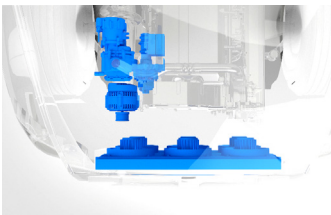
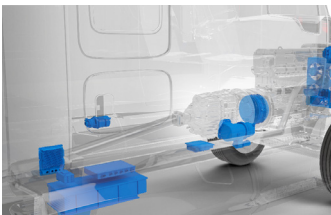
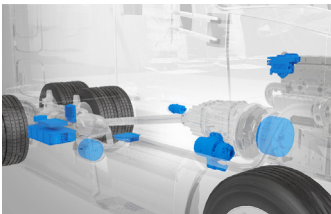


Why 48-volt electrical systems may be the key to achieving future emissions regulations for commercial vehicles



Executive summary

Many commercial vehicles will shift from 12- and 24-volt electrical architectures to 48-volt to enable manufacturers to achieve future emissions regulations. As a leader in power conversion and protection, Eaton can assist commercial vehicle manufacturers in the transition to 48-volt systems with a variety of solutions to produce and manage that power safely and efficiently.

More stringent emissions regulations drive change

Across the globe, emission standards are tightening for vehicle manufacturers. In Europe, the next stage of emissions standards, Euro VII, are targeted for introduction in 2026-27. In the U.S., the California Air Resources Board (CARB) and the U.S. Environmental Protection Agency (EPA) are introducing their own more stringent regulations in 2024 and 2027, respectively. In China, plans call for emissions regulations that will be equivalent to, or in some areas even more severe, than the current European (Euro VI) standard, although timing has yet to be formalized. Collectively, these new regulations will reduce tailpipe NOx limits by up to 90 percent and CO₂ by up to 30 percent, thus accelerating the need for global engine manufacturers to employ additional emissions reduction strategies.

Demands on electrical architecture increase

Traditionally, vehicles have operated with a 12- or 24-volt system, but with fuel economy regulations tightening and new power-consuming components, such as advanced driver assistance systems, being added to vehicles, the need for more power is driving the move towards 48-volt systems.

Global commercial vehicle manufacturers are increasingly adopting 48-volt architectures for their next-generation vehicles, as there are several inherent benefits. The increased power can be used to power systems such as HVAC and the engine cooling fan, which are traditionally run by the engine. 48-volt architectures also create the potential for mild hybridization of drive systems on commercial vehicles and can be used to power electrified heaters to quickly heat a vehicle's aftertreatment catalyst, leading to reduced emissions.

"Major global vehicle manufacturers are making decisions on what technologies they will adopt to meet emissions regulations," said Ben Karrer, manager, Technology Development, Eaton's Vehicle Group. "Of the options available, a 48-volt electrical architecture is increasingly becoming a popular choice, because it enables a variety of technologies that can help OEMs address both CO₂ and NOx."



Powering Business Worldwide

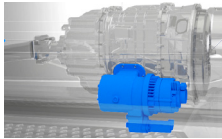
Developing tailored solutions

Eaton can assist commercial vehicle manufacturers in the transition to 48-volt systems with technologies that reduce mechanical and incorporate more electrical components.

From improving diesel engine efficiency, to 48-volt systems, to full vehicle electrification, Eaton takes a consultative approach to tailor the 48-volt technologies to meet emissions regulation challenges and system requirements.

Eaton's 48-volt system solutions can be categorized as power production, power management, and power usage.

Power production



Pictured above: Transmission-mounted motor generator

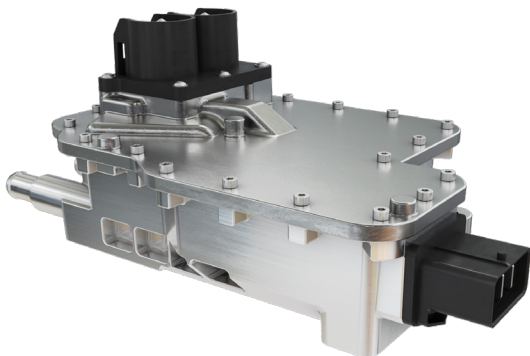
Many vehicle systems including the air conditioning compressor, cooling fan, power steering pump, and alternator today are powered by a front-end accessory drive on the engine. Electrical power is generated by an alternator producing 12- or 24-volts. As the demand for more electrical power increases, commercial vehicles need to generate 48-volts of power.

Eaton believes that there are three main 48-volt power production architectures for generating power while moving and while stopped:

- The 48-volt alternator allows for the most economical and lowest power production.
- The engine-mounted motor generator provides higher power and pairs with any transmission.
- Eaton's transmission-mounted motor generator is flexible and enables engine-off coasting and engine crank while also proving maximum power generating capability.

Power management

Eaton's portfolio of power distribution units (PDUs) safely and efficiently manage electric power distributed in an electric vehicle. The PDUs are fully customizable based on a vehicle's power level, number of electric auxiliaries and battery packs.

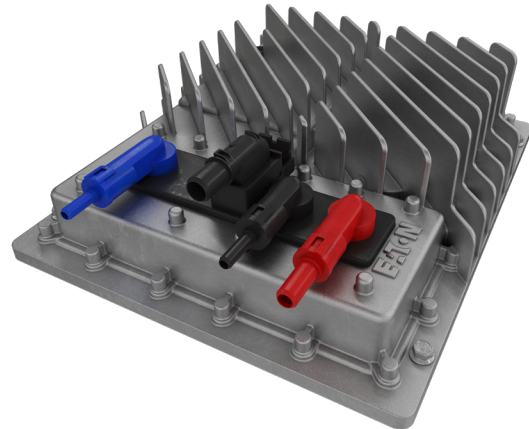


Pictured above: 48-volt inverter

Inverters convert Direct Current (DC) to Alternating Current (AC). Eaton's family of power-dense inverters offer flexibility for a variety of electric systems and power levels, with robust packaging designed for harsh environments. This flexible design works with permanent magnet or induction motors, ranging from 5kW to 30kW.

Exceptionally reliable, safe, and easily customizable, Eaton DC/DC converters change the 48-volts of the battery to the 12- or 24-volts

needed to power a vehicle's base electrical structure, entertainment system, and safety features. Our 50+ years of DC/DC converter expertise, including 5+ years of BEV production allow us to deliver a proven product. Eaton's family approach to 48-volt DC-DC Converters means that there is an air-cooled converter to specifically meet your power requirements.



Pictured above: DC/DC converter

Eaton also offers energy storage management via proven supercapacitor technology. Eaton currently is developing a wide range of 48-volt energy storage solutions, including lead-acid batteries and supercapacitors.

"What we are doing now is integrating various energy storage technologies into a larger storage pack including controls, fusing, and contactors," said Carl Smith, Commercial Manager, Sales and Applications Engineering for eMobility at Eaton. "Eaton's Electrical Components group is our partner for supercapacitors, and for lead-acid batteries we will be working with most commercial vehicle battery manufacturers." Lead-acid batteries are inexpensive compared to lithium-ion packs, and are well known, safe, and used in the market today. By efficiently managing battery charge and discharge, Eaton is able to increase the lifespan compared to existing lead-acid battery applications.



Pictured above: Supercapacitor

"Our supercapacitors have been used in heavy transportation on transit buses, we are excited to be bringing this technology to commercial vehicles," said Jason Lee, Global Product Manager, Electronics Division at Eaton.

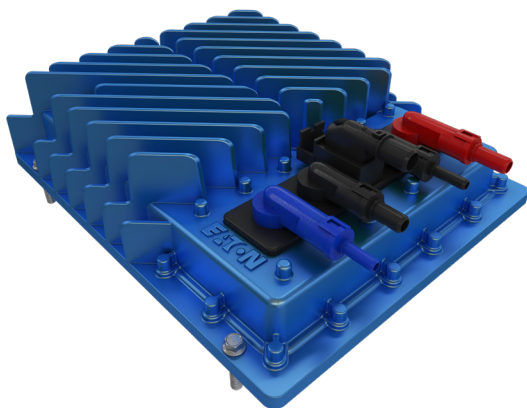
Power usage

Power usage components reduce emissions and enable high efficiency and improved packaging by exchanging some mechanical parts for electric. Engine-driven accessories such as air conditioning compressors and cooling fans can now be powered by 48-volt motors, reducing parasitic losses, and increasing fuel efficiency by up to 2 percent. Both products are under development at Eaton.

An electric air conditioning compressor (eHVAC) can cool the sleeper cabin in a commercial engine overnight without having to start the engine, reducing emissions and fuel consumption. With additional energy storage, this can eliminate idling to run the air conditioning or eliminate the APU (auxiliary power unit) completely.

Electrifying the cooling fan has multiple benefits including environmental, efficiency, and packaging improvements. The cooling fan can be reduced in size and be strategically placed within the engine bay, allowing for improved aerodynamics to reduce fuel consumption.

Eliminating parasitic losses from accessories is just one way to improve the efficiency of commercial vehicles. A 48-volt electrical architecture also gives us the power to improve aftertreatment efficiency and reduce engine pumping losses.



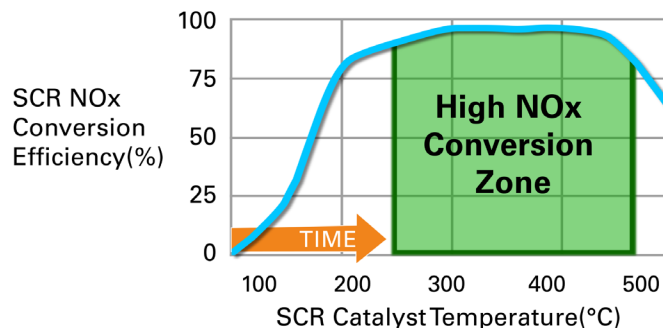
Pictured above: E-Heater power electronics controller

An essential strategy for reducing NOx to the levels required by future global regulations will be getting and keeping the aftertreatment system in the optimal efficiency range of 250 degrees to 500 degrees Celsius. Eaton has developed an air-cooled power electronics controller for the 48-volt electric catalyst heating system

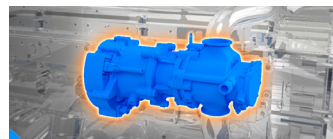


Pictured above: Electric catalyst heater

which regulates and supplies power to the heating coil while ensuring high power quality for the 48-volt vehicle system. This power is provided to a heating coil in the vehicle's aftertreatment system which actively heats catalyst components, such as the SCR, and helps reach efficient operating temperatures as quickly as possible upon engine start and maintain these temperatures during low load operation resulting in a significant NOx reduction of 75 percent.



Eaton's TVS EGR Pump improves fuel economy and EGR flow control by replacing the less efficient variable geometry turbocharger (VGT) and EGR valve with a less expensive, more efficient fixed geometry turbo (FGT). Using power from a 48-volt DC motor allows the TVS EGR Pump to be completely independent from engine speed and provide better control than traditional EGR systems. The 48-volt motor has faster response times than today's system with EGR valves and better control of EGR, because the volumetric flow rate of a positive displacement pump can be precisely measured as a function of the pump speed. The result is a 2.5-5 percent improvement in brake specific fuel consumption.



Pictured above: TVS EGR pump

Conclusion

A 48-volt electrical architecture enables many solutions as commercial vehicle manufacturers look for ways to achieve future emissions regulations. Eaton has a long history of low, medium and high voltage expertise and can develop a fully integrated 48-volt electrical system with a portfolio of power electronics that meet commercial vehicle duty cycles and durability requirements.