
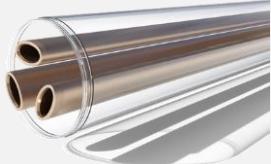


## Technology comparison: Pressurized Air Cable vs. XLPE cable

Pressurized Air Cable or XLPE cable? Here is a comparison table for system parameters, economy, society, and technical parameters<sup>1</sup>. All values provided are typical values for actual products or projects which may vary for every application.

### Comparison: system parameters

Topic	<b>XLPE cable</b> 	<b>Pressurized Air Cable</b> 
<b>Main layout</b>	Underground, concrete encased cable duct block	Underground: Microtunnel, Pipes, walkable Tunnels.
<b>Space requirement</b>	Corridor 145 kV: ≈ 2.0 m Corridor 220 kV: ≈ 2.6 m Corridor 420 kV: ≈ 3.5 m	Pipe 110 kV: 0.7 m Pipe 220 kV: 1.0 m Pipe 420 kV: 1.2 m
<b>Construction along the line</b>	Wide trench for duct block. Jointing pit every ~1000 m	Pipe. Installation pit every ~300-500 m.
<b>Line losses at I = 1000 A (Scales with I<sup>2</sup>)</b>	145 kV: ~50 kW/km 245 kV: ~45 kW/km 420 kV: ~30 kW/km	145 kV: ~46 kW/km 245 kV: ~25 kW/km 420 kV: ~19 kW/km
<b>Transmission power (typical values)</b>	145 kV: ~400 MW 245 kV: ~900 MW 420 kV: ~2300 MW	145 kV: ~800 MW 245 kV: ~1600 MW 420 kV: ~3600 MW
<b>Large scale use in the grid?</b>	Limited: Resonances, reactive power requirement	Not yet. Can replace all overhead lines.
<b>Operational experience</b>	Extensive operational experience in all voltage levels	New technology. Experience similar to GIL or GIS.
<b>Localization of a fault</b>	Distance protection, impedance method.	Integrated in pressure monitoring: Indicates compartment
<b>Repair in case of fault</b>	Difficult repair. Jointing. No standard spare parts.	Repair per busduct. Standard spare parts.
<b>Duration of a repair case</b>	Several month	Several days
<b>Parallel systems</b>	Required for redundancy and high transmission power	Required for redundancy
<b>Parallel systems</b>	Required for >2000 A	Not required up to 4000 A
<b>Monitoring in operation</b>	Extra monitoring systems. E.g. PD, DTS, Sheath	Integrated pressure monitoring for all key parameters
<b>Grounding</b>	Cross-bonding with SVL to limit losses	Enclosure grounding at every available ground connection
<b>Voltage upgrade 245kV → 420kV</b>	Needed to reduce losses and increase transmission power	Optional to reduce losses and increase transmission power

<sup>1</sup> Focus on voltage levels  $\geq 145$  kV. However, PAC can similarly be used for MV as well.

<b>Options for upgrade and grid enhancement</b>	Can only replace sections of OHL	Continuous expansion of the grid possible
<b>Exposition (as critical infrastructure)</b>	Underground. Protected by duct block. Exposed interfaces.	Underground. Protected access. Rigid metallic enclosure.

## Comparison: Economy

Topic	XLPE cable	Pressurized Air Cables
<b>Investment cost: Line plus installation<sup>2</sup> (without approval costs)</b>	145 kV: ~1.2 MCHF/km 245 kV: ~2.7 MCHF/km 420 kV: ~5.0 MCHF/km	145 kV: ~1.5 MCHF/km 245 kV: ~2.9 MCHF/km 420 kV: ~4.3 MCHF/km
<b>Cost for electricity losses during a 40-year operation at 1000 A</b>	145 kV: ~2.1 MCHF/km 245 kV: ~1.6 MCHF/km 420 kV: ~1.0 MCHF/km	145 kV: ~1.0 MCHF/km 245 kV: ~0.6 MCHF/km 420 kV: ~0.4 MCHF/km
<b>Costs dependency on rated current</b>	Strong dependency: Higher current → higher cost	Low dependency on rated current
<b>Economic limit to line length</b>	Limited by reactive power and resonances	No limit in modern grids with battery storage
<b>Costs for reactive power compensation</b>	Significant for > 20 km length	None up to ~60 km length. Needed for >60 km length.
<b>Delivery time: Wires, towers, pipes</b>	Years	~month's
<b>Cost for jointing pits, installation pits</b>	~ 20 kCHF/pit	~ 20 kCHF/pit
<b>Operation and maintenance</b>	Little effort for maintenance.	Little effort. Integrated monitoring system.
<b>Installation process</b>	Digging trench. Concrete pouring. Cable pulling. Jointing	Dig pipe or microtunnel. Connect tubes. Roll them in.
<b>Public tendering</b>	Standardized. Many established suppliers.	No product-specific tenders yet. Only 1 supplier.
<b>Expected lifetime</b>	~40 years	> 40 years (like GIS)

## Comparison: Environment and society

Topic	XLPE cable	Pressurized Air Cables
<b>Approval process for line projects</b>	Lengthy (cable duct block) Naturally project specific.	Faster due to zero emissions. Use of existings corridors.
<b>Acceptability by societies</b>	Bad during construction. Better than for OHL.	No reference yet. But better due to zero emissions.
<b>Outside electric fields</b>	None: Shielding.	None. Metallic enclosures.
<b>Outside magnetic fields at 1000 A</b>	< 100 $\mu$ T in > 1.0 m distance < 1 $\mu$ T in > 10 m distance	<100 $\mu$ T in >0.3 m distance <1 $\mu$ T in >3.0 m distance
<b>Safety hazards</b>	Fire. Internal arc fault. Grounding error.	Overpressure < 10bar in large pressure vessel

<sup>2</sup> Typical values for long, mostly straight installations.

<b>Exposition for vandalism, sabotage, terrorism</b>	Minimized. Arson attacks. Mechanical damage.	Minimized: Underground. Locked access. Rigid enclosure
<b>Emissions to environment</b>	Magnetic fields, heat, concrete ducts	Minor emissions.
<b>Effects on neighborhood</b>	Limited effect from EM fields.	Minor effects.
<b>Recycling at end of life</b>	Metals wires_ recyclable. Insulation material: Disposal	~ 99 % Aluminum. Fully recyclable.

### Comparison: Technical parameters

Topic	XLPE cable	Pressurized Air Cables
<b>Design and installation</b>	Complex design & extrusion. On-site jointing needed.	Simple assembly. Installation in pits with special tools.
<b>Insulation medium</b>	Cross-linked PE (XLPE)	Pressurized air (~10 bar, dry)
<b>Conductor material</b>	Aluminum, Copper	Aluminum
<b>Field stress on conductor during operation</b>	~10 - 18 kV/mm	2-4 kV/mm
<b>Shielding / enclosure</b>	Thin, conductive sheet	Thick aluminum enclosure
<b>Fire protection</b>	Insulation: Can burn and produce smoke.	Metallic enclosure: Non-flammable.
<b>Conductor cross section (Single wire or bundles)</b>	240 - 2500 mm <sup>2</sup>	Minimum: 2200 mm <sup>2</sup> Maximum: 5000 mm <sup>2</sup>
<b>AC-resistance at operating temperature</b>	145 kV: ~26 mΩ/km 245 kV: ~24 mΩ/km 420 kV: ~20 mΩ/km	145 kV: 12 mΩ/km 245 kV: 10 mΩ/km 420 kV: 8 mΩ/km
<b>Capacitance per meter</b>	145 kV: ~160 nF/km 245 kV: ~140 nF/km 420 kV: ~140 nF/km	145 kV: ~50 nF/km 245 kV: ~50 nF/km 420 kV: ~50 nF/km
<b>Charging current per km per phase at rated voltage</b>	145 kV: ~4.2 A/km 245 kV: ~6.2 A/km 420 kV: ~10.7 A/km	145 kV: ~1.30 A/km 245 kV: ~2.22 A/km 420 kV: ~3.81 A/km
<b>Reactive power for 3-phases</b>	145 kV: ~1.1 MVar/km 245 kV: ~2.64 MVar/km 420 kV: ~7.76 MVar/km	145 kV: ~0.33 MVar/km 245 kV: ~0.94 MVar/km 420 kV: ~2.80 MVar/km
<b>Reactive power compensation</b>	Required if >20 km length	Required if >60 km length
<b>Bending radius</b>	Typical: 20-30 * D <sub>K</sub> . ~ 2-3 m bending radius	Continuous bending or 90° angles if required
<b>Fault arc resistance</b>	None. Internal arc fault leads to cable fire.	Yes. Arc remains internally. Pressure < Bursting pressure
<b>Temporary overloading</b>	Bad due to thermal insulation by XLPE layer.	>1h at 1.5* I <sub>r</sub> . Good heat dissipation by metal enclosure
<b>On-site testing after installation</b>	High inductivity required to test a longer cable section.	