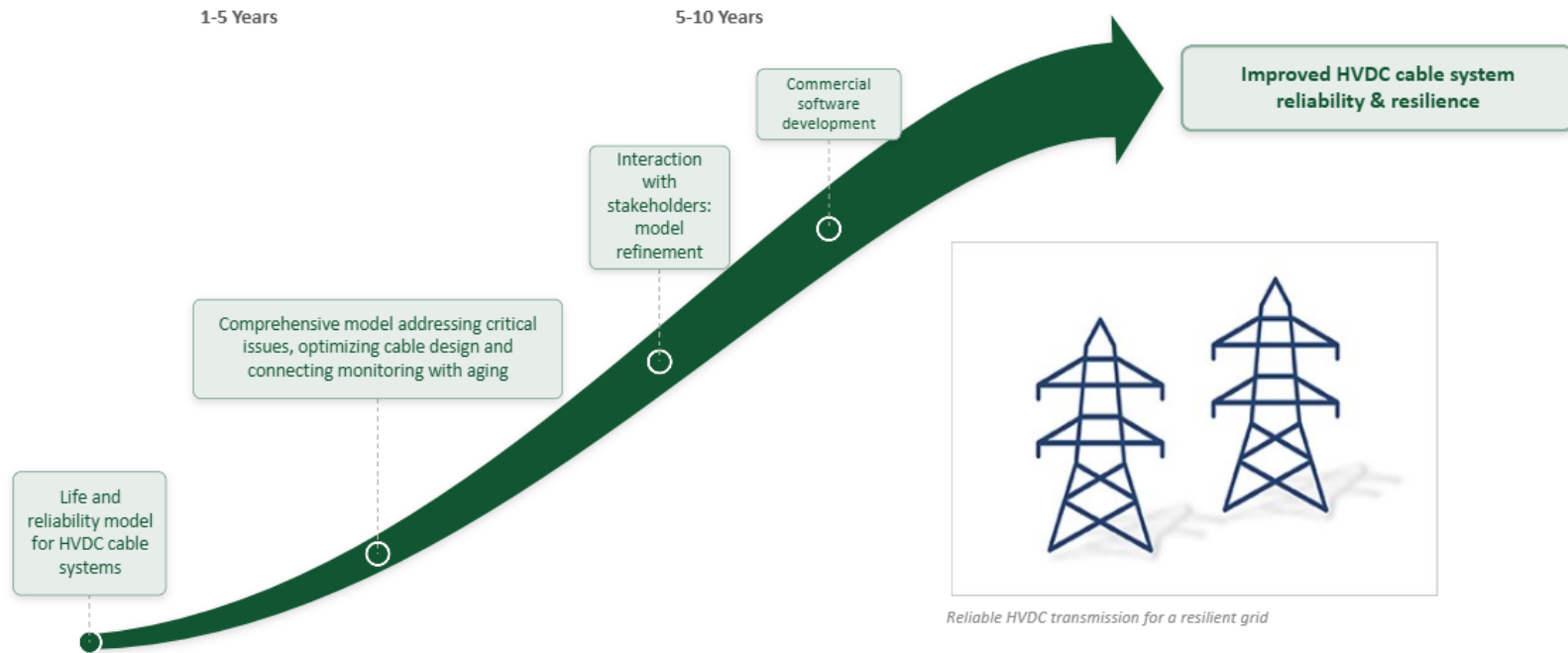
Owner

University of Bologna

Target customers

HVDC asset owners
Research institutes
Cable manufacturers

KER 4: Exploitation pathway



Co-validation & consulting → credible benchmarks → software licensing

KER 4: Barriers, risks and mitigation

Life and reliability modelling of HVDC cable systems

BARRIER	RISK	MITIGATION
1 Industry scepticism	Manufacturers prefer real-time monitoring and view predictive forecasts as uncertain	→ More validation to counteract industry scepticism towards predictive models
2 Validation still ongoing	Accelerated tests and simulation assumptions require continued validation and benchmarking	→ Continue validation with additional datasets and comparison against monitoring outputs
3 Representativeness of test objects	Much available data is based on flat specimens; full-size cable-system data remain limited	→ Use closer-to-real cable data and refine validation for HVDC cable joints
4 Data gaps for PP and interfaces	Additional data are needed for PP systems, insulation-accessory interfaces and material-specific effects	→ Further validate PP cable and EPDM joint insulation; engage stakeholders to improve the commercial software

VALIDATE → ADD DATASETS → COMPARE WITH MONITORING → ENGAGE STAKEHOLDERS

Market opportunity: sizeable, but evidence must be read carefully

KER 1 Advanced insulation

~1,500 km/year PP cable
scenario; 7500 tonnes of PP
insulation

Internal adoption scenario

KER 2 Extrusion upgrades

€50–100m over next decade

KER-owner estimate

KER 3 Monitoring & diagnostics

€100–200m/year

KER-owner estimate

KER 4 Reliability modelling

€5–50m/year

Analytical assumption

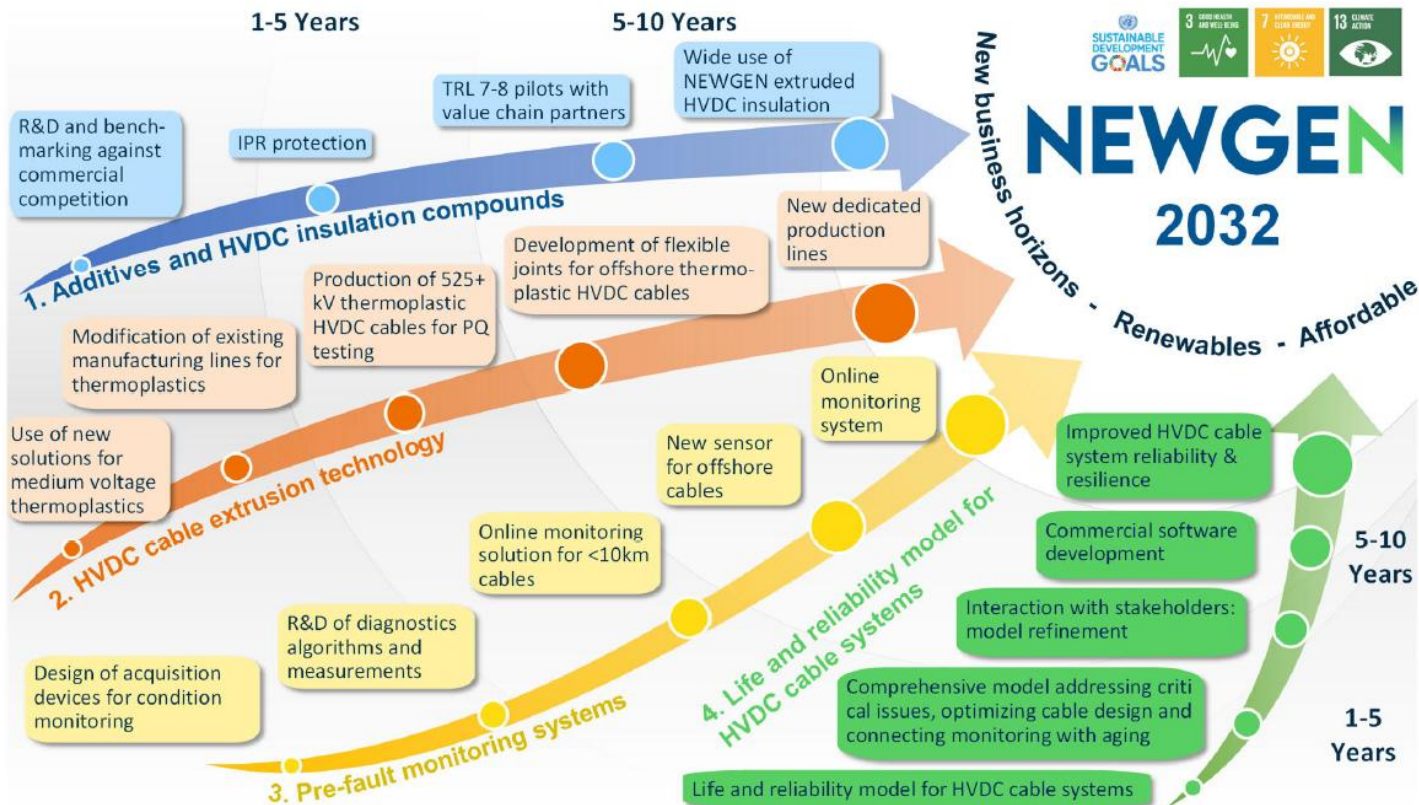
These are indicative opportunities for exploitation planning, not forecasts of direct NEWGEN revenue.

NEWGEN : Next steps



**NEWGEN has created credible routes to impact.
The next value-creating step is industrial validation with committed adopters.**

NEWGEN overall impact pathway

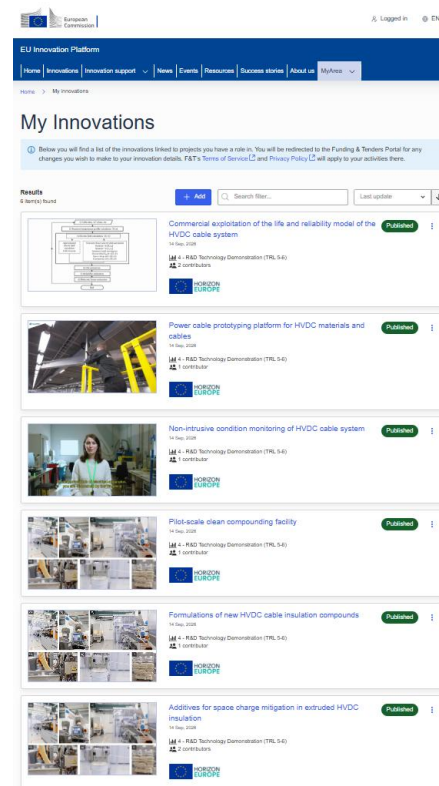


NEWGEN KERs in European Innovation Platform

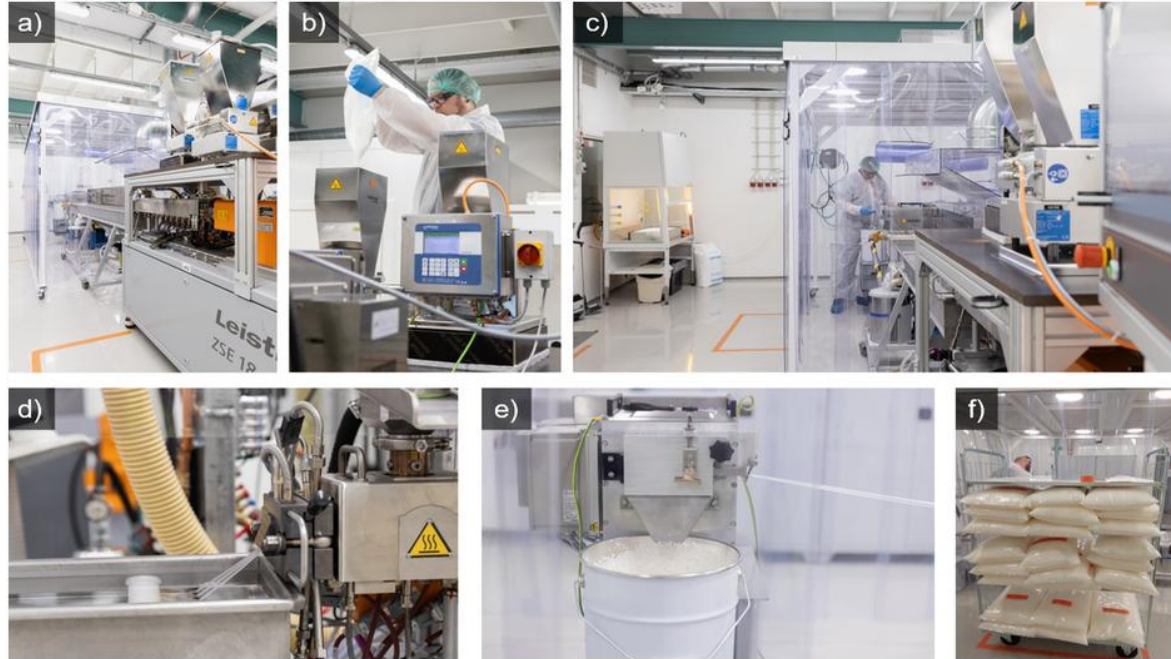
EU Innovation Platform (EUIP): A centralized digital hub connecting European innovators, investors, and service providers with funding, business support, and networking opportunities to accelerate market-ready solutions.

Total 6 KERs from NEWGEN published in EUIP:

- KER1
 - [Pilot-scale clean compounding facility](#)
 - [Additives for space charge mitigation in extruded HVDC insulation](#)
 - [Formulations of new HVDC cable insulation compounds](#)
- KER2
 - [Power cable prototyping platform for HVDC materials and cables](#)
- KER3
 - [Non-intrusive condition monitoring of HVDC cable system](#)
- KER4
 - [Commercial exploitation of the life and reliability model of the HVDC cable system](#)



- Pilot-scale clean compounding facility
- Additives for space charge mitigation in extruded HVDC insulation
- Formulations of new HVDC cable insulation compounds



KER2- Power cable prototyping platform for HVDC materials and cables



[Power cable prototyping platform for HVDC materials and cables](#)

Maillefer's R&D Center has equipment and test lines for wide range of cable prototype manufacturing. Latest additions include optimized manufacturing setup for PP based model "A" and model "B" cables as well as short full size HVDC prototypes.

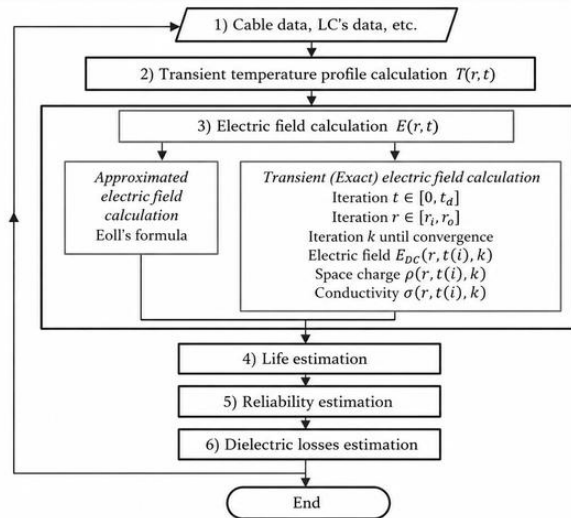
KER3 - Non-intrusive condition monitoring of HVDC cable system



[Non-intrusive condition monitoring of HVDC cable system](#)

Supergrid Institute is developing a non-intrusive online leakage current monitoring system for HVDC cable systems. The leakage current can provide insightful information about the electrical insulation performance of the cable system and hence be used for detection of HVDC cable pre-fault conditions. The system developed by Supergrid Institute is based on a magneto-optical technique and as a result does not interfere with the energy transmission system.

KER4: Commercial exploitation of the life and reliability model of the HVDC cable system



Commercial exploitation of the life and reliability model of the HVDC cable system

In NEWGEN project, University of Bologna has developed a life and reliability model of a full HVDC cable system including accessories (joints and terminations), capable of treating different operating conditions, including: constant voltage and temperature, load cycles of cable current, voltage transients. The model has been validated, based on the results of accelerated life tests carried out at Tampere University on flat specimens of PP blends, developed at VTT Technical Research Center of Finland, with space charge suppressing additives developed at University of Twente.

Scientific impact

No	Title	Views [website]	Citations [Google Scholar]
1	The NEWGEN European Union Research Project for a New Generation of HVDC Cable Systems	321	6
2	Macroscopic Conductivity Models Fit for HVDC Cable Insulation	225	6
3	FEVER – Fem Electrothermal solVER: application to an HVDC joint	210	4
4	Updated Review of the Life and Reliability Models for HVDC Cables	4119	61
5	The Effect of Superimposed Switching Impulses on Space Charge Accumulation in XLPE-insulated HVDC Cables	170	5
6	Screening of Suitable Random Copolymer Polypropylene Blends for HVDC Cable Insulation	300	13
7	Characterization of Isotactic-Polypropylene-Based Compounds for HVDC Cable Insulation	293	14
8	Updates About the Horizon Europe NEWGEN Research Project for a New Generation of HVDC Insulation Materials, Cables and Systems	233	5
9	Comparative Analysis of Partial Discharge Measurements for Artificial Defects under HVAC and HVDC Voltage Stresses for Cable Insulating Materials	141	3
10	About the Feasibility and Performances of Automatic DC PD Sources Discrimination	104	5
11	Polypropylene Copolymers and Blends for HVDC Cable Insulation: Initial Characterization and Pilot-scale Production	202	6
12	Discussion on the Defects in HVDC Cables and Their Relation with the Occurrence of Partial Discharge Phenomena	189	5
13	The Horizon Europe NEWGEN Research Project: For a New Generation of High-Voltage DC Insulation Materials, Cables, and Systems after 24 Months since the Start of the Project	444	10
14	Novel Grafted Additives for Space Charge Mitigation in Extruded HVDC Cable Insulation	116	4

No	Title	Views [website]	Citations [Google Scholar]
15	ALT Data Fitting for Polypropylene-Based HVDC Cable Insulation Developed in the HEU-NEWGEN Project	121	2
16	Evaluation of Charge Trapping and Transport Phenomena in Polymer Insulation by Means of Thermally Stimulated Current Measurements	309	0
17	Partial discharge detection and analysis in polymeric HVDC insulations	1272	0
18	Life Estimation of HVdc Cable Insulation Under Load Cycles: From Macroscopic to Microscopic Charge Conduction Modeling	324	3
19	The Influence of Space Charges on the Life Exponent derived from Accelerated Life Tests on PP-based HVDC Cable Insulation. Part 1: Ternary Blends	52	2
20	The Influence of Space Charges on the Life Exponent from Accelerated Life Tests on PP-based HVDC Cable Insulation. Part 2: Binary Blends and Final Comparison with Ternary Blends	54	2
21	Evaluating Space Charge Behavior of Polypropylene Blends Using TSDC Measurements	0	0
22	Effect of Additive Concentration on the Dielectric Properties of Extruded HVDC Cable Insulation	0	0
23	Preliminary Evaluation of the Challenge Set to HVDC Extruded Cables by Switching Overvoltages Due to the Operation of Direct Current Circuit Breakers	0	0
24	Loss-of-Life Fraction Estimation for HVDC Extruded Cables in the Presence of Long Temporary Overvoltages Recorded in the Field	0	0
25	Accelerated Life Test Fitting of Bi-Layer Insulations for HVDC Cable Accessories	0	0
26	Characterization of Bi-Layer XLPE/EPDM and PP-Blend/EPDM Insulations for HVDC Cable Accessories	0	1
27	Characterizing HVDC Accelerated Ageing in Artificially Defected Thermoplastic Materials	0	0
Sum		9199	157



NEWGEN publications & social media

- <https://www.newgen-project.eu/publications/>
- <https://www.youtube.com/@NEWGENEU-project>
- <https://www.linkedin.com/company/newgen-eu-project/>



Overall dissemination of NEWGEN

Selected progress indicators and final-stage achievements

297 LinkedIn followers

5995 Publication campaign impressions

3060 Views across five YouTube videos

6 KERs published on the EU Innovation Platform

27 Publications
9199 Publication page views

5 Journal articles
157 Google Scholar citations

NEWGEN

Thank you for your attention!



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