

Traction inverter techniques

In this three-part series, Exro's Chief Technology Officer, Eric Hustedt, helps us explore what a traction inverter is, how inverters work, EV traction inverter development, and the latest advancements in technology for traction inverter design. This third part of the article focuses on the recent advancements related to electric vehicle inverter design. Specifically, we explore switches in traction inverters, semiconductor advancements, and cooling methods, and other developments that have contributed to the evolution of traction inverter design.

Welcome to part three of our series on inverter technology. In part one, we provided an introduction to inverters and how they work, and in part two, we explored the early advancements in inverter technology and the differences between AC and DC motors. Now, in part three, we will dive deeper into the latest advancements in inverter technology and take a closer look at critical components such as switches, semiconductor advancements, cooling methods, and interconnects.

Since its invention, the fundamental concept behind a three-phase inverter has not changed; however, there have been major advancements in the devices, fabrication techniques, and components used. These advancements have enabled the production of smaller, more affordable, and more powerful inverters. In the following section, we will delve into each of these crucial developments in greater detail.

The switches in an inverter play a crucial role in regulating the flow of electrical energy and converting DC to AC power. They are responsible for switching the current ON and OFF at a rapid rate to create the desired AC waveform. The type, construction, and cooling of the switching elements are arguably the most significant elements of an inverter design.

The switches used in modern inverters must be able to handle high currents sometimes exceeding 500 amps per phase or more. They must also rapidly switch this current on and off with voltages ranging from 400V to 800V DC. This is no small task and requires switches that can handle this level of power without generating excessive heat or voltage.

To put the power requirements of an inverter into perspective, it is helpful to compare them to an average household outlet. Household outlets typically operate at only 15 amps and 120V, or 10 amps and 240V, depending on the region. In contrast, inverters used in electric vehicles and other high-power applications must often handle an order or two magnitudes larger currents and voltages. This highlights the complexity and sophistication required in designing the switches for these applications.

Since the 1980s, MOSFETs have been the preferred device for lower voltage inverters, while IGBTs have been the go-to choice for higher voltages of around 150V or higher. IGBTs remained the top choice in the high voltage market until the mid-to late-2010s when wide band gap semiconductors like silicon carbide (SiC)

MOSFETs became commercially viable.

Wide band gap semiconductors are materials that require more energy to be applied to them to transform them from insulators to conductors compared to conventional semiconductors such as silicon. This reduces sensitivity to external energy, allowing them to operate at higher voltages, frequencies, and temperatures.

As of 2023, two wide-bandgap semiconductors are commercially available for power devices: silicon carbide (SiC) and gallium nitride (GaN). At present, SiC is leading in terms of cost per ON-resistance and are available with higher voltage capability; as such, it has become the dominant choice for inverter power semiconductors.

Power semiconductor switches, regardless of type, generate heat when operating, and how well they can be cooled determines how much silicon area is required for a given application. Silicon area is directly proportional to the cost of the switch, therefore improving the cooling methods has a direct cost benefit.

The heat generated in the switches is a result of two main factors: conduction loss and the already discussed switching loss. Conduction loss is the heat generated by the movement of electric current. An example of this can be seen when a coiled extension cord is connected to a high-powered device, such as a space heater, causing the cord to become warm. With the exception of superconductors, conduction loss occurs in all materials through which current flows, including power semiconductors, bus bars, and power delivery cables.

As power semiconductors become more compact and high-powered, the challenge lies in effectively removing heat from these smaller devices. Additionally, the cooling solution must provide electrical isolation, as the chips within them operate at hundreds of volts and are “live”, while the cooling system is typically made of metal and connected to the chassis/ground.

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