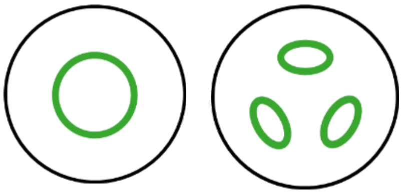
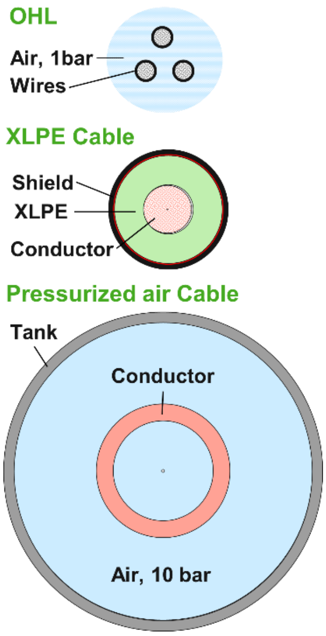
Life Cycle Analyses for pressurized air cables



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 matches all ratings from medium voltage (12 kV) to transmission voltage (420 kV).

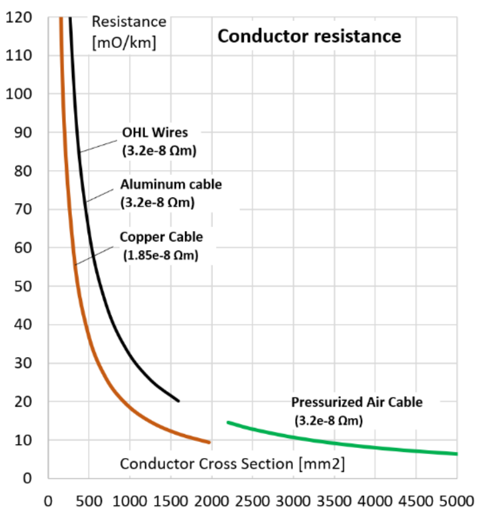


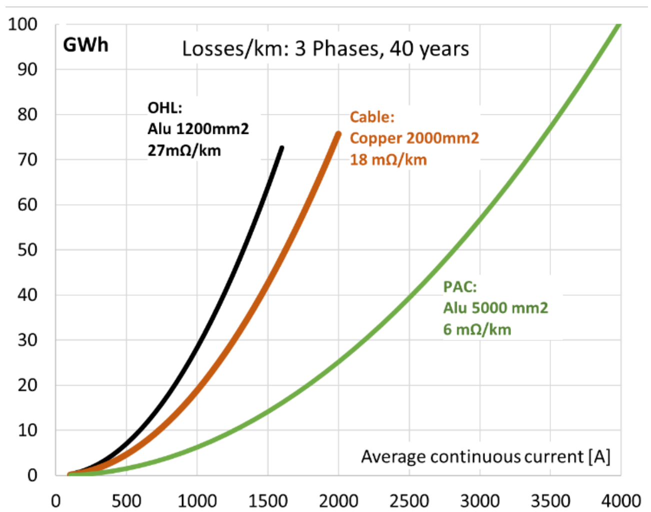
Due to their functionality and flexibility, PAC can replace overhead lines (or sections of it), XLPE cables, Gas-insulated busducts (GIB), and insulated high-current busbars. Using pressurized air as main insulation medium creates two key properties which both reduce its CO_2 emissions during operation.

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

Losses of PAC and other technologies

Typical OHL wires have 400-600 mm², while wires can be bundled to provide up to 1600mm² 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 4000-6000 mm² for rated voltages above 245 kV, see chart.





The chart shows the conductor resistance of different technologies and the resulting ohmic losses $E_{loss} = 3 * I_{avg}^2 * R_{AC} * t[h]$ 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 10 GWh per km over 40 years compared to OHL or XLPE cables – a tremendous amount of not wasted energy.

*<u>Note</u>: In the Swiss high-voltage grid >100 kV, around **2 TWh of energy are lost annually** - mostly on overhead lines. This shows the enormous saving potential if PAC replace them.*

In addition to a better LCA result, less ohmic losses improve many other related problems of XLPE cables: no forced cooling required, no concrete bed, no parallel cable systems, no additional losses for reactive power compensation, and – of course – less money lost.

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 per km	*t CO_2 per km*	*t CO_2 per km*	*t CO_2 per km*	*t CO_2 per km*	*t CO_2 per km*	*t CO_2 per km*	*t CO_2 per km*	*t CO_2 per km*
Product									
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

Given the lower losses shown in the chart above, the CO_2 footprint for operation for PAC is ~**5 times less than OHL**, and ~**3 times less than XLPE**. Therefore, pressurized air cables save at least 1’200 t of CO_2 per every km installed in their 40-year lifetime.

PAC can replace SF_6 gas-insulated busbars – a typical use case that is forced by European legislation banning SF_6 in new high-voltage equipment from 2026. The SF_6 offset was calculated using the amount of SF_6 required per km busbar (filled with 5.5 bar_{abs}) and a CO_2 footprint of **23’000** kgCO_2/kg SF_6. A 100% offset may be considered, if PAC are used as 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. **0.1%/year** as claimed by the manufacturers leads to **~4%** loss in 40 years – its offset is shown in separate columns. The SF_6 offset values can be considered negative values – e.g. CO_2 footprint savings.

Conclusions

The comparison shows that offsetting SF_6 busbars has the biggest 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’s mostly aluminum which can be fully recycled.

The calculation of losses, the SF_6 offsetting, the recyclability of the mostly aluminium product, and the reduced CO_2 footprint during operation confirm the suitability of pressurized air cables to strongly reduce the carbon emissions of the electric grid.

Note: Around 560 tons of SF_6 is in use in Swiss High Voltage equipment today with target emissions of less than 1000 kg (equivalent to 23’000 tons of CO_2) per year.