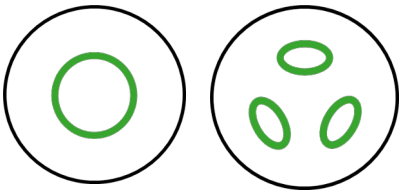
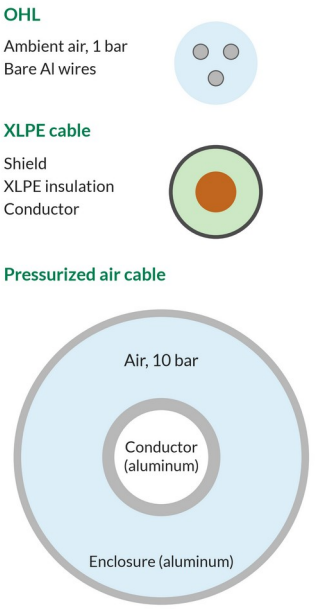
Life cycle analyses for pressurized air cables



Introduction

Hivoduct pressurized air cables (PAC) are designed to transmit electric energy at high voltage (12 kV – 420 kV) and AC currents (1000 A – 5000 A). The Hivoduct standard portfolio covers all ratings from medium voltage (12 kV) to transmission voltage (420 kV).

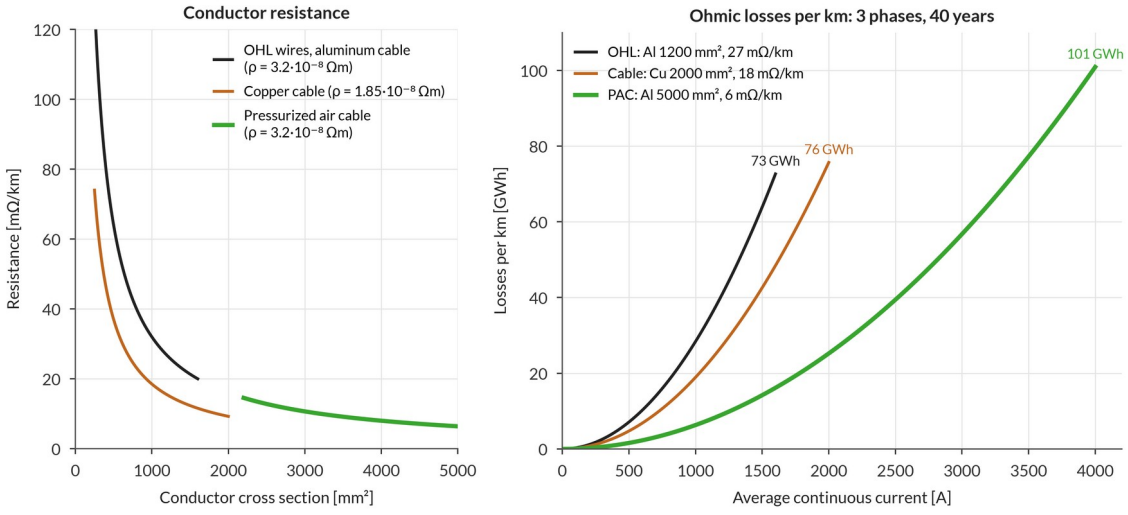


Due to their functionality and flexibility, PAC can replace overhead lines (or sections of them), XLPE cables, gas-insulated busducts (GIB) and insulated high-current busbars. Using pressurized air as the main insulation medium results in two key properties that both reduce CO_2 emissions during operation.

First, SF_6 (GWP = 23'000) or other PFAS **gas mixtures** (GWP > 600) used in GIB are **replaced by air** with GWP = 0. Second, the basic design of PAC has larger overall dimensions than XLPE cables due to the lower breakdown strength of air insulation. The resulting **larger conductor cross section** has a lower resistance and thus produces lower losses during operation than other technologies. Reduced losses in cable systems are the main contributor to a lower CO_2 footprint.

Losses of PAC and other technologies

Typical OHL conductors have 400–600 mm², while wires can be bundled to provide up to 1600 mm² conductor cross sections. Aluminum and copper cables have project-specific conductors – with an upper limit of around 2000 mm² of usable cross section due to manufacturing and transportation limitations. PAC have aluminum conductors with more than 2200 mm² and 4000–5000 mm² for rated voltages above 245 kV, see chart.



The charts show the conductor resistance of different technologies and the resulting ohmic losses for 3 phases over a 40-year lifetime as a function of the average continuous current. A single OHL or cable system cannot handle rated currents above 2000 A due to

overheating. PAC save several tens of GWh per km over 40 years compared with OHL or XLPE cables – a substantial amount of energy that is not wasted.

*Note: In the Swiss high-voltage grid (> 100 kV), around **2 TWh of energy are lost annually** – mostly on overhead lines. This illustrates the large saving potential of replacing them with PAC.*

In addition to a better LCA result, lower ohmic losses avoid several related issues of XLPE cables: no forced cooling, no concrete bed, no parallel cable systems, no additional losses for reactive power compensation, and – of course – lower loss costs.

Life Cycle Assessment of pressurized air cables

A life-cycle assessment (LCA) has been performed for various ratings and operational conditions to calculate the CO_2 equivalents. LCA is a useful method to estimate the environmental impact of a product and to compare different technologies.

The selected functional unit (FU) is the **production and operation of one kilometer of pressurized air cable for an estimated lifetime of 40 years**.

PAC products consist of > 98 % aluminum for which a CO_2 footprint of **5.66 kg CO_2-eq/kg** was used as the only material contribution. For losses during operation the CO_2 footprint of **60 g CO_2-eq/kWh** (Swiss electricity mix) is used. The end-of-life aluminum recycling recovers most of the material usage footprint. Transport, installation and maintenance are not considered here. The table gives an overview of the CO_2 footprint for each category.

	PAC Material		PAC Operation for 40 years				SF_6 offset		
Parameter	Alu	CO_2-eq	1 kA	2 kA	3 kA	4 kA	100 %	18 %	4 %
Unit	tons	*t CO_2*	*t CO_2*	*t CO_2*	*t CO_2*	*t CO_2*	*t CO_2*	*t CO_2*	*t CO_2*
Product	*per km*	*per km*	*per km*	*per km*	*per km*	*per km*	*per km*	*per km*	*per km*
145 kV (3x1ph)	83	470	1’188	4’740	7’320	n/a	71’415	12’976	2’857
245 kV (3x1ph)	120	679	582	2’340	5’280	9’360	218’799	39’756	8’752
420 kV (3x1ph)	150	849	420	1’740	3’900	6’900	361’698	65’721	14’468
52 kV (3ph)	53	300	1’188	4’740	n/a	n/a	40’158	7’297	1’606
145 kV (3ph)	62	351	582	2’340	5’280	n/a	71’415	12’976	2’857
245 kV (3ph)	80	453	582	2’340	5’280	9’360	218’799	39’756	8’752
420 kV (3ph)	96	543	420	1’740	3’900	6’900	361’698	65’721	14’468

Owing to the lower losses shown in the charts above, the operational CO_2 footprint of PAC is about one fifth of that of OHL and about one third of that of XLPE cables. Pressurized air cables therefore save at least 1’200 t of CO_2 per km installed over their 40-year lifetime.

PAC can replace SF_6 gas-insulated busbars – a typical use case driven by European legislation that phases out SF_6 in new switchgear from 2026 onwards. The SF_6 offset was calculated using the amount of SF_6 required per km of busbar (filled at 5.5 bar abs.) and a CO_2 footprint of **23’000 kg CO_2/kg SF_6**. A 100 % offset can be considered if PAC are used as a replacement in new equipment. A leakage rate of **0.5 %/year** (allowed per standard) over 40 years leads to a loss of **18.2 %** of the SF_6. **A rate of 0.1 %/year, as stated by manufacturers, leads to a loss of ~4 % in 40 years; the corresponding offsets are shown in separate columns.** The SF_6 offset values can be regarded as negative values, i.e. CO_2 footprint savings.

Conclusions

The comparison shows that offsetting SF_6 busbars has the largest positive impact on the CO_2 footprint of pressurized air cables, followed by the reduced operational losses. The net footprint of the material used is small, as it is mostly aluminum, which can be fully recycled.

The calculation of losses, the SF_6 offsetting, the recyclability of the predominantly aluminum product, and the reduced CO_2 footprint during operation confirm that pressurized air cables are well suited to significantly reduce the carbon emissions of the electricity grid.

Note: Around 560 t of SF_6 are in use in Swiss high-voltage equipment today, with a target of less than 1000 kg of emissions per year (equivalent to 23'000 t of CO_2).