

## Internal arc faults

### Introduction

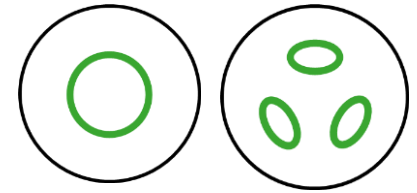
Hivoduct pressurized air cables (PAC) are designed to transmit electric energy at high voltage (12 kV - 420 kV) and high AC currents (1000 A - 5000 A). They are built and used according to IEC 62271-204 standard.

PAC use Hivoduct's proprietary flange connection which is specifically optimized for a lifetime sealing for the differential air pressure of <11.5 bars and a large margin for bursting pressure.

Internal arc faults are rare events where a failure of the internal insulation (air or spacers) leads to a flashover during operation.

The resulting internal arc carries the short-circuit current and pushes along the inside of the busbar between conductor and enclosure at speeds of >20 m/s due to "Lorentz"-forces. Due to its high temperature, it produces melting points on both ends and strongly increases the air pressure around it - destroying the inside of a PAC and producing a high-pressure wave. The effected busbars have to be replaced after an internal arc fault event.

Typical short-circuit current ratings for high-power connections are 40 kA, 50 kA, and 63 kA with typical worst-case interruption times of 0.1 s and 0.3 s.

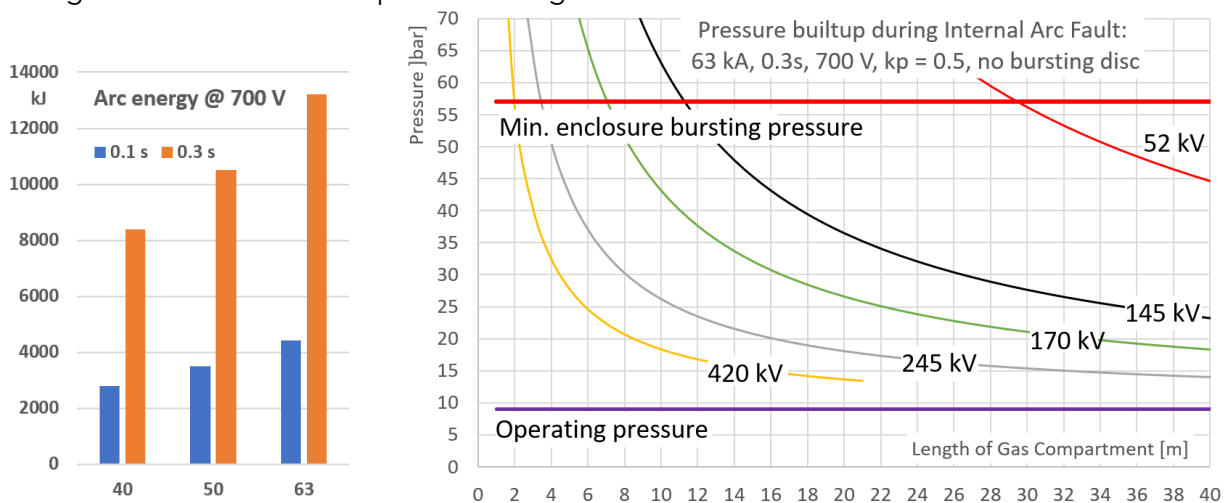


Process	Pressure
Filling	10 bar
Warning level	9.8 bar
Alarm level	9.6 bar
Max operating pressure (T <sub>max</sub> )	11.5 bar
Bursting pressure	> 57.5 bar

### Energy and pressure during internal arc fault

The energy dissipated by the arc during an internal arc fault can be calculated by  $E_{arc} = U_{arc} \cdot I_{arc} \cdot t_{arc}$  using the specified short-circuit current and time and a typical arc voltage in air of  $U_{arc} = 300$  to  $700$  V. The chart below shows the arc energy for different short-circuit currents and time. It is generally in the several MJ range for the given ratings.

It is a standard simplified model approximation that 50 % of the arc energy is transferred into melting of both electrodes whereas the other 50 % are transferred into heating the air and therefore creating overpressure. The temperature increase inside the busbar is  $\Delta T_{air} = 0.5 \cdot E_{arc} / (m_{air} \cdot c_{p,air})$ , using the specific heat capacity of air  $c_{p,air} = 1$  kJ/kg/K. The air mass calculates from its specific density  $\rho_{air} = 1.2$  kg/m<sup>3</sup> and the length and diameter of the busbar. The resulting pressure increase is  $\Delta p_{arc} = \rho_{fill} \cdot \Delta T_{air} / T_{20}$  as it is a closed volume. The chart shows resulting pressure for different PAC products for 63 kA, 0.3s arcing time and 700 V arc voltage as a function of compartment length.



The chart shows that the pressure buildup is lower for higher rated voltages due to their much larger inside air volume. For single-phase enclosed MV busbars, a minimum length of 30 m is required to stay below bursting pressure during internal arc fault at 63 kA, 0.3 s.

## Minimum gas compartment length

The pressure rise during internal arc fault shall remain lower than the bursting pressure to avoid rupture of the enclosures and to avoid danger to the environment.

The table shows the inside air cross section, the air weight per product, and the resulting minimum compartment lengths.

Parameter	Key values		Minimum compartment length		
	CS	Air	40kA,0.3s	50kA, 0.3s	63kA, 0.3s
Unit	m <sup>2</sup>	kg/m	m	m	m
Product					
145 kV (3x1ph)	0.056	0.67	4.5	5.5	7
245 kV (3x1ph)	0.113	1.36	2.5	3	3.5
420 kV (3x1ph)	0.196	2.12	1.2	1.8	2
52 kV (3ph)	0.035	0.42	7	9	11
145 kV (3ph)	0.113	1.36	2.5	3	3.5
245 kV (3ph)	0.196	2.12	1.2	1.8	2
420 kV (3ph)	0.347	4.04	1.0	1.3	1.5

According to the chart above and the values provided in the table, a minimum length > 15 m is sufficient for all HV products to cover all short-circuit current specifications. 3-ph encapsulated products have less pressure increase during internal arc fault due to their larger inside air volume.

The large margin of the enclosures for bursting pressure provides mechanical rigidity for all possible site conditions and additional safety in case of an internal arc fault.

As most connections are much longer than 15 m and less demanding short-circuit specifications, there are generally no bursting discs required for pressurized air cables.

The short-circuit current loop is closed via the enclosure. The large enclosure cross section leads to a moderate temperature increase in case of short-circuit - which is below enclosure temperature during temperature rise testing. Short-circuit current events therefore do not require extra measures to cope with thermal expansion.

## Fault location and repair after internal arc fault

Internal arc fault cases are rare and the most damaging events that can happen to a PAC connection. After such an event, the affected busducts and probably several ones in the vicinity of the failure must be replaced as they are damaged by arcing and hot gas spreading. The location of the fault may not be visible from the outside.

Hivoduct's proprietary monitoring system can be used to monitor pressure and temperature during operation as well as to predict the fault location for long installations. Two pressure sensors are placed in each gas compartment on either end. The pressure wave created by the arc propagates along the busbars and support spacers in both directions and eventually reaches the pressure sensors. The time difference of the pressure increase at each sensor can be used to locate the fault.

*Note: Gas-insulated switchgear require bursting discs to avoid rupture during internal arc fault, as they have separate, sometimes very small gas compartments for each functional element.*