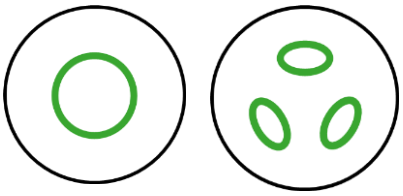
Single-phase and three-phase encapsulation



Introduction

Hivoduct pressurized air cables (PAC) are designed to transmit electric energy at high voltage (12 kV – 420 kV) and high AC currents (200 A – 3150 A). They are built and used according to IEC 62271-204 standard.

Two different designs regarding encapsulation are available to meet various technical, operational, spatial, and economic requirements: **Single-phase** or **three-phase**.

Single-phase encapsulated designs have one cylindrical phase conductor placed coaxially inside a cylindrical enclosure tube to form an optimal and rotational dielectric arrangement. The air gap between conductor and enclosure provides the main insulation. The enclosure is a pressure vessel and seals the inside air pressure. Three such arrangements are needed for a system.

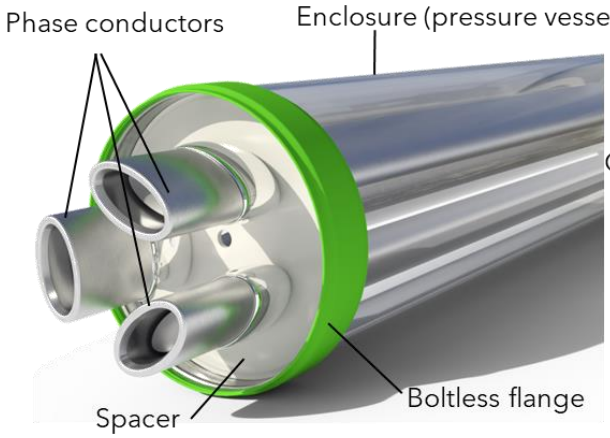
Three-phase encapsulation is done by placing all 3 phase conductors inside one common cylindrical enclosure tube in an equilateral triangle. The air gap between the conductors and towards enclosure provides the main insulation. One arrangement is needed for a system.

These different arrangements lead to different technical and application options which are detailed below. Note: Traditional gas-insulated lines or busducts predominantly utilize three-phase encapsulation up to 145 kV rated voltage and single-phase encapsulation above.

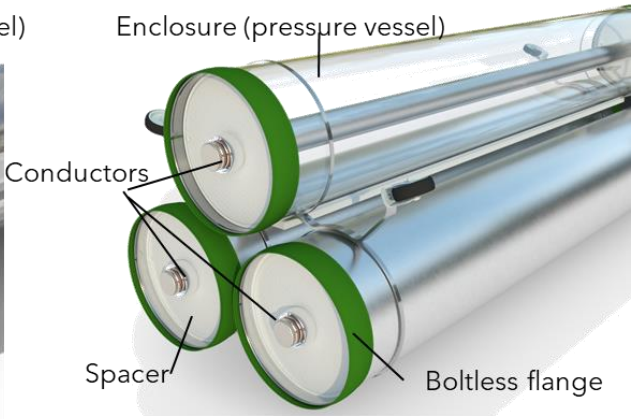
Basis design comparison: 3-ph vs. 1-ph encapsulation

The principal arrangements for pressurized air cables in a 3-phase enclosed design vs. 3 times a 1-phase enclosed designs are shown here:

3-ph enclosed design



3 x 1-ph enclosed design



Three-phase enclosed systems in general built more compact as it is a fully integrated system using optimized shapes for all items: Cylindrical shape for the enclosure to provide maximum strength against inside pressure. And elliptical shape for the conductors to optimize inside volume for dielectric and conductor cross section. However, more complex flange connections, the larger diameter of the single enclosure, non-rotational symmetric field calculations, and non-trivial manufacturing are demanding for three-phase designs.

In contrast, single-phase systems use standard tube shapes, are rotational symmetric for calculations and manufacturing, and have vast operational experience at all voltage levels.

Other key advantages of single-phase systems are its layout flexibility, and avoiding 3-phase short-circuits.

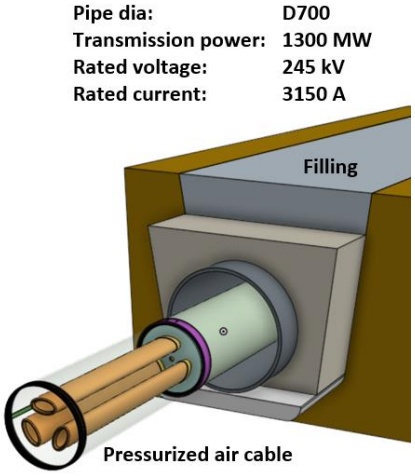
Hivoduct has developed a full portfolio of PAC components like: Straight busbars, angle pieces, air bushings, and other interfaces to allow engineering solutions for any layout in both encapsulation options. The table compares its technical data for different products.

Comparison of technical data

	52 kV		145 kV		245 kV		420 kV	
Characteristic	**1ph**	**3ph**	**1ph**	**3ph**	**1ph**	**3ph**	**1ph**	**3ph**
Transmission capacity per system [MW]	280	230	800	630	1600	1300	3600	2900
Installation size W x H [m]	0.4 x 0.4	0.3 x 0.3	0.7 x 0.7	0.5 x 0.5	0.7 x 1.2	0.7 x 0.7	0.8 x 1.8	0.8 x 0.8
Rated current	3150	2500	3150	2500	4000	3150	5000	4000
Weight per m, 3-ph system [kg]	55	53	83	62	120	80	150	96
Inside volume, 3ph, per m [liter]	43	40	162	115	345	196	595	365
Capacitance per m per phase [pF/m]	107	83 + 3*25	55	41 + 3*12.5	55	40 + 3*12	43	31+ 3*9
Number of flanges / km	~600	~200	~600	~200	~600	~200	~600	~200
Sealing length / km [km]	271	172	516	247	740	323	970	536
Layout flexibility	High	Limited	High	Limited	High	Limited	High	Limited
Best application: Principal layout case	Short & zig-zag	Long, straight	Short & zig-zag	Long, straight	Short & zig-zag	Long, straight	Short & zig-zag	Long, straight
Reference installations	Yes	Soon	Yes	Soon	Yes	Soon	Soon	No

The transmission capacity for all PAC variants is significantly higher than transmission capacities of OHL systems or XLPE cables. They can therefore replace two or more parallel systems of these technologies.

Three-phase enclosed PAC design requires less installation space, which together with the proprietary roller system make them specifically advantageous for installation in pipes, micro-tunnels, or existing service tunnels.



The reduction in rated current for three-phase encapsulated systems origins from the reduced overall enclosure surface to dissipate the heat due to ohmic losses. The surface reduces proportionally to the inside air volume and the weight per system by around 30 % for three phase encapsulations vs. single-phase encapsulation. An upgrade with painted enclosures to enhance its emissivity can alleviate current limitations.

The sealing length and the number of flanges both are reduced for three-phase systems. They are a key indicator for installation effort, pressure monitoring efforts, and gas-tightness.

Hivoduct will support customers in choosing the most suitable enclosure option during the project engineering phase.