ABB HVAC WEBINARS

Variable speed drives for reliable and efficient tunnel ventilation

Technical requirements and solutions to answer the needs

Maria Fedorovicheva – Global HVACR Product Marketing Manager, ABB Motion

ABB at a glance

Facts and figures

What
Offering

For whom
Customers

Where
Geographies

Pioneering technology

Products | **Systems** | **Services & software**

Buildings | **Industry** | **Transport & infrastructure**

Globally

Asia, Middle East and Africa | **Americas** | **Europe**

Revenue ~$28 bn | Countries ~100 | Employees ~110,000*

Source: Annual Report 2019 published financial results
*As of July 1, 2020

Overview

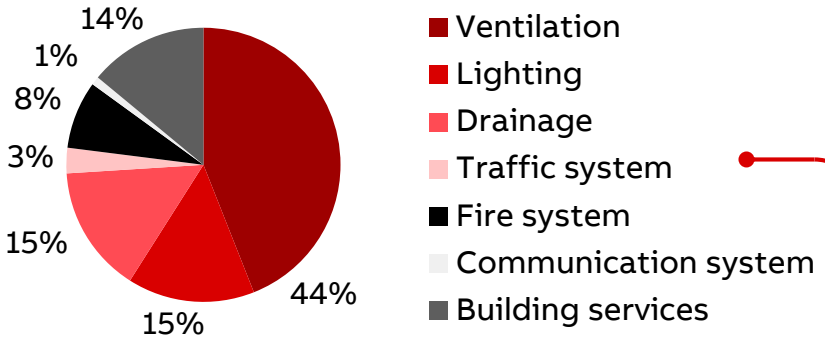
- Introduction into the tunnel ventilation segment
- Standards in the industry
- Drive features to support tunnel ventilation requirements
- ABB drives and motors for tunnels ventilation
- Success factors
- Where to find more info

Introduction into the tunnel ventilation segment

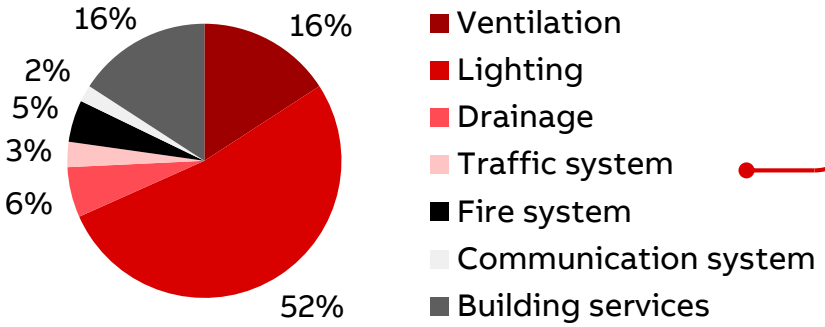
Tunnel energy use

Where the focus on ventilation is coming from

Installed power[1]

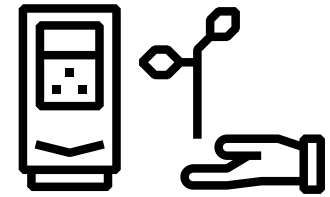


Consumed power (normal mode)[1]



40% of installed power accounts for ventilation

16% of energy used accounts for ventilation



20 to 60% of energy is saved with VSDs for ventilation

1. Based on data from different road tunnels in Netherlands, Zero energy Tunnel-concept by R. Dzhusupova and TUE.

Tunnel ventilation

General highlights

Tunnel ventilation design and requirements depend on:

- **tunnel length**
- **tunnel purpose** – road, rail
- **tunnel design** – uni- or bi-directional, single or double decked
- **landscape and surrounding environment** – underwater or underground, city or country area

Tunnel ventilation can be:

- **dual purpose** – ensure air quality in normal situations and extract smoke / maintain evacuation routs in case of a fire
- **single purpose** – smoke is extracted by dedicated fans withstanding high temperatures for a relatively long time

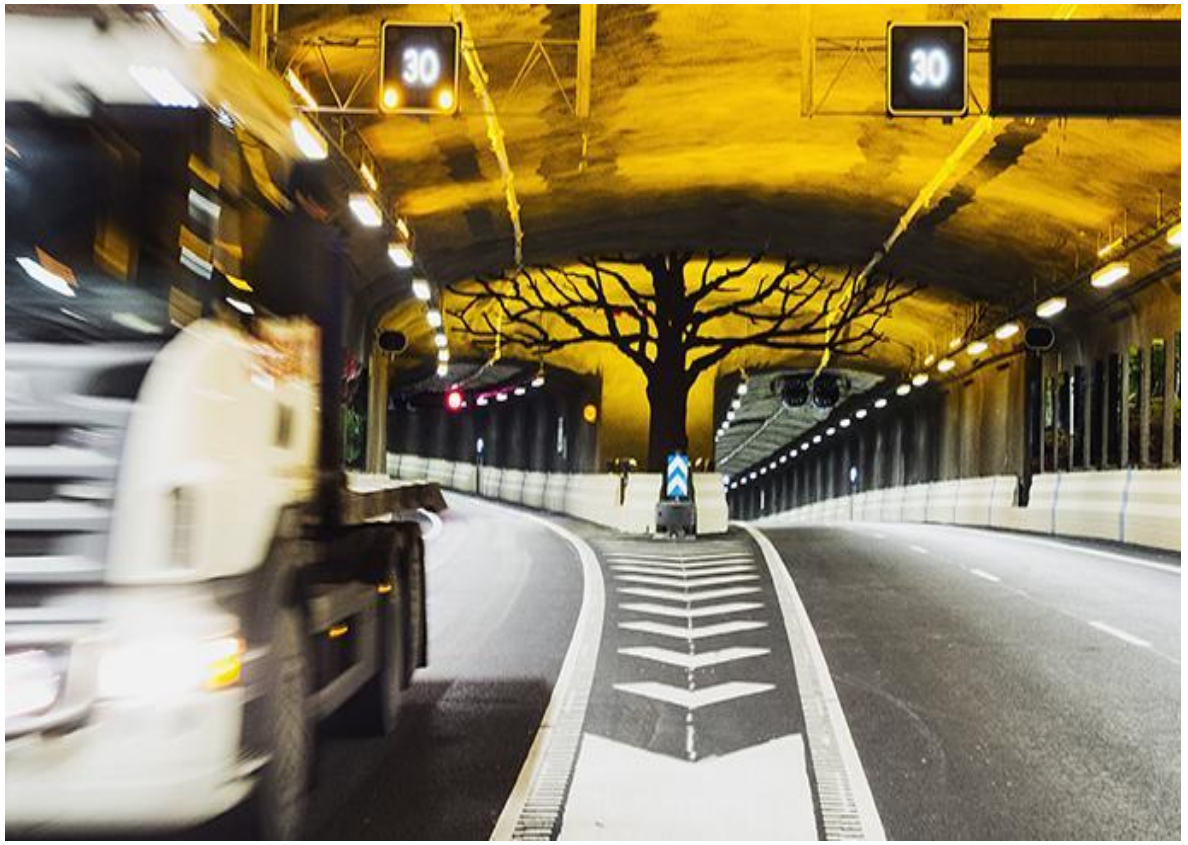
ABB Drives offer control solutions for fan-driven tunnel ventilation for both normal and emergency situations.

Tunnel ventilation

Road tunnels

- Ventilation intensity in road tunnels depends on CO, CO2, NOX and SO2 concentration, particulate matter in the air, volatile organic compounds and in-tunnel temperatures.
- For tunnels up to ca. 500 m[1] long natural airflow is usually sufficient to maintain in-tunnel air quality.
- For longer tunnels active fan-driven ventilation is required to ensure in-tunnel air quality.
- Emergency ventilation for smoke extract, heat withdrawal and evacuation maintenance is often part of any road tunnel longer than ca. 150 m.[2]

Note: road tunnel ventilation often runs on 690V (substations are at the end of the tunnel) – this means longer intermediate cables and higher power losses as a result.



1. Advisory Committee on Tunnel Air Quality, NSW Government – TP04: Road Tunnel Ventilation Systems. The EU Directive on minimum safety requirements for tunnels in the Trans-European Road Network sets the limit 1000 m.
2. Transport Asset Standards Authority, NSW Government Australia – Technical Note TN 004: 2019, Updates to ESC 340 Tunnels, v2.3.

Tunnel ventilation

Rail tunnels

- Natural ventilation in rail tunnels is ensured by the piston effect created by moving trains.
- Air conditioning may be needed for stations and passages where the temperature is high and the oxygen concentration is low at rush hours.
- Emergency ventilation for smoke extract and evacuation is often part of any tunnel longer than 150 m.[1]

Note: rail tunnel ventilation mostly runs on 400V (substations are at the intermediate stations) – this means shorter intermediate cables and lower power losses as a result.

1. Transport Asset Standards Authority, NSW Government Australia – Technical Note TN 004: 2019, Updates to ESC 340 Tunnels, v2.3.

Standards in the industry

Tunnel ventilation

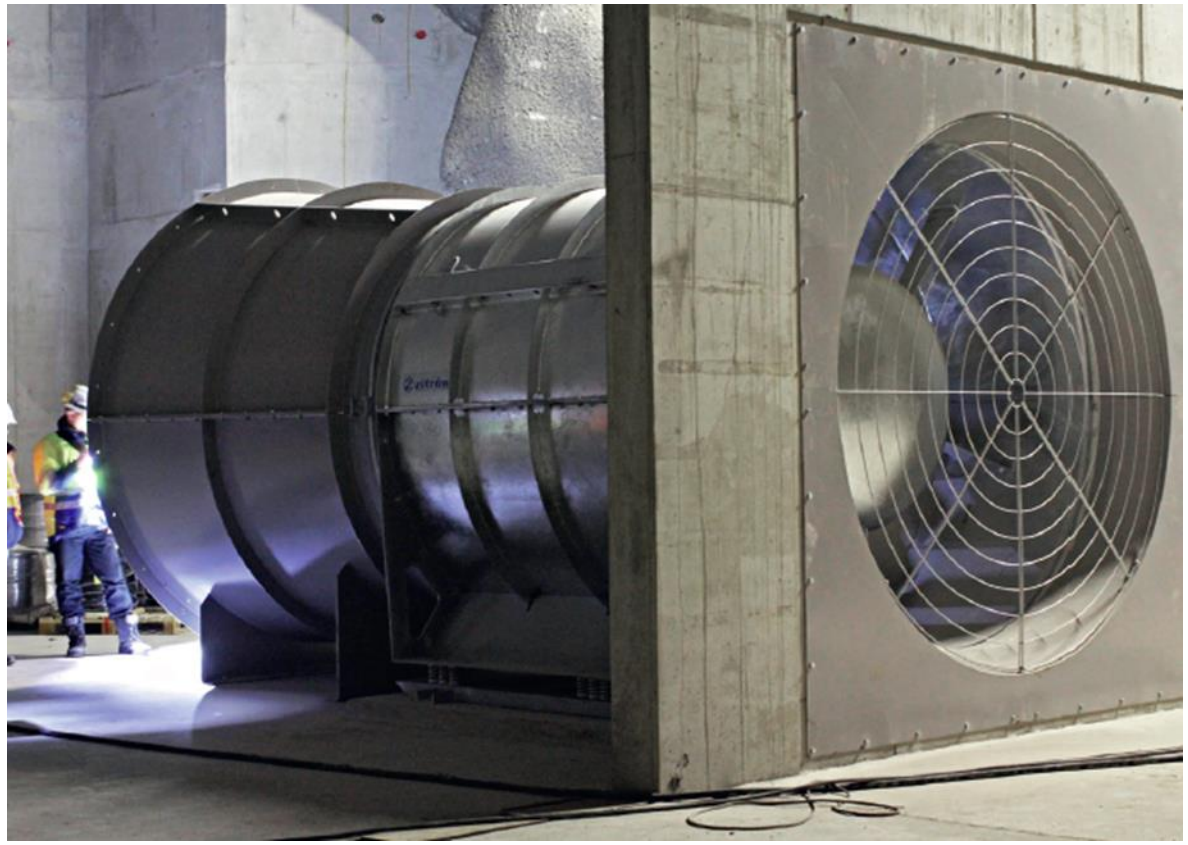
Standards in the industry

EN 12101-3 “Smoke and heat control systems – Part 3: Specification for powered smoke and heat exhaust ventilators”.

- Set requirements for smoke and heat control fans as part of a smoke and heat control ventilation.
- For fans, full compliance with the standard requires:
  - testing and certification of fan + VSD package, or
  - bypass of the VSD during a fire event, or
  - 20% derating of fan motor and voltage waveform filter.
- ABB has tested ACH580 and ACS880 drives with selected OEMs for compliance with the standard.

Harmonic requirements are coming from local electricity distribution codes.

- E.g. tunnel projects in Australia follow IEEE 519 “Recommended practice and requirements for harmonic control in electric power systems”.



Tunnel ventilation

Standards in the industry

Projects can have more severe requirements set e.g. by operating companies or national codes.

- E.g. ACH580-01/31 IP55 drives recently obtained a national French certification on running 1 h at 70°C requested by a metro operator.

ABB

HELSINKI, NOVEMBER 21, 2017

Manufacturer's Statement

ACH580-01/-31 performance at 70 °C

ABB Low Voltage Drives ACH580-01/-31 run normally in ambient temperature of 70 °C for 1 hour.

We hereby confirm that ABB HVAC drives ACH580-01/-31 power range from 0.75 kW to 250 kW run normally in ambient temperature of 70 °C for 1 hour when so called Override mode has been activated.

ABB Oy

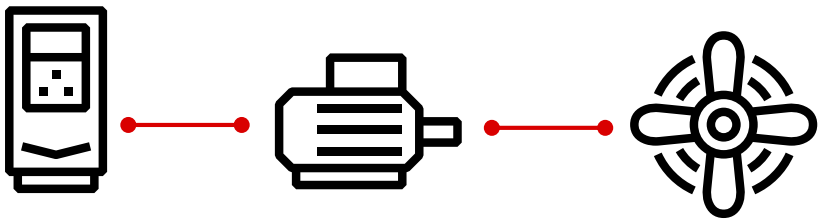
Katja Hakoneva
Product manager
Low Power Drives and Automation
ABB Drives

The Manufacturer's statement available in ABB library under 3AXD10000668190.

Drive features to support tunnel ventilation requirements

Drive role in the tunnel ventilation

What it is capable of



The drive controls a motor running a fan

- **secures the tunnel environment** maintaining visibility, low fume concentration and comfortable temperature through the fan speed
- **saves energy** adjusting the fan speed to the everchanging needs of the tunnel environment
- **prevents mechanical and electrical shocks** starting the fan smoothly
- **delivers nominal power** to the fan compensating voltage drop in long cables and network fluctuation
- **eliminates power quality issues in the power network** decreasing harmonics to a minimum and keeping power factor equal to 1
- **helps in evacuation and fire suppression** promptly changing fan speed and rotation direction according to a need
- **cuts project costs** related to system and component sizing

Flying start

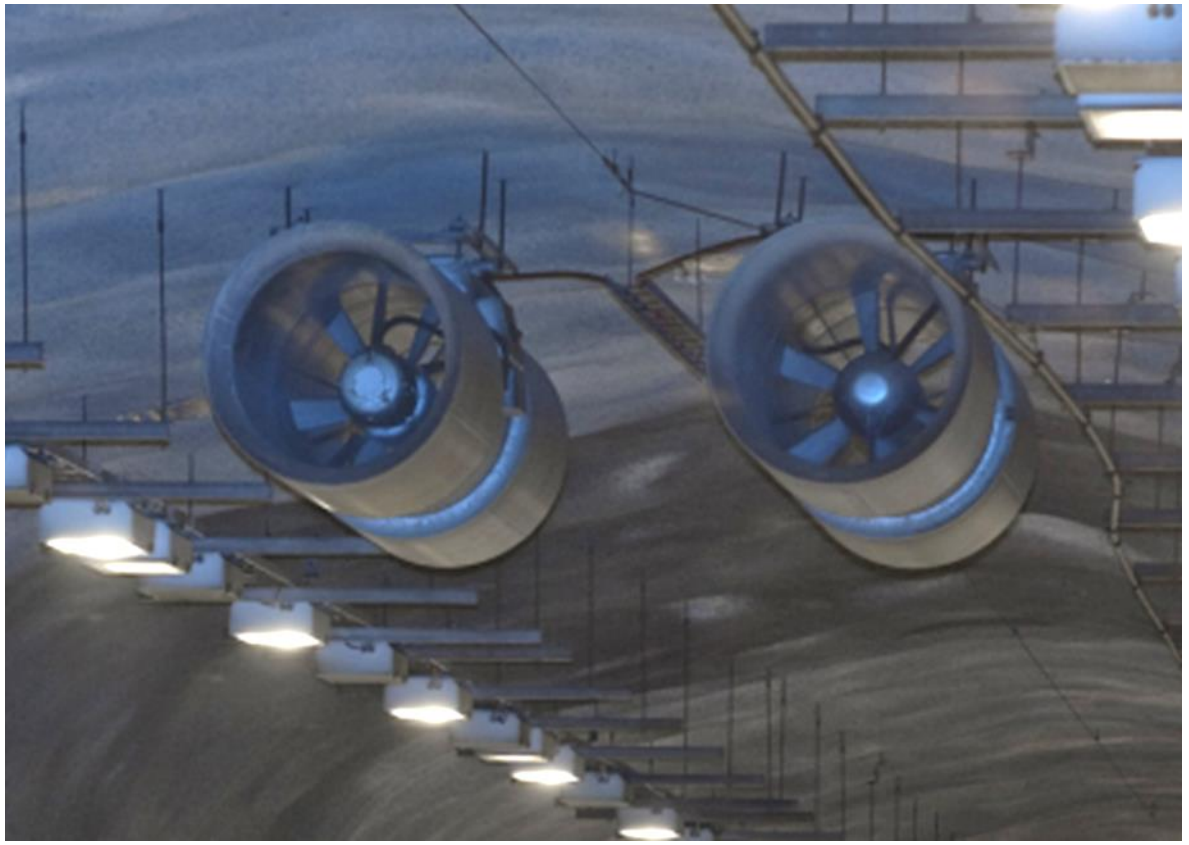
Catching a freely spinning load

Drives' flying start is particularly important for tunnel fans.

Allows to catch a freely spinning fan on the fly:

- no wasting time on braking the fan to zero speed first
- no mechanical stress caused by braking, damage to gearboxes or couplings
- no drive electrical stress due to overcurrent trip

The drive motor control program identifies the flux and the mechanical state of the motor and starts the motor instantly at the current frequency.



Fireman’s override

Ventilation response in case of emergency

Override is an emergency mode in drives allowing to run motors “at all costs” ignoring interlocks, warnings and faults.

Benefits of ABB drives with fireman’s override:

- Seamless shift from normal mode to override and back:
  - regular test runs won’t upset the ventilation system since the drive comes back to normal with no need for manual reset

- Multiple speeds during the override mode:
  - helps avoid dangerous smoke back-layering in case of fire in tunnels

- Ability to change the rotation direction:
  - flexibility in evacuation and smoke extraction strategies
  - additional smoke extraction capability

Fireman’s override

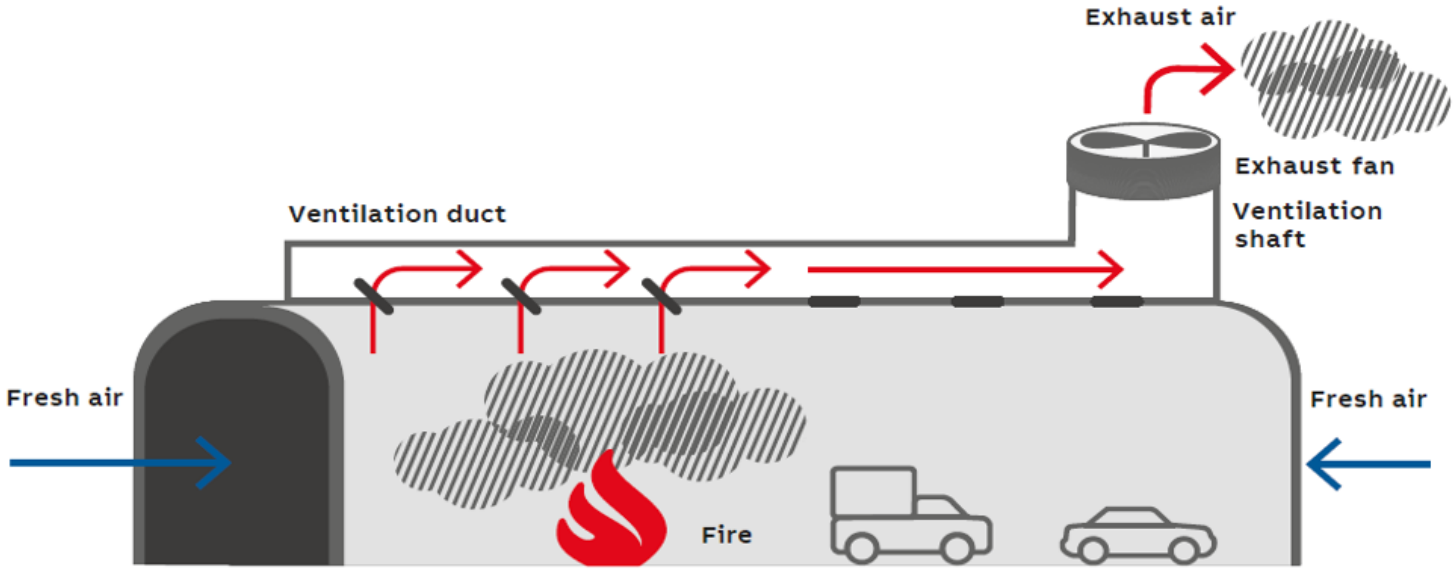
Ventilation response in case of emergency

The emergency ventilation strategy depends on the tunnel ventilation design.

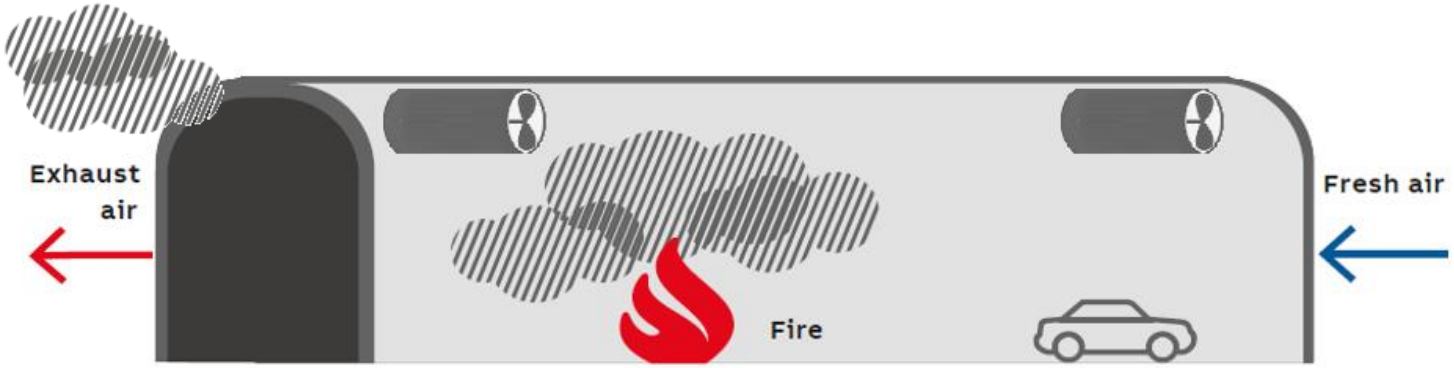
Transverse ventilation is flexible – the smoke can be extracted in the fire area at max speed.

Longitudinal ventilation implies:

- usage of bidirectional fans
- in unidirectional tunnels, the smoke extraction in the traffic direction
- in bidirectional tunnels, the smoke extraction towards the closest portal
- slow fan start to maintain stratification and provide escape routes under the smoke layer
- fan speed increase after the evacuation to keep the smoke on the fire downstream for safe fire brigade access



Semi-transverse road tunnel ventilation



Longitudinal road tunnel ventilation

Braking

Flux braking, resistor braking and active braking

Project requirements for fans can set a max braking / acceleration time which is critical for fire emergency.

- E.g. in the event of fire, the fan should change the direction from max speed forward to max speed reverse within 30s.

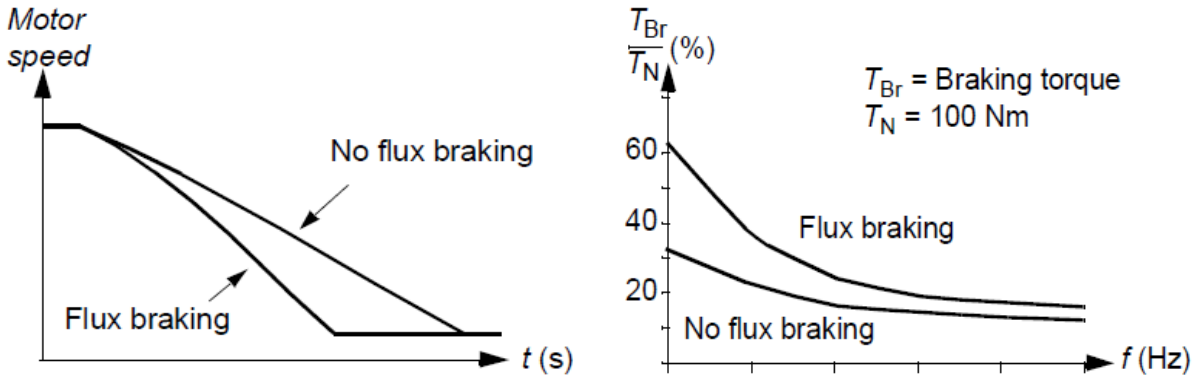
There are several ways to brake a fan including:

- magnetic flux braking
- resistor braking
- active (regenerative) braking

See ABB Technical guide N8 – Electrical braking for braking time calculation examples.

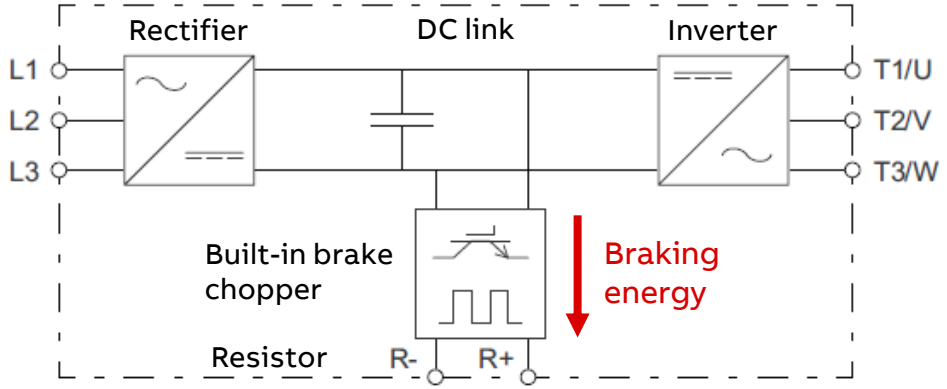
Braking

Technologies – flux braking, resistor braking and regenerative braking



Flux braking eliminates the need for resistors in low inertia systems.

- The drive provides deceleration by raising the motor magnetization and converting mechanical braking energy to thermal energy in the motor.



Brake choppers and brake resistors equipping the drive allow shorter braking time.

- The chopper operates when the DC link voltage exceeds a max limit – typical for deceleration of a high inertia motor.

ABB's ACH480 and ACH580-01 up to R3* have brake choppers built-in decreasing installation footprint, complexity and cost.

Braking

Technologies – flux braking, resistor braking and regenerative braking

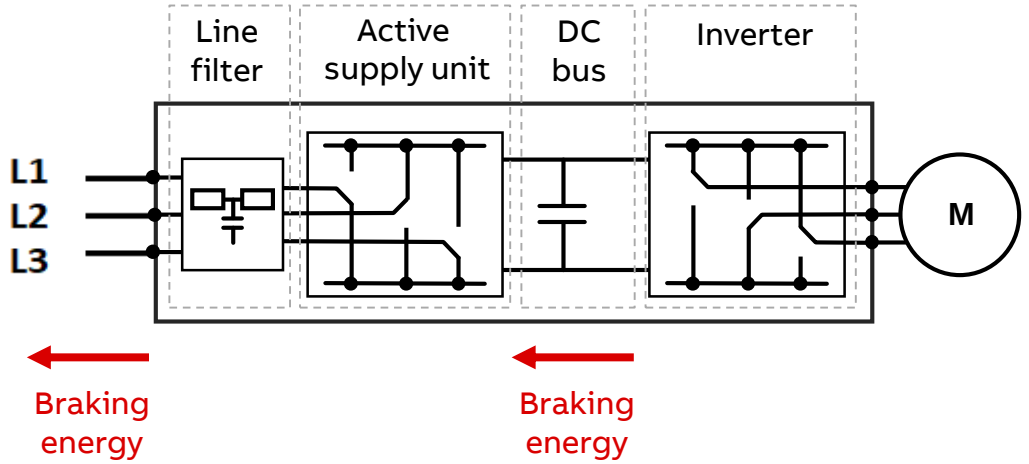
Regenerative braking returns braking energy of the motor back to the drive and further to the supply network.

There are different active braking solutions exist – matrix drives, IGBT-supplied drives, external regenerative braking units, modular solutions with regenerative rectifier.

ABB's ACS880 regen drives with active front end supply come in one compact package:

- drive includes an active supply unit making the energy recovery possible
- active supply unit is also controlled to eliminate low order current harmonics
- line filter suppresses harmonic components above the switching frequency of the active supply unit IGBTs

IGBT-supplied active front-end drive



Braking

Regenerative drives advantages

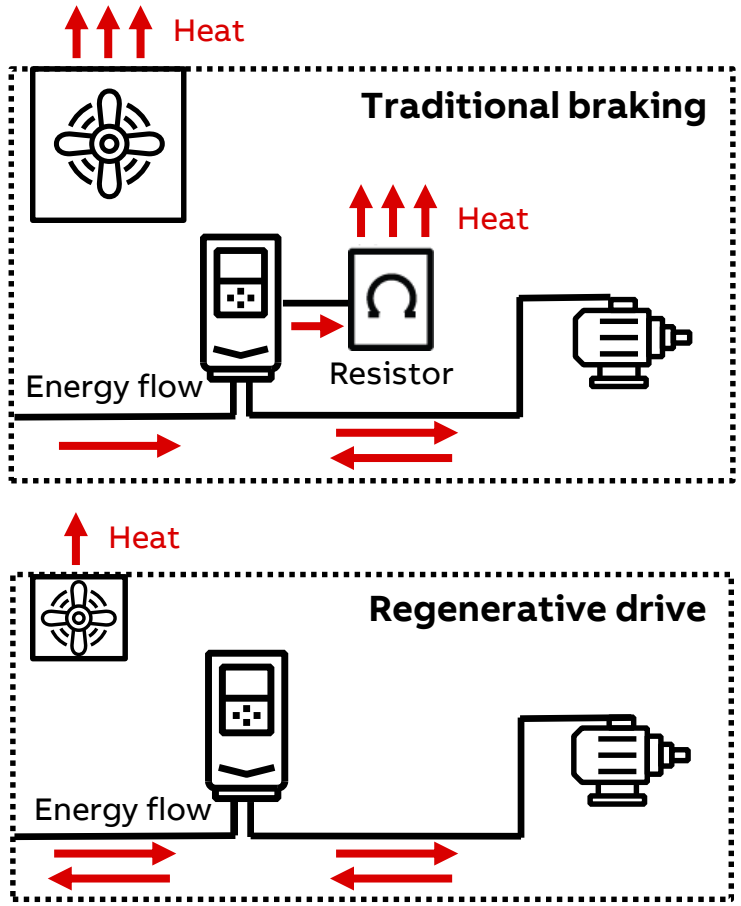
In resistor braking energy dissipates as heat.

With regenerative braking no extra heat is produced resulting in:

- lower investment cost on air conditioning
- lower operational cost of air conditioning

Above aforementioned, ABB regenerative all-in-one concept benefits in:

- lower installation footprint since braking modules need more space to accommodate extra hardware



Braking

ABB regenerative drives advantages

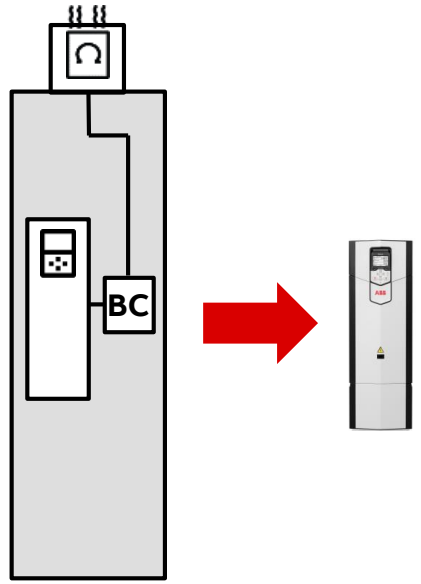
Multiple components require bigger cabinet and larger footprint.

ACS880-11 offers IP55 protection class which enables cabinet-free installation.

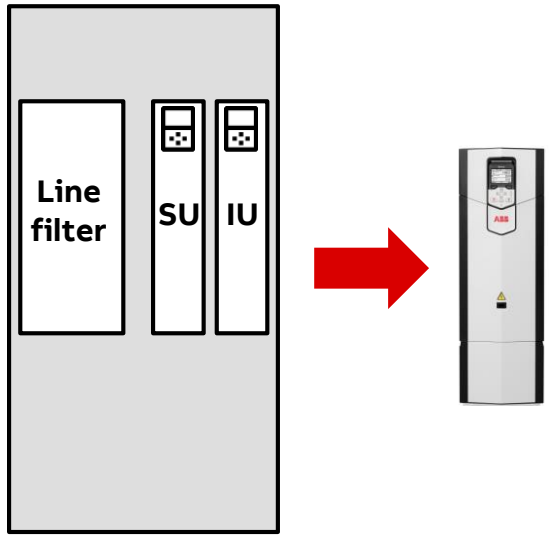
With ACS880-11 everything required for regenerative operation is built-in. This one single component reduces:

- engineering effort
- installation volume
- installation work
- equipment cost

Up to **85%** space savings



ACS880-11 vs resistor braking
55 kW, 400 V



ACS880-11 vs modular solution
110 kW, 400 V

55 kW:
BC = Brake chopper
Cabinet & braking resistor: H x W = 2220 x 600 mm
ACS880-11: H x W = 771 x 252 mm

110 kW:
SU = active supply unit, IU = inverter unit
Cabinet: H x W = 2000 x 1000 mm
ACS880-11: H x W = 965 x 300 mm

Braking

Comparison of different braking technologies

	6-pulse drive with brake chopper and resistor	6-pulse drive and external regen braking unit	Matrix drive	Regenerative rectifier unit	IGBT supplied low harmonic drive
Typical THDI%	No input choke >100% With input choke ~40%	No input choke >100% With input choke ~40%	<5%	> 5 to 100% depending on used technology and filters	<3%
Capability to return braking energy to network	No	Yes	Yes	Yes	Yes
Drive system efficiency (excl. supply and motor)	98%	96%	95%	97%	97%
Motor voltage	~0.95 × supply voltage	~0.95 × supply voltage	~0.87 × supply voltage	~0.95 × supply voltage	full motor voltage
Basic components to be installed	Standard 6-pulse drive Brake chopper Brake resistor Input choke EMC filter	Standard 6-pulse drive Braking unit Braking reactor Input choke EMC filter	One single component	Motor inverter Rectifier unit Input choke EMC filter	One single component
Fuses required for drive	Yes	Yes	Yes	Yes	Yes
Fuses required for braking circuit components	No	Input fuses are required for braking unit	No	No	No
Installation footprint	600%	220%	250%	220%	120%

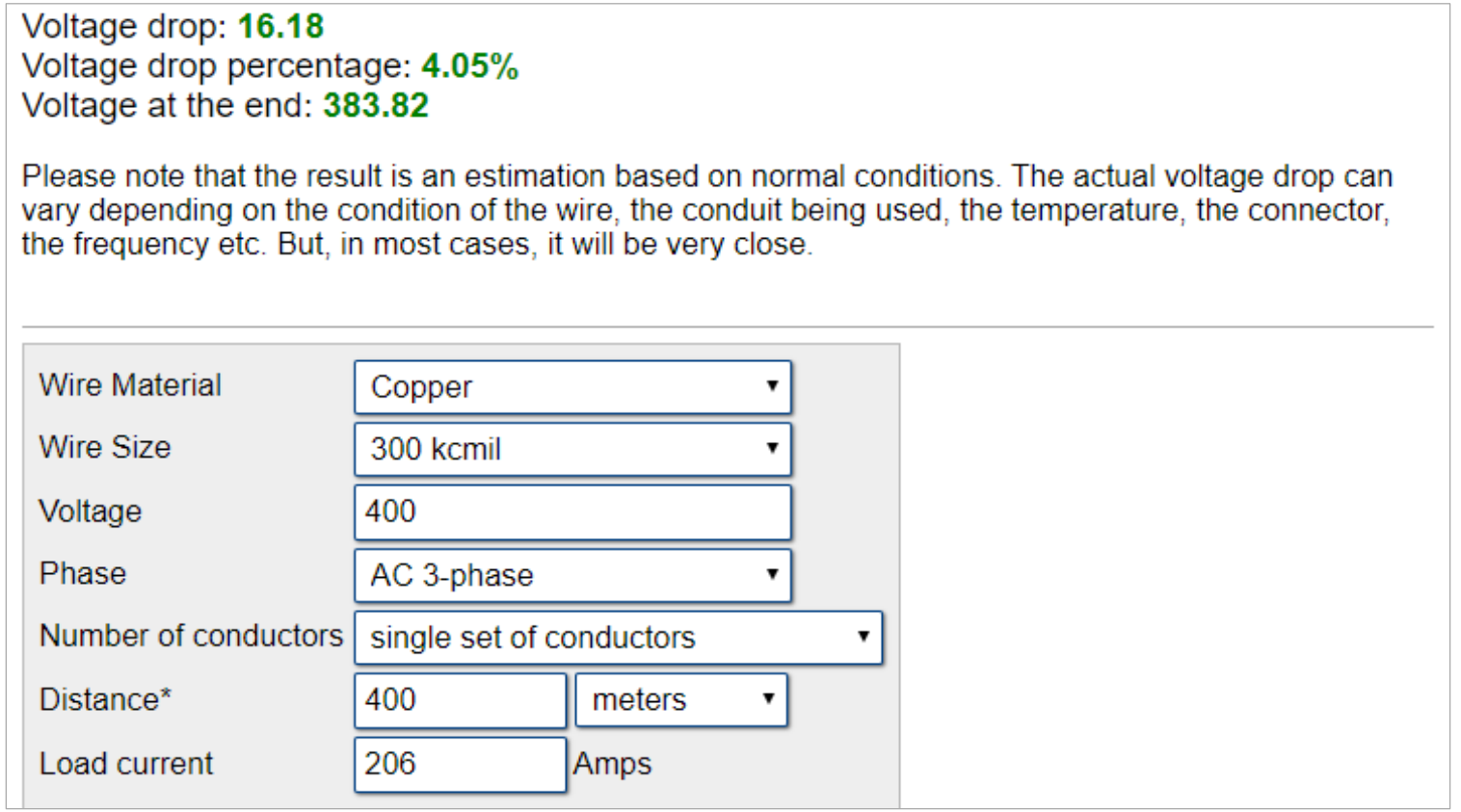
See more in ABB Technical guide N8 – Electrical braking https://search-ext.abb.com/library/Download.aspx?DocumentID=3AFE64362534&LanguageCode=en&DocumentPartId=1&Action=Launch&DocumentRevisionId=C

Voltage boost

Delivering full load voltage even with long cables

Voltage drop happens due to internal resistance of the conductor affected by:

- cable length
- wire material – copper is a better conductor than aluminum and will have less voltage drop
- wire size – larger wire sizes have less voltage drop due to lower resistance
- temperature – electrical resistivity of metals increases with temperature



Voltage drop calculator: https://www.calculator.net/voltage-drop-calculator.html

Voltage boost

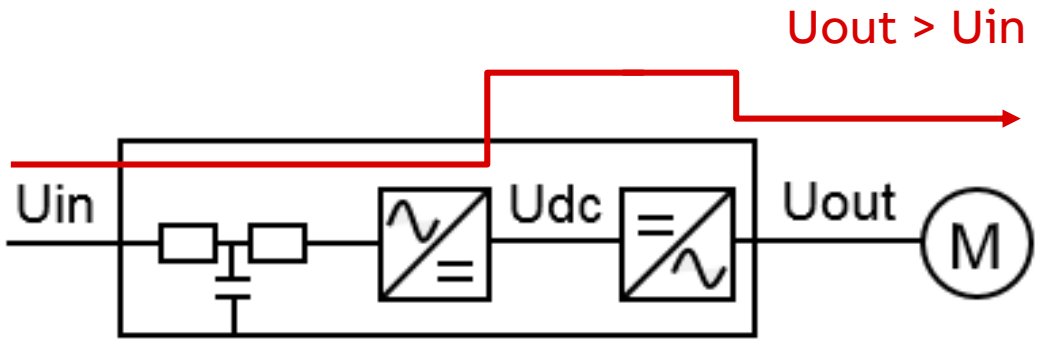
Delivering full load voltage even with long cables

ABB active front end drives can boost output voltage ensuring full motor voltage when the supply voltage is below nominal.

- possible to run motors in a weak network where voltage is below motor's nominal voltage
- possible to compensate voltage loss in the system caused by long supply or motor cables or filters
- may lead to a smaller motor selection due to reduced current – with higher voltage the same power is achieved with less current

Up to **10%**

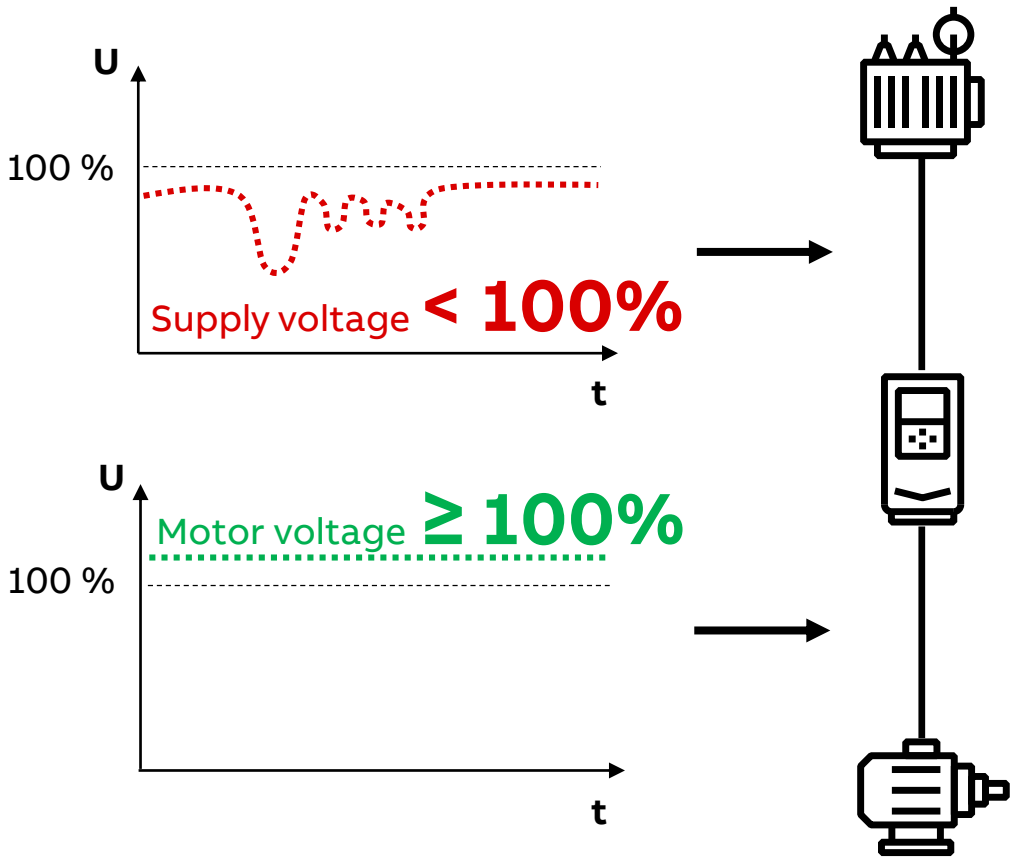
output voltage boost



Voltage boost

Reliable operation in fluctuating networks

- ABB drives with active front end control the DC voltage to guarantee full motor voltage even when the supply voltage is below nominal.
- This secures reliable operation in weak networks – drive compensates for fast variations in the line voltage.
- As result no extra motor heating occurs because there is no need to increase the motor current to stabilize the motor voltage.



Long motor cable support

Application control even at large cable lengths

A drive system's motor cables should be kept as short as possible, but in tunnels, long motor cables are inevitable.

Using long motor cables weakens motor control features and torque production due to:

- motor cable voltage losses
- voltage reflections in the motor terminals

Under motor control features are meant e.g. the ability to change the motor rotating direction, ramp time realization.

Long motor cables also decrease the motor performance.

ABB has tested drives with large motor cable lengths typical for tunnel projects.

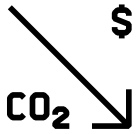
Note! ABB does not guarantee the functionality with longer motor cables than declared in the Hardware manual!

	Maximum motor cable length	
	Scalar control	
Frame size	HW manual	Special
R1	150 m	300 m
R2	150 m	500 m
R3	150 m	500 m
R4	300 m	700 m
R5	300 m	700 m
R5 – 690V (7.3 – 18A)	150 m	300 m
R6	300 m	700 m
R7	300 m	700 m
R8	300 m	700 m
R9	300 m	700 m
R10	500 m	700 m
R11	500 m	700 m

Harmonics performance

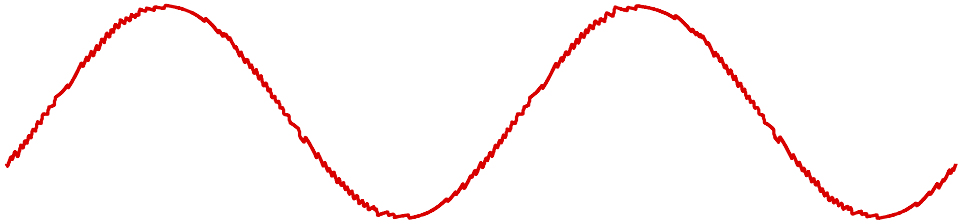
Why to pay attention

Drives save energy controlling motors which run pumps, fans and compressors

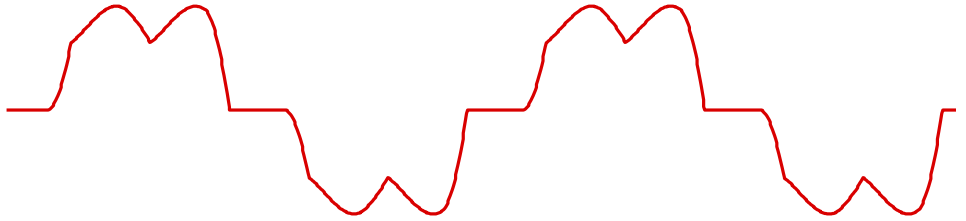


Motor control may result in current and voltage waveform distortion in the network called harmonics

Excessive harmonics decrease system reliability and energy efficiency, increase capex and opex



Ideal current wave form



Current distortion caused by non-linear loads in the network

Harmonics performance

Effect on power network efficiency

The passage of an electric current through a conductor produces losses resulting in heat:

$$\mathbf{P = I^2 \cdot R}$$

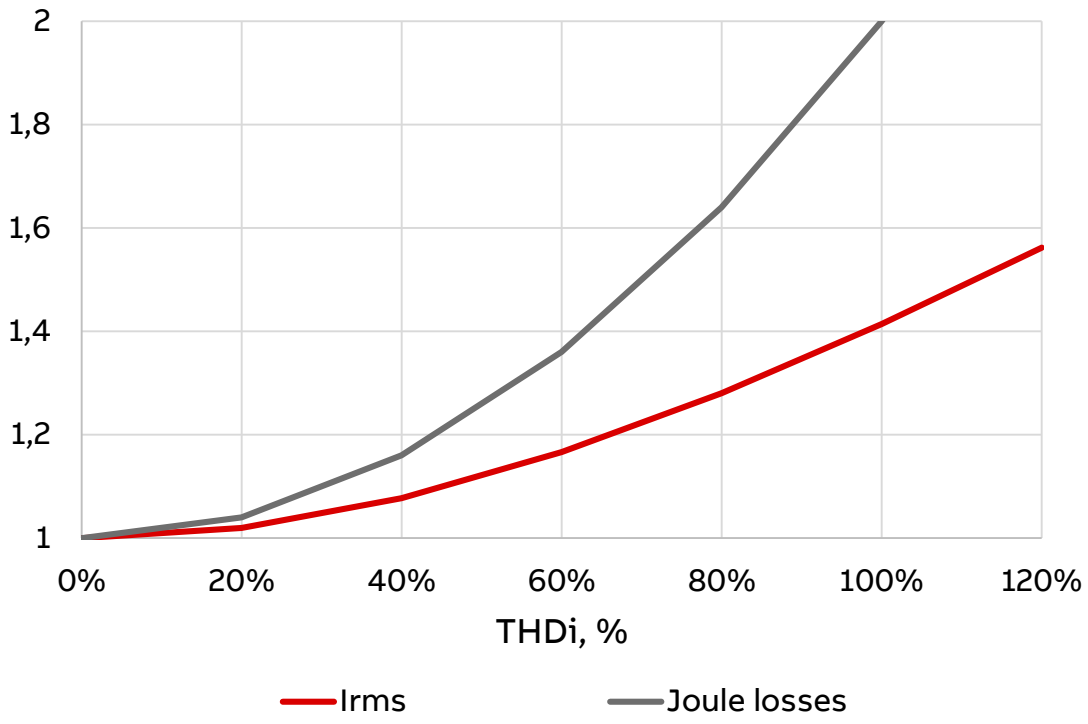
The transmitted active power is a function of the fundamental current I1.

When the current contains harmonics, its total value Irms is greater than the fundamental current I1.

$$\mathbf{Irms = I_1 \cdot \sqrt{1 + THDi^2}}$$

The harmonic currents cause increased Joule losses in all conductors they flow through.

40% THDi results in **16%** higher energy losses!



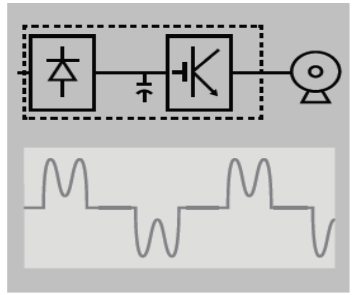
Harmonics performance

Solutions to reduce harmonics

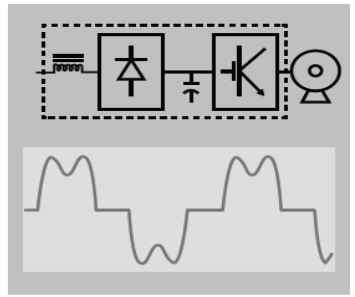
- There are different harmonics mitigation solutions with a different complexity level, cost, effect on the power quality.
- An optimal harmonic mitigation solution is defined by the project type (brownfield/greenfield), grid and load.
- One of the project requirements must be solution analysis on a cost/performance basis.

AFE drive technology with DC caps is superior, allowing to mitigate harmonics to a minimum over the load profile while avoiding installation complexity and massive footprint.

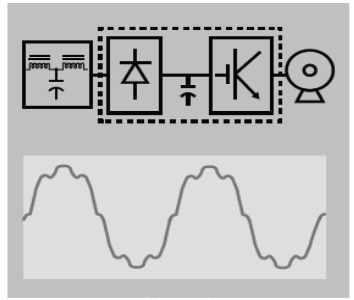
THDi ≤ **3%**



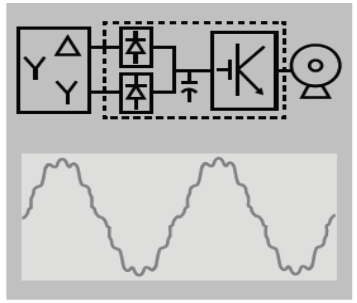
6-pulse drive, no harmonic reduction
THDi = 40 to 120%



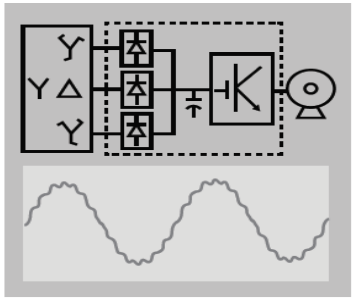
6-pulse drive, input reactor
THDi = 32 to 48%



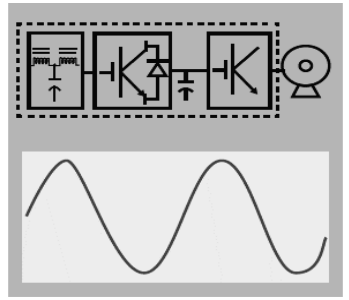
6-pulse drive, input passive filter
THDi = 6 to 12%



12-pulse drive
THDi = 8 to 12%



18-pulse rectifier
THDi = 4 to 8%



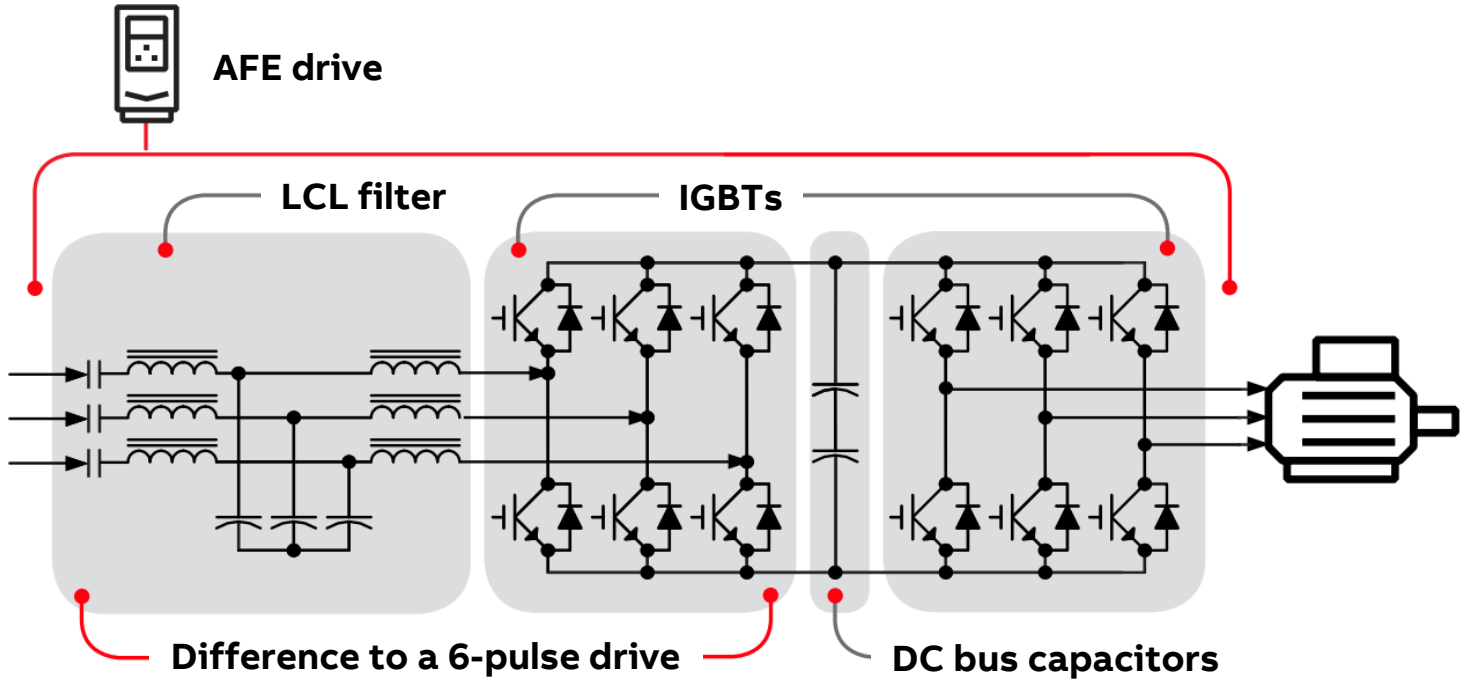
Active front end drive THDi ≤ 3%

Selecting a drive technology for tunnel ventilation

What is the active front end technology by ABB

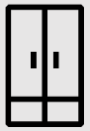
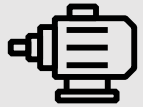
Design highlights

- The technology used is active front end with DC bus capacitors
- IGBTs replace a traditional diode-based rectifier to create a smooth AC current waveform into the drive
- An LCL circuit is installed before the front end IGBTs to clean up high frequency noise caused by the IGBTs
- DC bus capacitors allow the AFE to achieve maximum output voltage



Harmonics performance

System efficiency over component efficiency

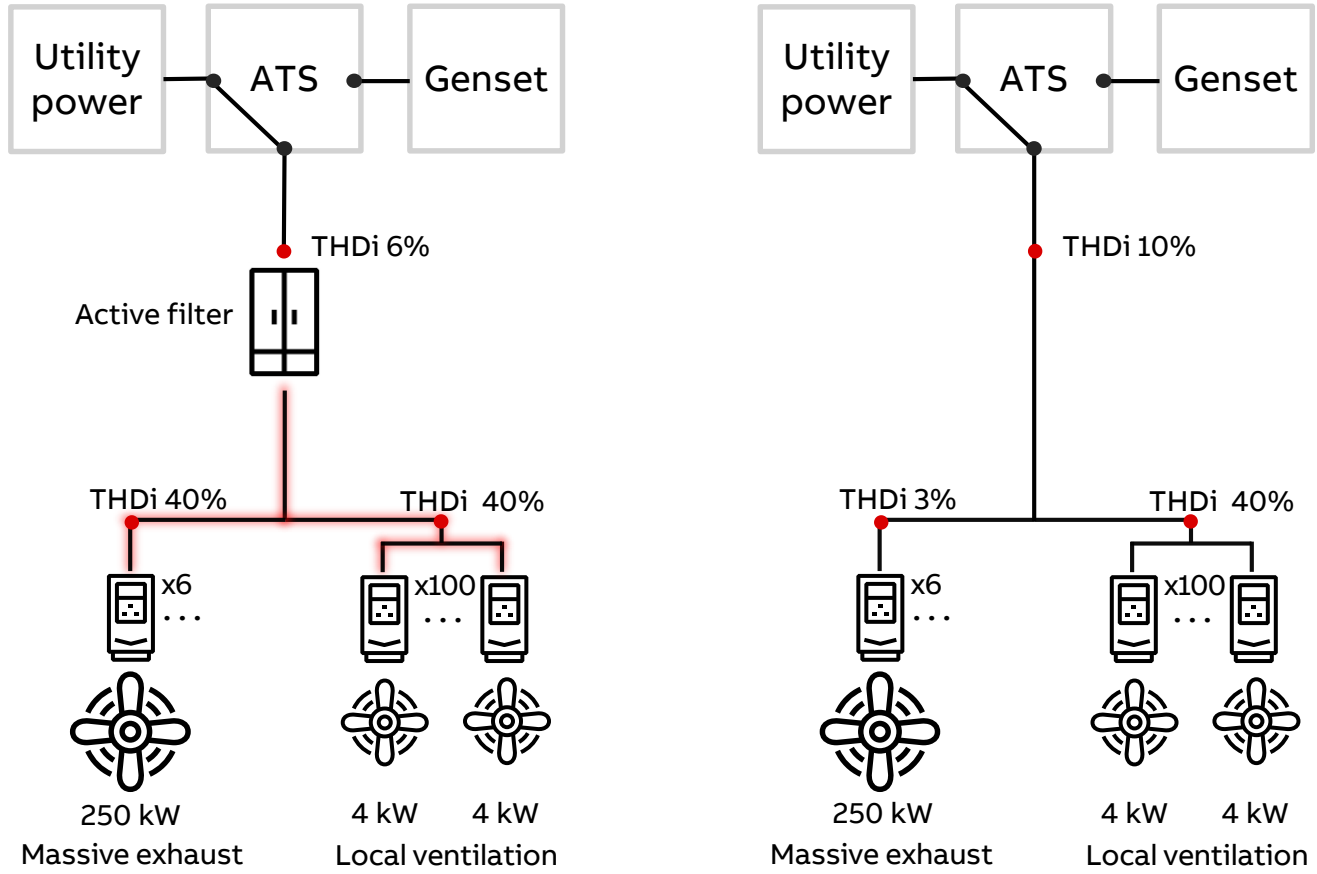
Supply voltage **400 V**	 Network efficiency **~ 98%**	 Passive filter efficiency **98.5%**	 6-pulse drive efficiency **98%**	 Actual motor efficiency due to drive waveform and lower motor voltage **92%***	Motor voltage after system losses **~ 370 V**	Network eff x PF eff x Drive eff x Motor eff = 0.98 x 0.985 x 0.98 x 0.92 = **87%**
Supply voltage **400 V**	 Network efficiency **~ 98%**	 ABB AFE drive efficiency **96.5%**	 Actual motor efficiency at nominal motor voltage **92.5%***		Motor voltage after system losses **400 V**	Network eff x Drive eff x Motor eff = 0.98 x 0.965 x 0.925 = **87.5%**

Note: Standard drive has higher efficiency than AFE, but the efficiency drop in the passive or active filter and the lower motor voltage make the system efficiency lower meaning higher operating costs.

Harmonics performance

Alternatives to harmonics mitigation with AFE drives

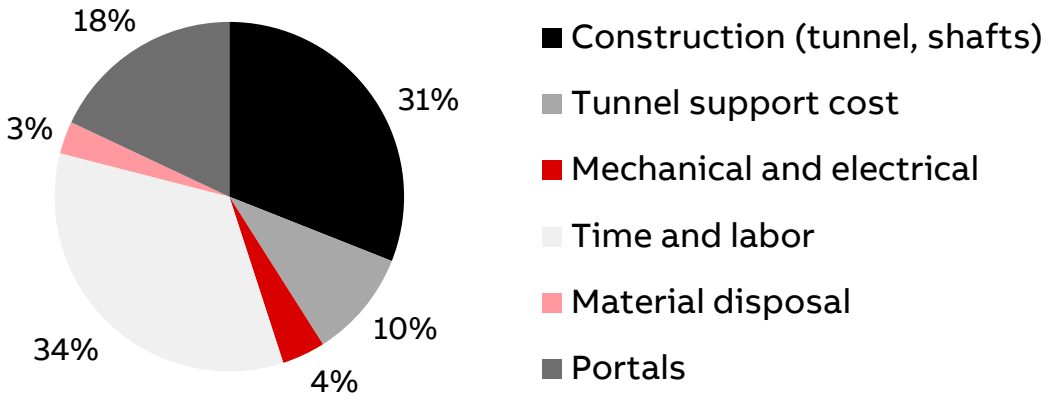
- ABB ultra-low harmonic drives with AFE is a decentralized harmonics mitigation solution
- Benefits of the decentralized harmonics management:
  - no overdimensioned cables and network components
  - no disruption in power network operation due to equipment overheating and failure
  - no energy losses over the power network including cables and network equipment
  - no risk of system overload in case of centralized active filter failure



Tunnel capital costs

What to focus on

Tunnel capital costs breakdown[1]



- 4% of tunnel capital costs come from mechanical and electrical systems
- Power quality significantly affects sizing of electrical system components

1. ARK Investment Management LLC, 2019

Specifying variable speed solutions for tunnels

Effect on capital investments with ABB ULH and regen drives

50%
cost down
with AFE

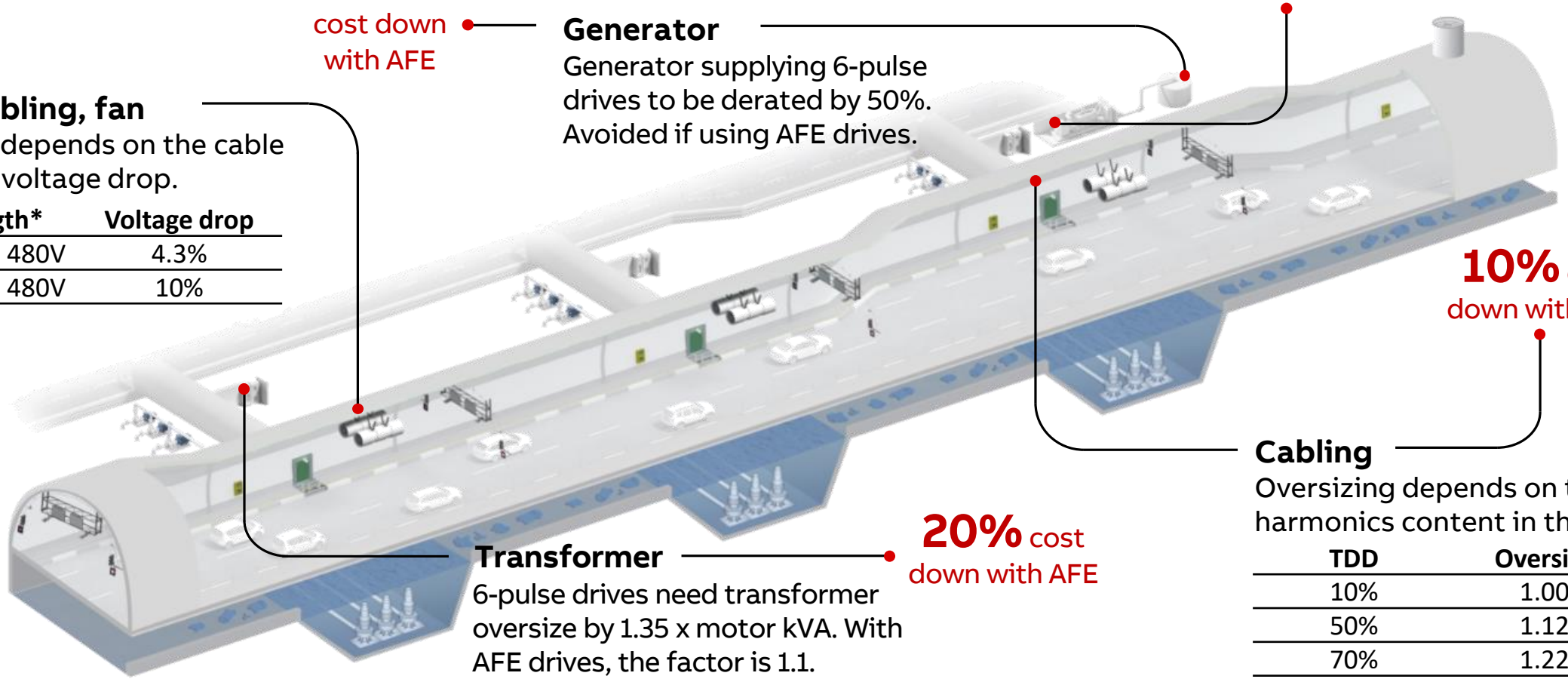
Up to **85%**
space savings

Generator
Generator supplying 6-pulse drives to be derated by 50%. Avoided if using AFE drives.

Motor, cabling, fan
Oversizing depends on the cable length and voltage drop.

Cable length*	Voltage drop
300m cable, 480V	4.3%
700m cable, 480V	10%

~30%
cost down
with AFE**



10% cost
down with AFE

Cabling
Oversizing depends on the harmonics content in the grid.

TDD	Oversize
10%	1.00
50%	1.12
70%	1.22

Transformer
6-pulse drives need transformer oversize by 1.35 x motor kVA. With AFE drives, the factor is 1.1.

20% cost
down with AFE

* Cable considered is copper conductor with a single conductor per phase in aluminum conduit, the application nominal power is 110 kW.
** Example: 55 kW fan, 106A 480V 300m (1000ft) → 4.6% voltage drop. Assumption that cable size increases from 1/0 AWG to 3/0 AWG → 3% voltage drop. 1/0 AWG price 1.45$/ft, 3/0 AWG price 2$/ft (40% higher price).

Specifying variable speed solutions for tunnels

Benefiting of ABB active front end ultra-low harmonic and regenerative drives

ACS880 regen ULH

ACH580 ULH

- **Continuously clean and disturbance-free power network for critical process stability**
- **No oversized power network components to compensate voltage drop or electrical harmonics effects**
- **Effective use of energy in both ventilation and power supply network**
- **Good motor control even over large motor cable lengths typical for tunnels**
- **Effective regenerative braking at eliminated installation complexity**
- **Compactness for tunnel electrical rooms with limited space available**

Compliance with IEC 61000-3-12: 2011
Harmonics are below the limits set by IEEE519-2014 and G5/4

ABB drives and motors for tunnels ventilation

ABB drives for tunnel ventilation

Comprehensive ABB regenerative and ultra-low harmonic drives portfolio

- Wide power range with voltage up to 690V.
  - ACS880-11 regen wall-mounted single drives 4 to 110 kW
  - ACS880-14 regen drive modules 132 to 400 kW
  - ACS880-14 high power regen drive module packages 250 to 2200 kW
  - ACS880-17 cabinet-built regen single drives 55 to 3200 kW
  - ACH580-31 ULH wall-mounted single drives 4 to 110 kW
  - ACH580-34 ULH drive modules 132 to 355 kW
- All inside - no additional hardware needed
- Fulfil requirements set by stringent harmonic standards
- Factory tested solution for high reliability
- Engineering and consulting services available from local ABB

ABB smoke extraction motors

Global offering

Features

- Certified for both horizontal and vertical mounting, either foot or flange mounted
- Certified for dual purpose in both direct online and VSD use
- Wide range of surface treatment solutions available
- Flexible cabling solutions
- Tested according to EN 12101-3, which is the most demanding standard for smoke extraction

Class	Temperature °C, time
F200	200°C, max 120 min
F300	300°C, max 60 min
F400	400°C, max 120 min
F250	250°C, max 120 min

Typical applications

- Tunnels
- Stairways
- Enclosed car parks
- Shopping malls
- Industrial buildings, warehouses

Range

- Motor type: M3BPW
- Output: up to 1000 kW
- Material: cast iron
- Frame sizes: IEC 160–450
- Poles: 4–12
- Voltage: up to 690
- IP class: IP55 (standard)
- Insulation: H-class
- Efficiency class: IE2, IE3, IE4

Success factors

Why ABB drives for tunnel ventilation were chosen for projects

Success factors

More compact ABB drive size was essential for tunnel electrical rooms with severe space limitation

ABB drives require less cooling → cheaper air conditioning system, smaller energy consumption and related costs

Output current derating: above 40°C or 50 °C depending on the unit, 1%/°C derating → ABB runs cooler with longer operating life and delivers more capacity in the same conditions while the alternate offers a bigger size drive due to derating

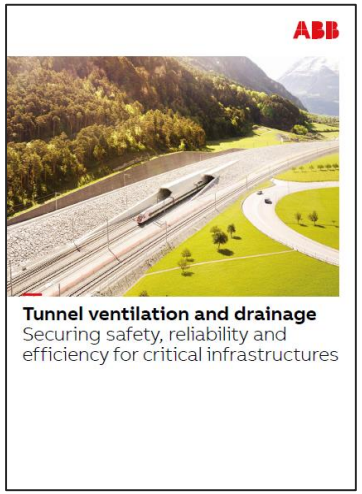
Easy installation of ABB drives: roll in/out vs the alternate's drive modules located e.g. in the cabinet upper part with a lift needed to move them

Where to find more info

Tunnel ventilation solutions by ABB

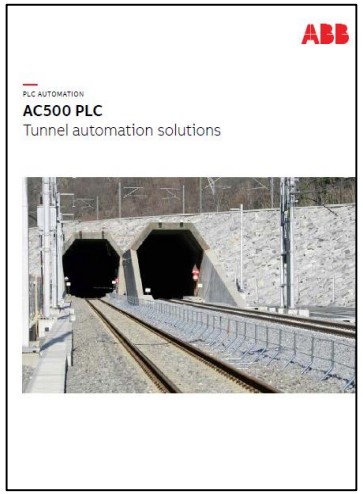
Where to find more info

1. ABB Motion tunnel ventilation and drainage brochure

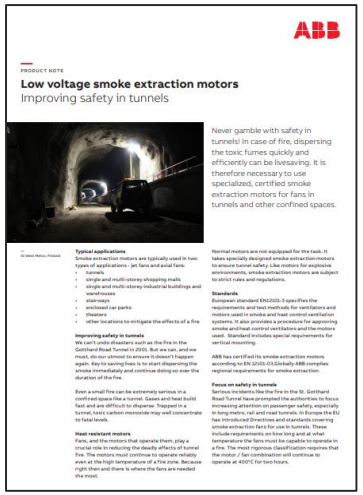


2. VSDs in tunnel ventilation article in Tunnels and tunneling magazine

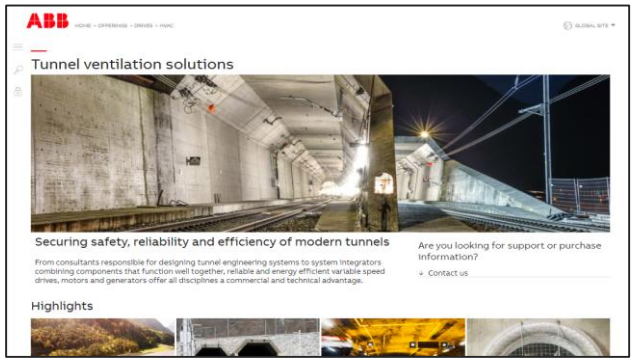
3. ABB automation solutions for tunnels leaflet



4. Low voltage smoke extraction motors product note



5. Web page on tunnel ventilation with MO offering and links to IA and EL offering




ABB