B1 – Installing passive sensing for condition monitoring of a 400 kV cable

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Overview

- Motivation
- 400 kV underground cable circuit
- Passive monitoring approach
- Initial data analysis
- Next steps
- Summary

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Motivation

- Most cable maintenance issues occur at **joints** and **terminations**
- Need to provide early warning of damage and failure modes at these locations
- This will reduce maintenance costs

- Conventional cable monitoring techniques do not improve visibility at joints/terminations
- Passive sensing avoids the need for control power or other infrastructure at remote monitoring locations

Sheath current monitoring CT at a cable joint

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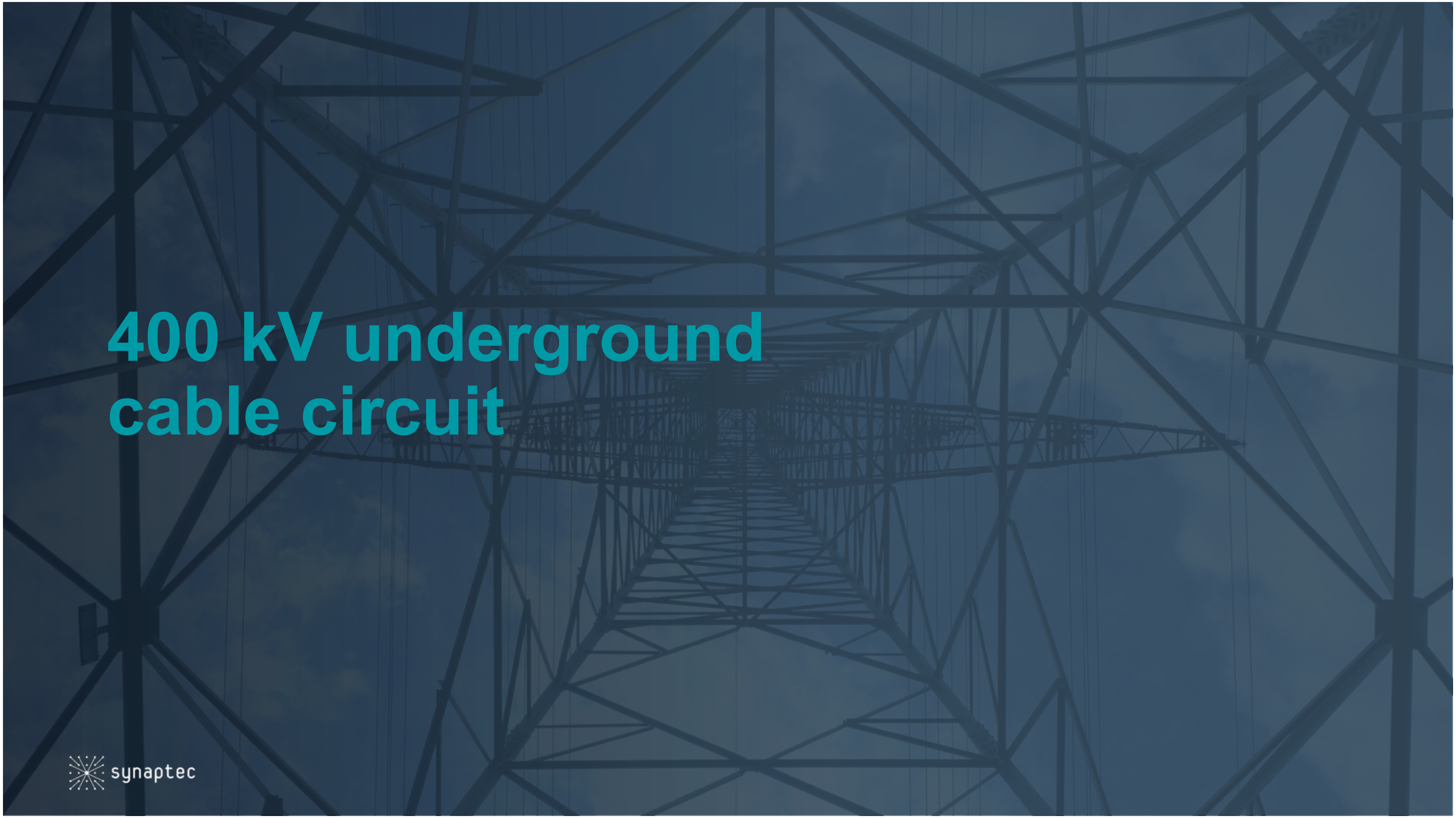
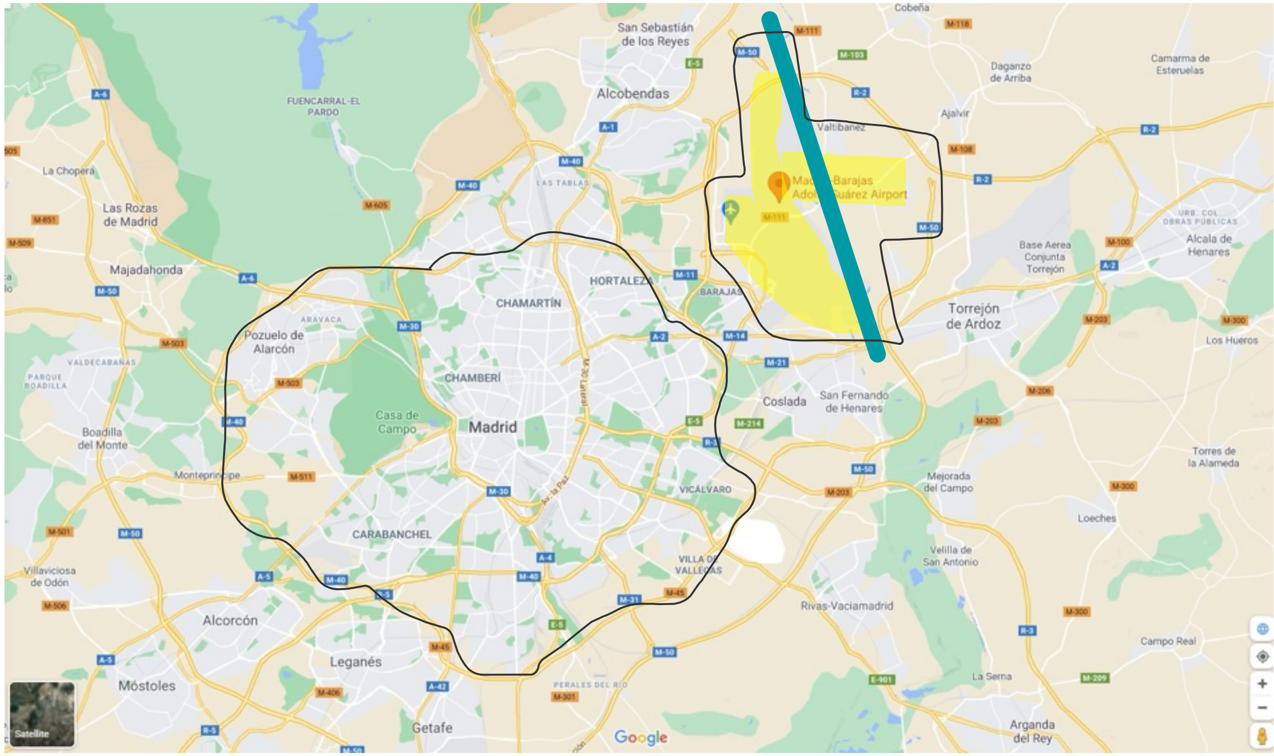
400 kV underground cable circuit



400 kV cable circuit



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Pórtico S.S.Reyes
TE - 11
TE - 12
TE - 13
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TE - 16
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TE - 07
TE - 06
TE - 05
TE - 04
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TE - 02
TE - 01
Pórtico S.F.Henares
Valtibanez
Paracuellos de Jarama
Los Berrocales del Jarama
Calle del Romeral
Calle de la Ronda de los Llanos
de Henares
North
M-11
M-13
M-14
M-111
M-22
M-21
M-103
M-115
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M-206
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R-2
Av. Hispanidad
Av. Logroño
Av. Aragón

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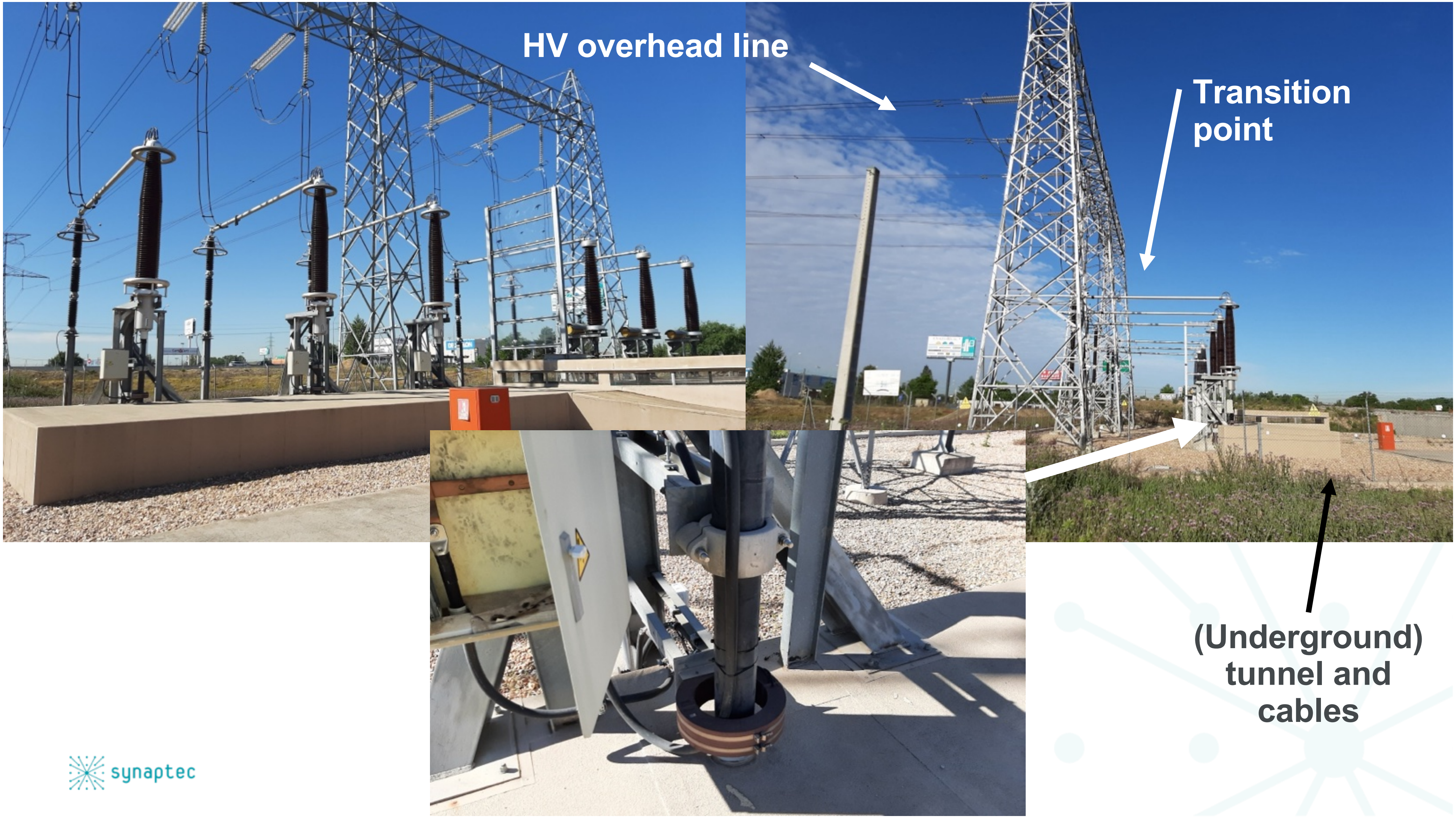
HV overhead line
Transition point
(Underground) tunnel and cables

Start of cable circuit

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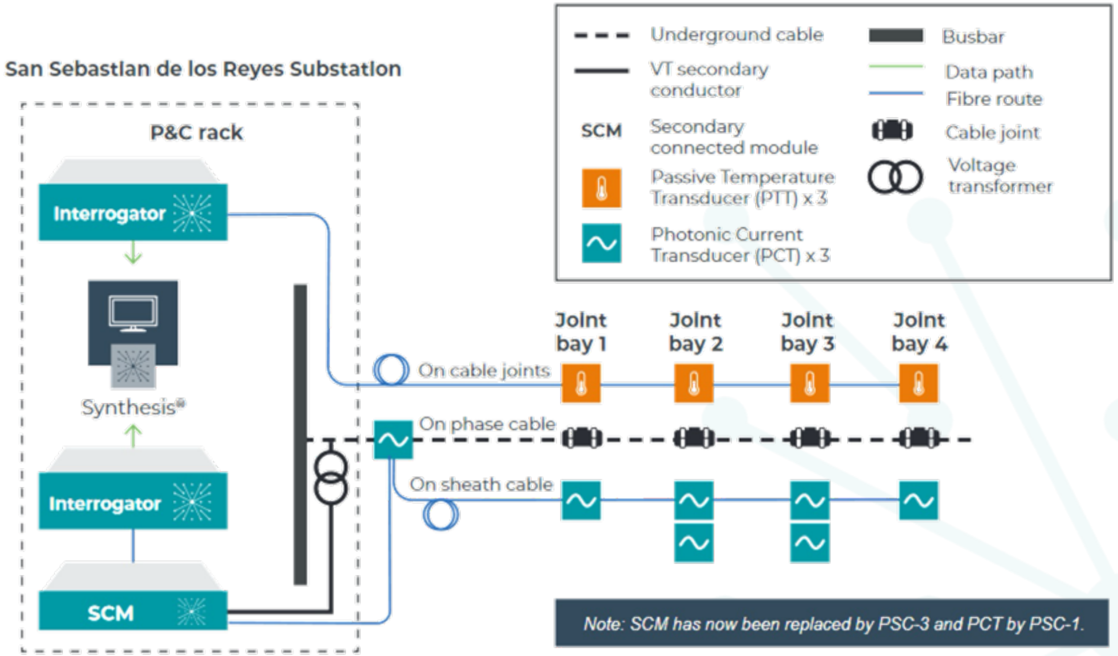
Passive sensing approach

Passive monitoring approach

- Phase current, sheath current, and spot temperature at multiple locations along HV cable
- No electronics or control power at sensor locations
- Sensors do not require maintenance after installation
- Sensors coupled to optical fibre, data available centrally at substation

Interrogator IEDs and server for data analysis



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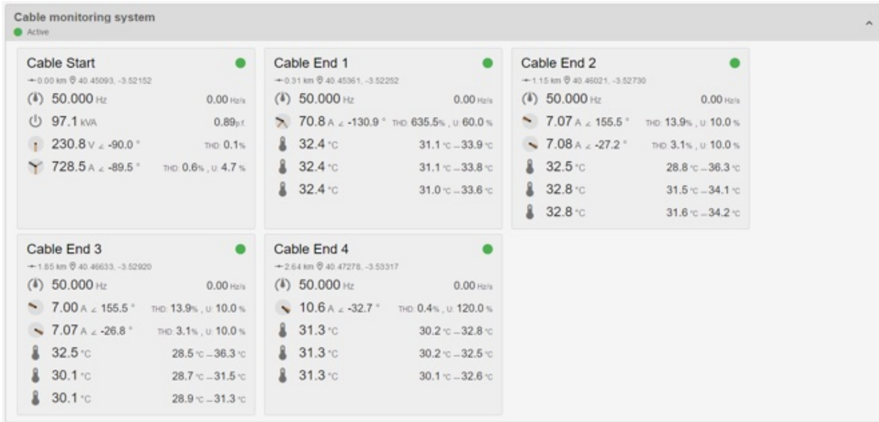
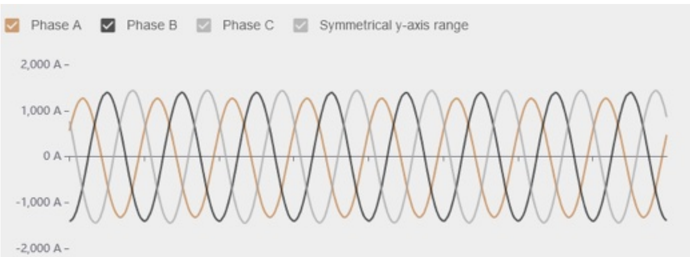
Real-time monitoring and control

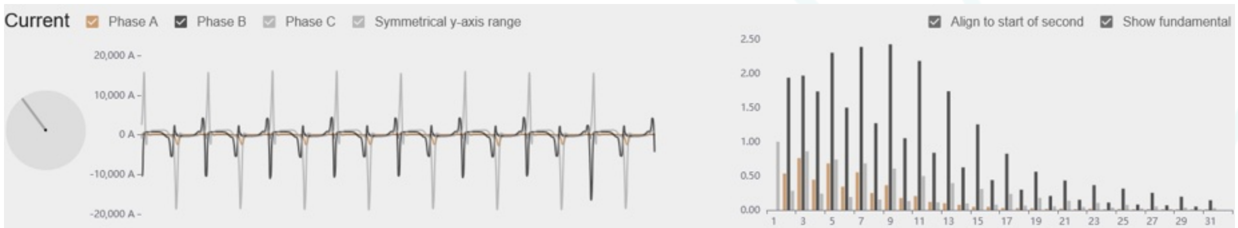
- System delivers 4 kHz waveform data from all remote sensors
- Real-time calculation of synchrophasors and harmonics
- Suitable for detecting transients such as incipient faults
- Can be combined with protection capabilities for blocking auto-reclose on cable sections



Dashboard of measurements, grouped by physical location



Phase current waveforms



CT saturation waveforms and harmonic spectrum

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Initial data analysis

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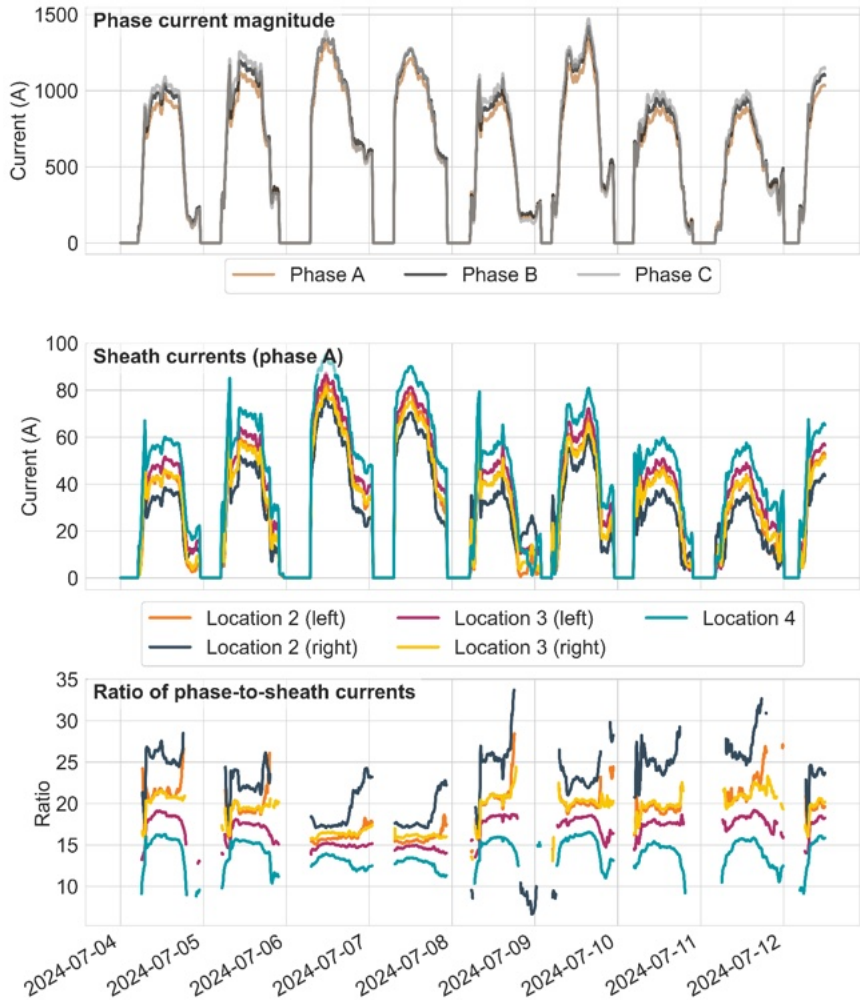
Initial data analysis

Cable health monitoring dashboard



One week of phase currents, sheath currents, and the ratio of phase-to-sheath current (for a healthy circuit)

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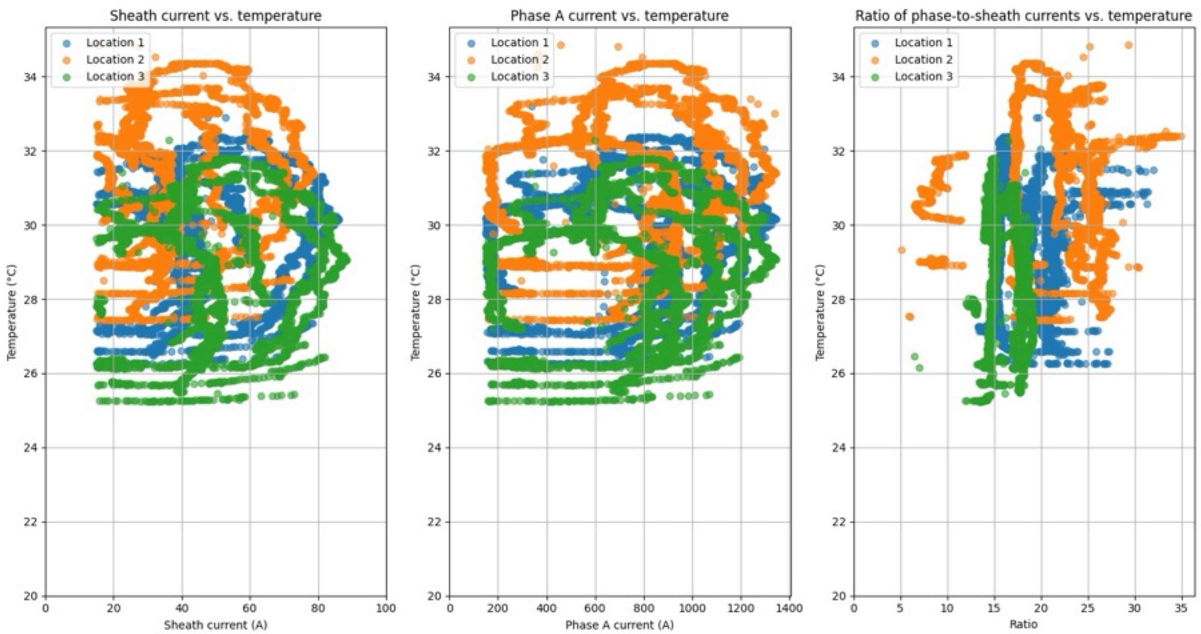
Comparison between locations and sensor types

- Simple heuristics such as **ratio of phase-to-sheath currents** can rapidly reveal indicators of cable health, such as detecting issues in the cross-bonding connections or an incorrect earth bonding
- Results show tendency for higher temperatures at joint location 2 – further long-term analysis will determine if behaviour is statistically significant



Combination of temperature and current data suggests possible deviation at location 2 (orange)

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Next steps

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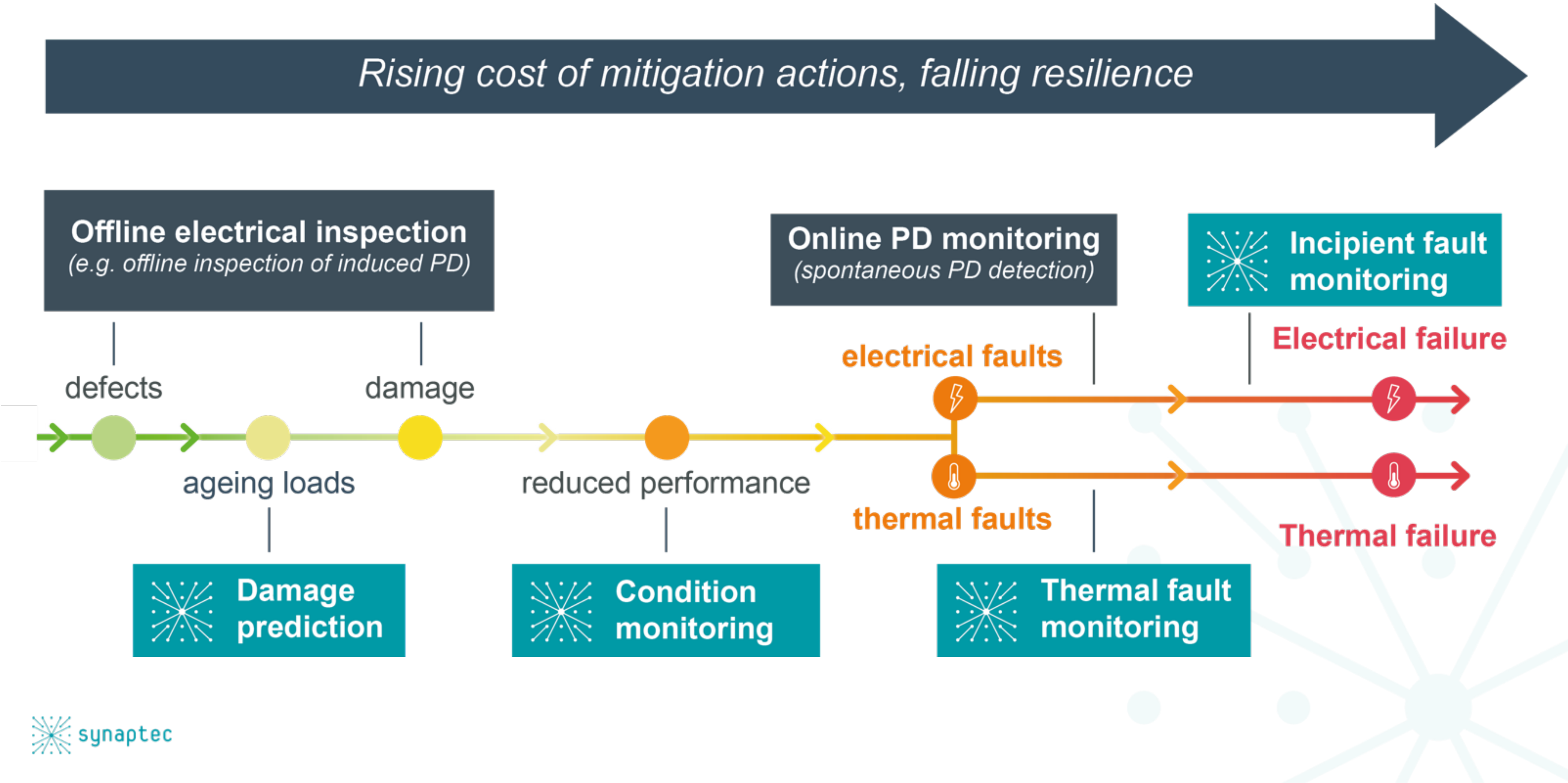
How damage leads to failure



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Monitoring HV cable circuits

Monitor **sheath currents, phase currents** and temperatures at **all joints and terminations** to detect subtle asset damage

Did damage occur? — Detect
Where is the damage? — Locate
What type of damage occurred? — Classify
How severe is the damage? — Quantify

Condition monitoring

Component affected	Damage description	Detect	Locate	Classify	Quantify
Termination	Manufacturing or installation defects, and ageing of sheath bonding (incl. weathering, movement, etc.)	✓	✓	✓	✓
	I^2R losses and insulation overthickness	✓	✓	✓	✓
Cable	Cable dielectric ageing (via changes in capacitive sheath current)	✓	n/a	✓	✓
Cable configuration	Cross-bonding defects and other grounding faults (e.g. flooding, animal bites)	✓	✓	✓	✓

Event Monitoring

Event description	Detect	Locate	Classify	Quantify
Incipient fault or electrical breakdown of termination, cable, system	✓	n/a	✓	✓
Termination thermal breakdown fault	✓	✓	✓	✓

Summary

Comparison with conventional monitoring approaches

Monitoring approach	Power and electronics required at sensor locations?	Interpretation of results	Continuous monitoring or manual inspection?	Outage required for measurement campaign?
Manual visual inspection of cable joints	Yes, for portable equipment	Manual, subjective	Manual and labour-intensive	Depends on measurements required
Conventional CTs and other sensors	Yes, merging unit, or equivalent digitisation electronics	Normal	Continuous	No
Partial discharge	Yes, high-frequency CTs, ultrasonic transducers, or similar	Complex	Manual	No
Dielectric loss/tan-delta	Yes, needs special equipment to inject low frequency signals	Complex, but handled by test equipment	Manual	Yes
Distributed temperature sensing (DTS)	No	Can only detect a limited set of failure modes	Continuous	No
Passive distributed electrical sensing	No	Normal	Continuous	No

Summary

- Provides a **simple, practical, and cost-effective** method to continuously monitor **damage and degradation** to **power cables, joints, and terminations**
- System delivers **permanent, continuous, passive** monitoring of long assets in hard-to-reach places
- Supports operators in **early fault or damage diagnosis**
- Applies equally to offshore wind cable networks