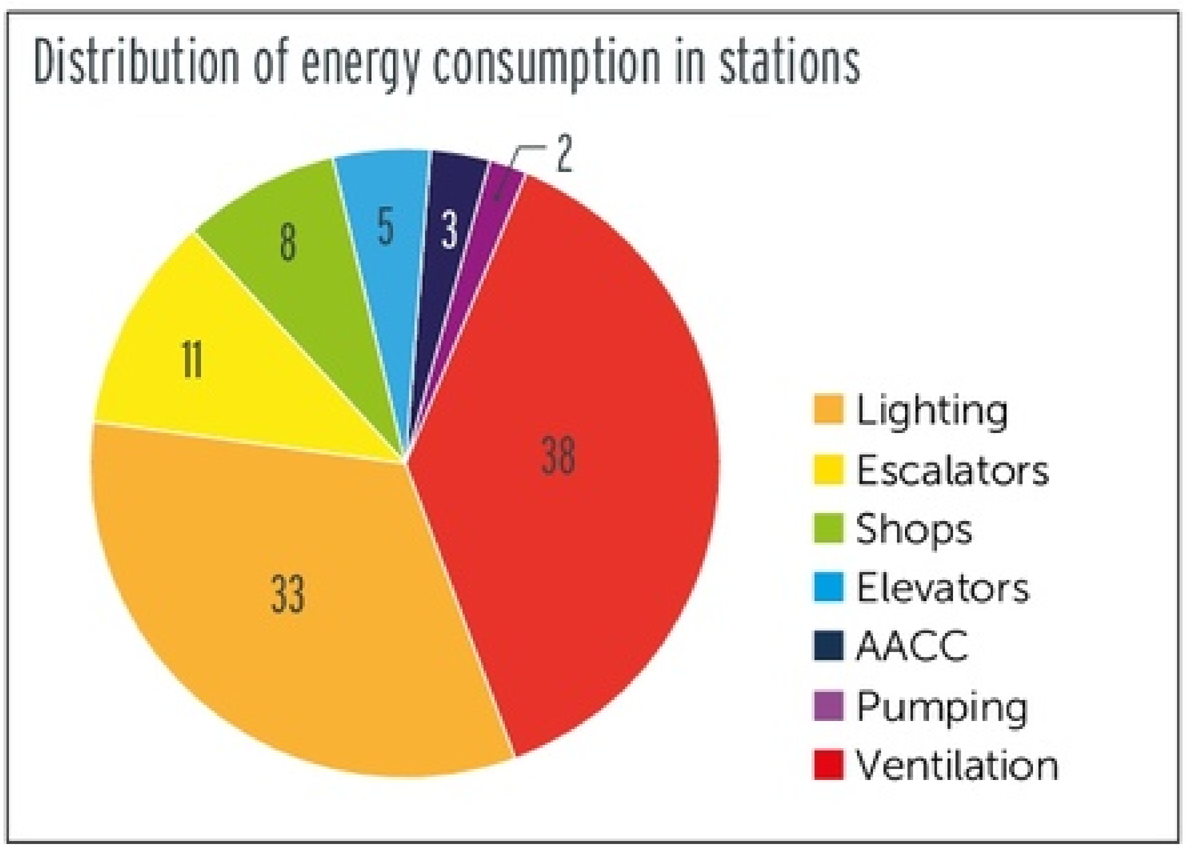
Energy efficient motors, drives, and PLC automation for safer tunnel HVAC systems

Meeting the growing demand for safe, highly cost-effective tunnels, requires each component to be engineered to meet the highest standards of reliability, energy efficiency, and user safety. Frank Grundholm, Vice President of Global HVACR Sales at ABB, explains how this applies to tunnel ventilation and dewatering systems.

Ventilation systems are vital for tunnels, helping to provide fresh air, avoid dangerous concentrations of vehicle emissions, and exhausting smoke in the event of a fire. The dewatering systems ensure water intrusion is managed safely. For these systems to work reliably, efficiently, and safely, it's crucial to choose the right electric motors, variable speed drive (VSDs) and programmable logic controllers (PLCs) for automation.

High-efficiency motors for extreme conditions

Fans and pumps use approximately 40% of all electricity in metro station systems and even more in road tunnels. In the European Union, the requirements for the minimum energy efficiency of fans are presented in the mandatory European regulation on fans based on the Ecodesign directive (EU Directive 327/2022).



The motors in tunnel systems are mainly used for smoke extraction. Just as motors deployed in explosive environments are subject to strict regulations, motors that extract smoke from tunnels must meet stringent certification standards. Indeed, the motor's safety function is so vital that fan manufacturers should look not only for regulatory compliance, but for additional assurance of reliability and performance.

It's also critical for tunnel designers to specify motors capable of surviving extreme heat conditions in emergencies. Fundamentally, a smoke extraction motor must be able to operate at a high temperature over a period long enough to allow tunnel users to escape from a fire. European Standard EN 12101-3 defines safety requirements for motors and fans in ventilation systems for closed or underground public spaces. The standard establishes three classes, according to how high a temperature the motor and fan combination can tolerate and how long it can continue operating in such heat.

Class	Temperature	Maximum time
F200	200^{0}C	120 minutes
F300	300^{0}C	60 minutes
F400	400^{0}C	120 minutes

Low-voltage cast iron motors are extremely robust and suitable for demanding environments, offering a lifespan of 30-plus years under normal conditions. The most common variant used in tunnel systems is high-insulation induction motors with extended protective cables and "flying leads" to connect the motor with the terminal box.

Bearing design is another critical issue for buyers to consider. The stresses on a motor's bearing system during emergency operation vary considerably depending on whether the motor is mounted horizontally or vertically. Motors can be specified with angular or double angular contact ball bearings to cope with high axial and radial shaft forces.

Because tunnel ventilation systems can have high operating costs and consume a lot of energy, making them energy efficient is always a project priority. High energy-efficiency motors help meet such specific tunnel design requirements.

The Ecodesign directive for low-voltage motors has established minimum efficiency levels based on the International Efficiency (IE) classes defined by the International Electrotechnical Commission (IEC). In July 2021, IE3 became the minimum standard for most industrial motors, including those used with VSDs.

While the initial cost of an IE4 motor is higher compared to an IE3 motor, pairing a motor with an IE4 energy rating with a VSD offers 20% more reduction in energy losses. The motor's payback period is also much shorter, making it more profitable overall.

Newer IE5 synchronous reluctance motors (SynRM) have 40% fewer losses than the traditional IE3 industrial motor. However, some stakeholders are cautious about deploying the technology in critical applications such as tunnelling. However, due to their superior energy efficiency, it's only a matter of time before IE5 motors are adopted.

Driving performance through the Alps

The 12km long Frejus road tunnel is one of the major trans-Alpine transport routes between France and Italy. Commissioned in 1980, the tunnel's ventilation systems underwent major renovations in 2016. Part of the project was to replace 24 fans with new technology – 12 for fresh air and 12 for smoke extraction.

The tunnel operator wanted a new fan design to reach F400 certification. The solution came as variable blade angle fans powered by ABB's massive 1 megawatt (MW) motors and associated controlling drives. The fans are 2.2m in diameter, and operators can change the blade angle during operation to adapt to differing conditions.

The fans and motor-drive packages have proved their capability to maintain high performance in changing environmental conditions. The motors were tested under extreme temperatures and withstood 400^0 C for two hours without external cooling – the minimum requirement for F400 classification.

Variable speed drives for ventilation systems

The primary function of variable speed drives (VSDs) is to optimize the performance of electric motors by ensuring that their speed matches the output demand. Without a VSD, a motor constantly runs at full speed, regardless of whether the task demands it. To reduce the output, it is usually throttled mechanically. This is like applying the brakes in a vehicle while keeping your foot on the accelerator pedal: it is inefficient and wastes power. Conversely, a VSD can adjust the motor's speed and torque to match demand. Accordingly, the motor only uses the power required, meaning that the system uses less electricity.

Using VSDs to control the motor adds further efficiencies, as it avoids unnecessarily high fan speeds and power consumption, reduces wear and maintenance, and extends equipment life. In modern tunnel control systems, VSDs make fan speed adjustments in response to information from sensors which monitor pollutant levels. In comfort mode, they'll run at reduced speed and in fire mode at full speed.

With a VSD, the startup is immediate. Limiting the starting current reduces the required size of transformers and the diameter of power cables, thereby saving on capital expenditure. A VSD can also enables the fan to operate in both directions at variable rotation speeds – this is a critical factor in establishing fire control zones.

Running tunnel applications with VSDs can bring instant savings in energy consumption. Since the relationship between motor speed and the energy consumption is non-linear, even a slight speed reduction of 20% produces energy savings of around 50%.

Reducing harmonics

VSDs have proven their substantial energy efficiency and performance gains in many applications. However, VSDs, in common with many other types of non-linear loads, such as EC (electronically commutated) motors, LED or fluorescent lighting, computers, and uninterruptible power supplies (UPS), can introduce harmonics into the electrical network.

The resulting electrical "pollution" can disrupt the operation of other assets in the system if not kept to a minimum. Harmonics can trip circuit breakers, blow fuses, and may cause overheating in cables, transformers, generators, and motors. This wastes energy and shortens the equipment's life.

A common mitigation technique to counter the troublesome effect of harmonics is to oversize electrical components or cables to deal with overheating. However, a more sensible alternative to investing in oversized (and therefore more expensive) equipment is to install devices that reduce or eliminate harmonic frequencies from the outset. Ultra-low harmonic (ULH) drives, also referred to as active front-end drives, add little to no harmonics to an electrical system. Other components can then be "right-sized" to lower the overall investment costs of the entire system.

For example, compared to standard VSDs, it is possible to reduce the size of incoming cables by about 10%, distribution transformers by 20%, generators by 50%, and switchgear and circuit breakers by 10 to 30%. Avoiding the need to oversize also makes the installation more sustainable due to decreased material usage and installation complexity.

Furthermore, alternatives to ULH drives would require additional components such as filters and special transformers, thereby increasing single points of failure. This is undesirable for HVAC systems in tunnels, where high availability and reliability are critical. Because ULH drives operate at a lower harmonic current of less than 3%, cable and motor heating also drop. This increases the resilience of the installation in cases of emergency, such as a fire.

Tunnels typically have unidirectional drafts, which means a fan may be spinning even without power. If the fan needs to be reversed in an emergency,

A tunnel's main vent and water systems

that spin must be ramped down quickly. VSDs play a critical role here since they slow fans down more rapidly, typically using a brake resistor. However, the excess heat generated by this passive braking action increases the heat load on the electrical room. This is highly undesirable in the event of a fire and potentially requires installation of additional air-conditioning equipment in the electrical room to keep temperatures low.

An important feature of a ULH drive variant for tunnel systems is active braking based on active front-end technology. Its regenerative capability allows energy to be recovered from system mechanics during application braking instead of wasting it as heat through braking resistors or mechanical brakes. Because the energy is recovered and can be reused, this avoids entirely the additional heat load and improves the overall energy efficiency of the ventilation and dewatering system.

Overall, ULH drives reduce the installation footprint and total cost of ownership (TCO) of a tunnel system.

Safe ventilation for Chennai Metro

In 2021, the Chennai Metro opened a 9km extension connecting the city's northern part with the Chennai International Airport in the south. The new line will play a key role in easing road traffic and enhancing public transportation.

Rail tunnels mandate rigorous ventilation standards for air quality and fire safety features. To ensure the safety of commuters, ABB provided ACH580 and ACS880 active front-end drives to support the metro line's ventilation system and platform cooling.

The dedicated voltage boost feature of these drives addresses voltage-drop issues caused by long cables in the tunnel network. With this feature, fans can always provide a nominal airflow without needing external equipment to compensate for voltage drop. This brought enormous cost benefits to the project.

Due to the drives' active front-end design, harmonics are almost non-existent, mitigating the network overload risk. It also ensures continuous ventilation and an efficient power supply.

The "fireman's override" feature allows VSDs on smoke extraction and pressurization fans to maintain safe passenger escape routes. It achieves this by ignoring non-critical faults and warnings, for example, if the temperature is too high. This mode is usually triggered with a special key at the fireman's control station in the event of a fire.

Tunnel automation

Programmable logic controllers (PLCs) are used in industrial and infrastructure automation and are critical to tunnel projects. Operating in redundant and distributed setups in tunnels, PLCs reduce energy consumption and manual operator interactions, and increase availability, safety, and sustainability.

A redundant or parallel PLC setup means that one unit or cable can be removed without affecting the system. This enables upgrades and repairs to tunnel infrastructure over long distances with little to no downtime and protects the system against single points of failure. PLCs control and monitor all equipment, such as smoke sensors to sense smoke in the event of a fire. Due to their high availability and distributed architecture options, PLCs maintain prioritised automatic operation, even if parts of the operator stations, SCADA, or network are lost. For example, if a fault occurs at one of the CPUs, the other CPU immediately takes over system control, as both continuously monitor each other and synchronise data.

Data-driven digital solutions play a crucial role in eliminating operating risks and improving the maintenance of the tunnel systems. For example, remote condition monitoring functionality built into motors and drives can deliver real-time information on energy usage, performance issues, and maintenance requirements. This enables an operator to schedule proactive repairs and maintenance for the system, avoiding any costly downtime and disruption to tunnel services.

Within tunnels, where maintenance access can be limited and corrosive atmospheric conditions are common, reliable performance of the ventilation and dewatering system is critical, as is the need for minimum operational maintenance requirements. Tunnel ventilation and smoke exhaustion systems must also meet global safety directives and standards. This extends to motors and drives, which must intelligently utilise advanced safety commands from the PLC, such as "fireman's override" mode, in the event of a fire to enable safe evacuation and access for emergency services. In addition, motors and drives must be built for the best possible performance in adverse conditions, such as extreme temperatures.

The safety standards for tunnels are regularly reviewed and adapted to the latest findings. New tunnels will be built and equipped with the most up-to-date and safe technologies, while older tunnels will have to be upgraded. Starting with the right motors, drives and PLCs is a step in the right direction.