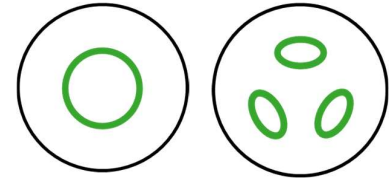


Sealing system, Air filling and top-up, and leakage rates



Introduction

Hivoduct pressurized air cables (PAC) are designed to transmit electric energy at high voltage (12 kV - 420 kV) and high AC currents (1000 A - 3150 A). They are built and used according to IEC 62271-204 standard.

PAC use Hivoduct's proprietary flange connection which is specifically improved regarding air tightness. All connections use a double radial sealing system with 4 sealing lips to provide a lifetime sealing for the differential air pressure of <11.5 bars.

The gaskets are protected inside the flange from environment by 2 layers of aluminum and a flange cover.

The sealing system is static (only minor slow movements due to temperature elongations), at a maximum of 75 °C enclosure temperature built on precise in-house flange machining.

The IEC 62271-203, 204 standards for Gas-insulated high-voltage switchgear specifies the gas-tightness for HV equipment in section 6.16.3, to be:

- For SF₆ and SF₆ gas mixtures: **0.5 %/year**
- For other gases: **1 %/year**

The standard therefore recognizes the less environmental impact of air in case of a leakage.

Filling, warning level, alarm level, and top-up

PAC are pressurized with technical air with 10 bar at 20 °C environmental temperature. Warning level and alarm level of the density sensors are set at slightly lower levels to inform the customer about pressure loss. The alarm level value is the minimum functional pressure used during type testing to confirm full functionality.

Process	Pressure
Filling	10 bar
Warning level	9.8 bar
Alarm level	9.6 bar
Max operating pressure (T _{max})	11.5 bar
Bursting pressure	> 57.5 bar

Heating during operation leads to temperature rise which may raise the inside pressure to maximum operating pressure. The bursting pressure is 5 x the maximum operating pressure for safety according to pressure vessel codes and internal arc events.

Inside air **density** is calculated from **pressure** and **temperature** by the gas equation using the universal gas constant for air $R_{air} = 287 \text{ J/kg/K}$.

Topping up is required, if the inside pressure (or its according density) reaches the warning level. Due to the optimized sealing system and the inherently large gas compartments, it may take years for the pressure to fall below warning level. Without any major event, it then takes similarly long to go from warning level to alarm level - which provides sufficient time to plan for refilling or top-up. We suggest to plan for top-up during a maintenance phase where the connection is not energized.

Topic	Pressurized air cable
Medium	Pressurized Air
Temperature range	-30°C + 75°C
Sealing direction	Radial
Sealing system	Form fit
# of sealing surfaces	1 per flange
Movement	Static sealing
Gasket type	Shaped, 2 Lips
Gasket material	NBR, FKM
Gasket protection	2 layers Alu
Redundancy	2 gaskets = 4 lips each sealing
Inside pressure	< 11.5 bar
Dust protection	Flange cover
Enclosure current	Spiral contact

Leakage rate and refilling interval

The leakage rate r is estimated based on available long-term measurements and internal tests to be $< 0.5\%$ p.a. for PAC products. With a leakage rate of $r = 0.5\%$ p.a., the time duration between filling pressure of 10 bar and $\Delta p = 0.4$ bar, i.e. $p = 9.6$ bar is:

$$9.6 \text{ bar} = 10 \text{ bar} * e^{-r*t} \quad \rightarrow \quad t = -\frac{\ln\left(\frac{9.6 \text{ bar}}{10 \text{ bar}}\right)}{r} \approx 8.1 \text{ years}$$

This results in an expected time to reach the warning level of > 4 years and time to reach the alarm level of > 8 years.

Equipment and procedure for refilling or top-up

Topping up is done by connecting a pressurized air bottle via a pressure reduction valve to the air filling valve of the according compartment. The following equipment is needed to perform a top-up:

- Technical air (N_2 : 80% O_2 : 20 %) in bottle, e.g. 50 liter, 200 bar
- Pressure reduction device connects to the technical air bottle and the filling hose.
- Filling hose of 1-3 m length.
- T-Connecting piece on the air filling valve
- Eventually for elevated installations: Scaffold or man lifter to reach to the valve

The following procedure is proposed to perform a top-up

1. Use a maintenance phase where the system is de-energized.
2. Bring a bottle of technical air nearby to reach the filling connections with the hose.
3. Unplug the pressure sensor from the gas compartment.
4. Connect a pressure reduction device to the technical air bottle and set maximum pressure at the valve to ~ 11 bar.
5. Plug the filling hose in the pressure reduction device
6. Plug the other end of the filling hose into the connection.
7. Slowly open the filling valve on the pressure reduction device. Air will start flowing into the gas compartment, making a continuous "zisch" noise.
8. Limit the air flow out of the air bottle to avoid freezing due to expansion cooling.
9. Watch the pressure rise on the pressure sensor. Due to large gas compartments, the pressure will increase slowly. Topping up may take minutes to hours.
10. After filling pressure is reached: Close the valve of the pressure reduction device.
11. Monitor the pressure for 30 minutes. The pressure settles slightly during this time.
12. Unplug the filling hose, pressure sensor, and T-Connection.
13. Plug the pressure sensor directly into the gas compartment. Make sure the plug is axially aligned when pushing it into the socket. 10 bar inside pressure produces significant counteracting force when plugging.
14. Store the synthetic air bottle, the pressure reduction device and the T-Connection for next time use.

