Commentary

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Electric Vehicles And Renewable Energy Drive Power Converters Toward Modularity, Higher Power And New Functionality

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Power converters such as rectifiers (ac-dc), inverters (dc-ac), and dc-dc converters are unavoidable parts in today's society, being utilized in many applications. The primary use of power converters is to modify the electrical energy from a source (electricity grid, photovoltaic panels…) to the load according to its specific requirements: direct current (dc) or alternating current (ac) and voltage level.

In this article, we'll examine the application and market trends that will be driving the growth of the power converter market in the years ahead. The focus here is mainly on the automotive and industrial segments, particularly the electric vehicle (EV) and EV charger applications and the renewable energy applications in solar, wind, and energy storage. As part of this discussion, we'll examine how rising voltage and power levels in these applications are affecting power converter developments.

A $125+ billion Power Converter Market By 2028

The power converter industry represents a great business opportunity for many companies in the supply chain; it was worth US$72.2 billion in 2022 for the applications shown in Fig. 1. According to Yole Intelligence's Status of the Power Converter Industry 2023 report,[1] it is expected to reach US$125.3 billion by 2028.

In 2022, industrial motors were the largest power converter segment, while xEV power converters are growing substantially and are expected to become the third largest market in 2028 after PV and industrial. Power converters for battery energy storage systems (BESSs) will feature the fastest growth in the coming five years, with a 2022 to 2028 compound annual growth rate (CAGR) of 30.3%**.**

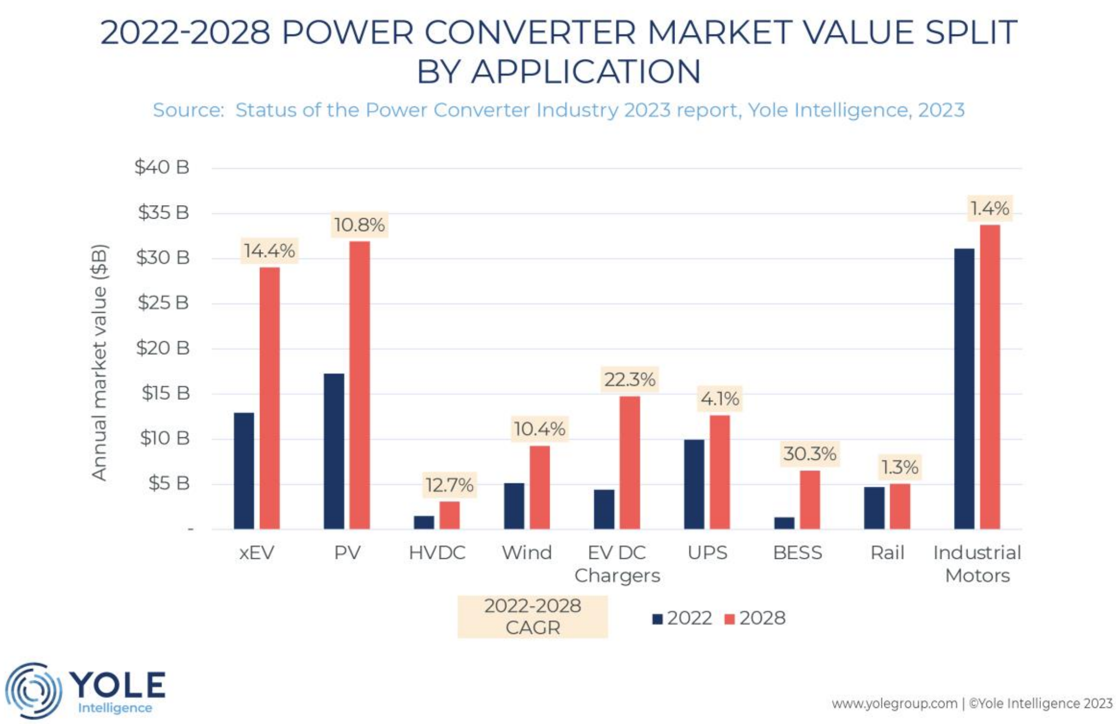

Fig. 1. The 2022 to 2028 Power converter market value evolution with value split by application. (Source: Status of the Power Converter Industry 2023 report, Yole Intelligence, 2023.[1])

Amongst the main drivers for power converter markets are governmental targets for CO_2 emissions reduction. The rapid deployment of renewable energy sources and the trend toward "electrification of everything" significantly increase the demand for power converters. This includes many applications, from EVs and EV dc charging stations to photovoltaics, wind power, and stationary BESSs and industrial motors.

In recent years, an enormous interest in vehicle electrification has been observed. The initial plan was considered very optimistic, with a rather long transition phase with hybrid electric solutions, such as mild hybrid electric vehicles, full hybrid electric vehicles, and plug-in hybrid electric vehicles. Meanwhile, fuel-cell electric vehicles have been developed in parallel to battery electric vehicles.

However, the rapid improvements in battery technology and battery cost reduction driven by, amongst other things, production scaling and growing competition have pushed the industry's efforts towards full battery electric vehicles (BEVs). BEVs emerged as the dominant xEV segment, projected to exhibit a double-digit CAGR between 2022 and 2028 to 24.1 million vehicles in 2028 (Fig. 2).

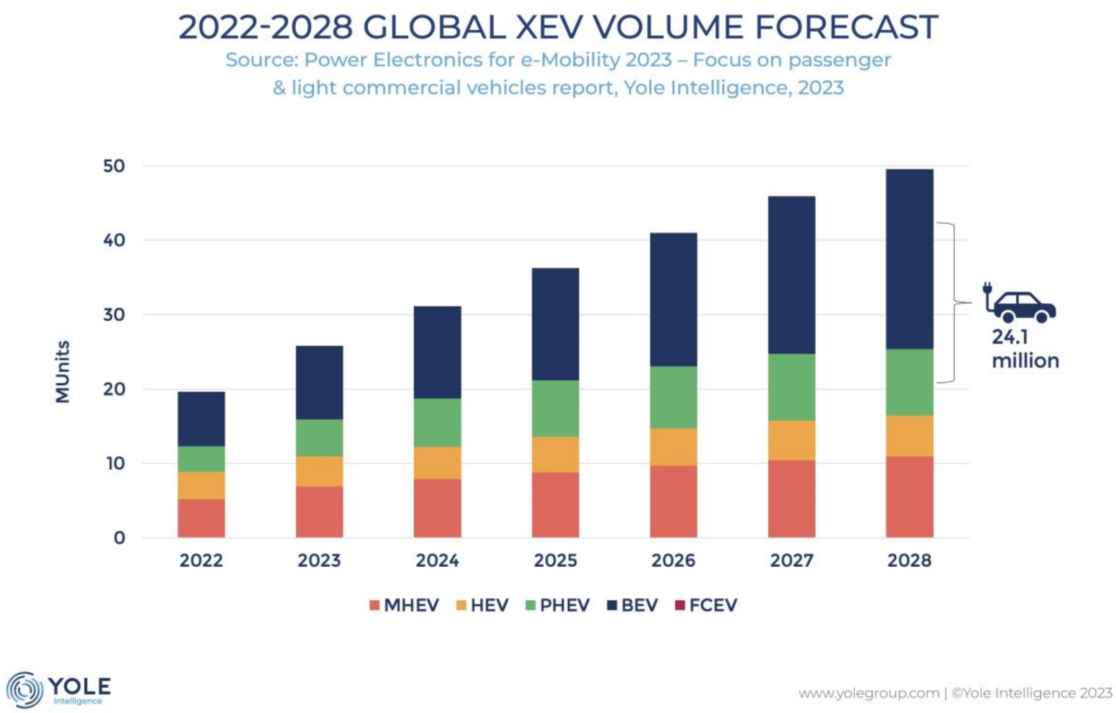

Fig. 2. 2022 to 2028 Global xEV volume forecast: mild hybrid electric vehicle (MHEV); hybrid electric vehicle (HEV); plug-in hybrid electric vehicle (PHEV); battery electric vehicle (BEV); and fuel-cell electric vehicle (FCEV). (Source: Power Electronics for e-Mobility 2023-Focus on passenger & light commercial vehicles report, Yole Intelligence, 2023.[2])

Electric passenger and light commercial vehicles occupy the most space in the media and are a strong focus of companies' R&D and business expansion strategies. However, this market sees growing cost pressure and increased competition. Moreover, the automotive market is associated with its own rules, which might be very challenging for some suppliers: automotive qualification, high-volume manufacturing capacities, long-term product warranties, and strong competition.

Therefore, there is a growing interest in non-automotive applications, like photovoltaics, wind, and stationary battery energy storage systems, EV dc charging stations, and industrial motors. Such industrial markets have different drivers and requirements compared to automotive applications in terms of converter density, reliability, lifetime, nominal voltage, and power. This offers business opportunities for a large variety of companies and products. The choice of power devices and system design are evolving to match power systems' requirements, leading to new technology trends observed across different applications.

Power Converter Trends In Automotive And Industrial Applications

There is a virtuous cycle between technology improvements and customer requirements. As customer needs evolve, technology providers innovate to meet these new requirements, driving continuous improvement. For example, to reduce energy consumption, power converters with higher efficiency would be needed. To do that, high-voltage components would be used. Therefore, device makers develop and invest in epitaxy thickness to handle higher voltages than before. Gradually, this "new" technology becomes increasingly mature and can be used by customers as required.

This section will focus on the main technology trends observed in power converters, as identified by Yole Intelligence.

The typical installation size for many industrial power electronic applications such as photovoltaic (PV) farms, wind farms, or stationary BESSs is increasing (Fig.3). This leads to higher power converter power levels. As of 2023, string PV inverters are available in sizes up to 385 kW, central PV inverters up to 6.8 MW, wind turbine converters up to 18 MW, and BESS power conversion units (PCUs) up to 5.5 MW. The same trend in increasing nominal power to 350 kW and more is observed in EV dc chargers to shorten vehicle charging time.

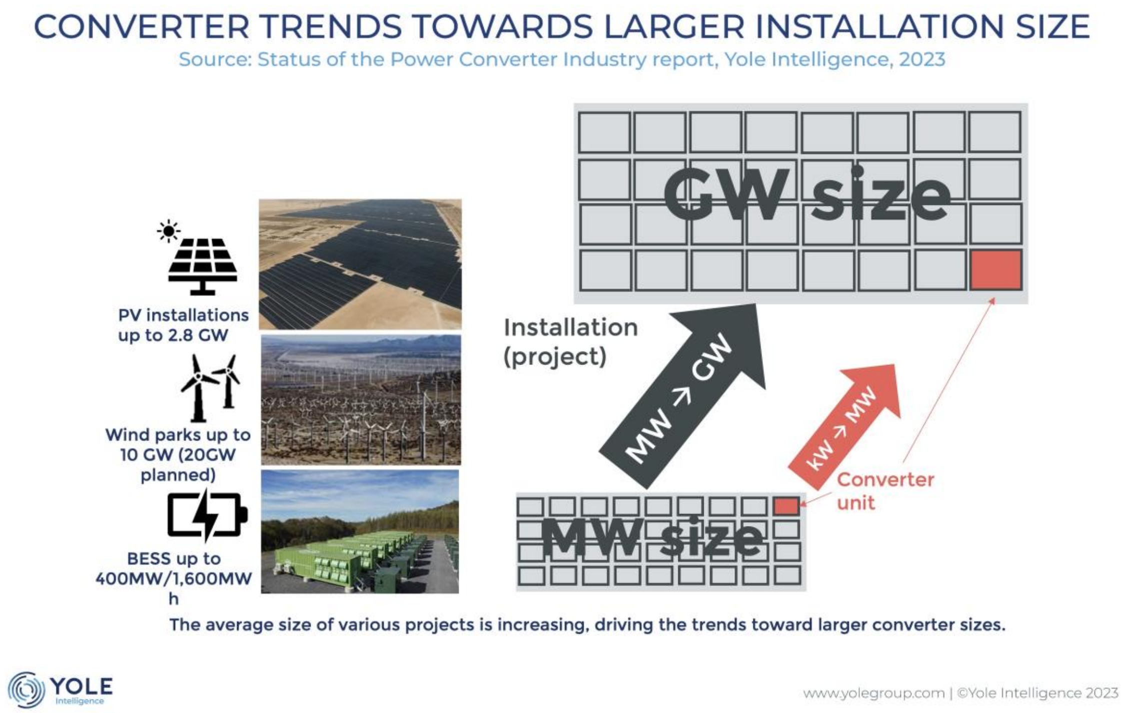

Fig. 3. Converter trends towards larger installation size. The average size of various projects is increasing, driving the trends toward larger converter sizes. (Source: Status of the Power Converter Industry report, Yole Intelligence, 2023.[1])

Increasing power can be achieved by increasing either the voltage, the current, or both. However, there are several limitations related to high current, such as conduction losses and thermal dissipation. That's why increasing the system voltage is the approach adopted across different applications (Fig 4).

Today, the majority of electric vehicles in the market utilize battery packs with a voltage in the range of 350 V to 450 V, the so-called "400-V battery". However, introduced commercially for the first time by Porsche in the Porsche Taycan electric vehicle in 2019, the "800-V battery" approach is now being increasingly adopted by other EV manufacturers, including Lucid Motors, BYD, Hyundai, and Kia.

But how to ensure the compatibility of 800-V battery vehicles with conventional EV dc chargers, rated at a maximum voltage of 500 V? Different strategies have been developed at the vehicle level, but the most straightforward approach is simply increasing the maximum charger voltage to 1,000 V. Most EV dc charger manufacturers are adopting this trend. One notable exception is Tesla, which remains stuck with a huge (and thus costly to upgrade) network of supercharger stations able to charge 400-V vehicles only, such as current Tesla car models.

Amongst industrial applications, photovoltaics made its first big move to higher voltage levels. Historically, the photovoltaic panel string voltage was 600 V or 1,000 V. In 2012, the first 1,500-V inverters were introduced to the market, intended to reduce the balance-of-system (BOS) costs of a photovoltaic installation. After overcoming the initial challenges, such as the lack of high-voltage components available at an affordable price, 1,500 V became a third voltage standard in photovoltaic installations.

PV installations are increasingly associated with energy storage systems, helping integrate intermittent PV electricity with the electricity grid. Stationary battery systems are the preferred means of energy storage here due to many inherent benefits like system power and energy capacity modularity, installation site independence, high round trip efficiency, etc. BESS power conversion units, utilized when a battery is charged or discharged, see their maximum voltage levels increasing to nearly 1,500 V.

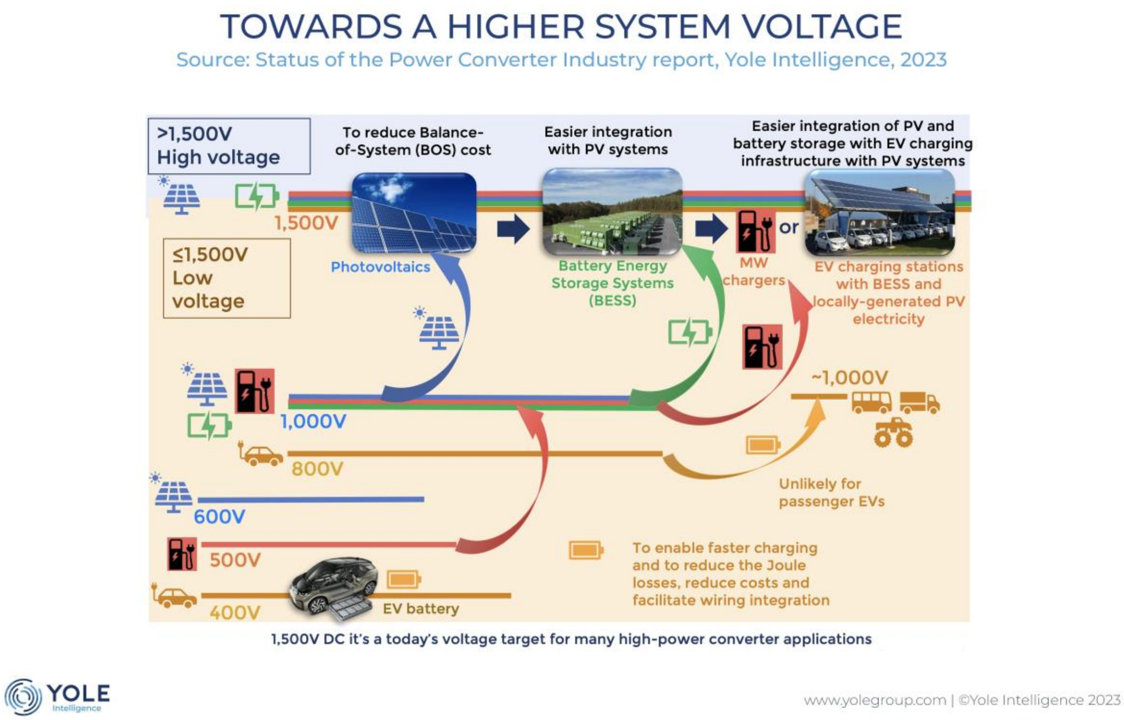

Fig. 4. Towards a higher system voltage. 1,500-V dc is today's voltage target for several high-power converter applications. (Source: Status of the Power Converter Industry report, Yole Intelligence, 2023.[1])

Although one might have the impression that a voltage increase benefits high-power and high-voltage systems only, similar trends are also being observed for lower-voltage applications, such as mild-hybrid electric vehicles (48-V battery systems, instead of traditional 12-V automotive battery voltage) or power supply units (PSUs) for servers in hyperscale data centers (transition from 12 V to 48 V).

Reduction of current and associated heat generation through a voltage increase has another benefit: reduction of cooling needs enabling smaller, more compact systems. This is aligned with a trend to do "more with less," i.e., integrate more power within smaller, lightweight systems.

Converter power density is desired for all applications but is especially important for applications where installation space and volume are very valuable such as in embedded applications like electric vehicles or power supplies for servers in data centers. A higher power density could be achieved using the higher switching frequency achievable with wide-bandgap (WBG) technologies, such as SiC and GaN. Indeed, although the utilization of SiC diodes and MOSFETs and GaN HEMT devices instead of conventional silicon devices helps to increase the power conversion efficiency, one of the key drivers for SiC and GaN device utilization is that they enable system downsizing.

In this era of rapid technological advancement, improving efficiency in power converters has become synonymous with commitment to innovation and responsibility toward a greener and more sustainable world. Every percent increase in efficiency may result in substantial energy savings with regard to high power levels in some applications (central PV inverter in the megawatt range, for instance). Different ways exist to improve efficiency, such as:

- Advanced topologies (e.g., resonant or multilevel converter)
- Soft-switching techniques: zero-voltage switching (ZVS) or zero-current switching (ZCS)
- Synchronous rectification: use of MOSFETs instead of diodes in the rectifier side of the converter.
- Modular design: losses can also be reduced by running the converter at the optimal point of load
- Bidirectional design: recuperating energy from braking in electric motors in xEVs or elevators, for instance.

Coming back to the concept of the virtuous cycle, Fig. 5 summarizes the interplay between customer requirements and technology trends.

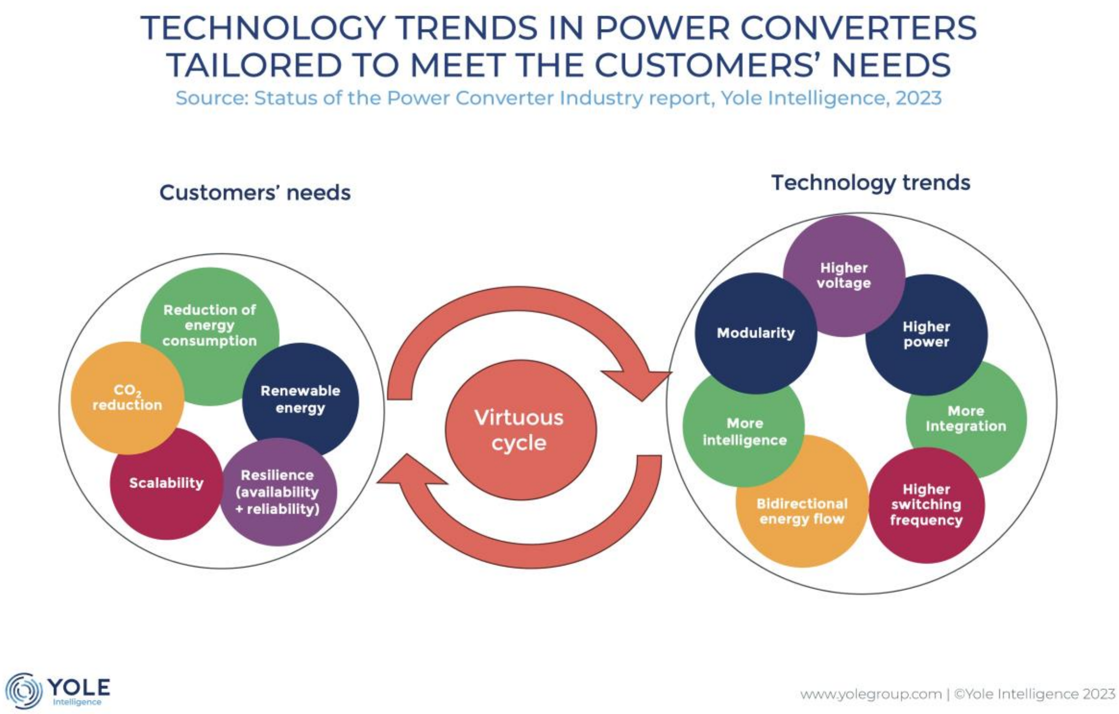

Fig. 5. Technology trends in power converters tailored to meet the customers' needs. (Source: Status of the Power Converter Industry report, Yole Intelligence, 2023.)

Conclusion

The power converter industry represents a great business opportunity for many companies along the supply chain. Although primarily driven by industrial applications in the past, xEV and electric mobility, in general, are the main driving forces for technology innovations today.

To achieve system requirements, technological trends in power converters, such as higher voltage, higher power, and modularity, are being adopted. SiC and GaN technologies are rapidly advancing towards greater technology and market maturity. As these technologies progress, their costs are poised to decrease, making them more accessible.

The integration of diverse system functionalities is also gaining traction, leading to synergistic hybrid solutions that optimize overall performance and efficiency. This convergence of advancements promises a future where SiC and GaN technologies play a pivotal role in reshaping various industries.

References

1. Status of the Power Converter Industry 2023 report, Yole Intelligence.
2. Power Electronics for e-Mobility 2023 – Focus on passenger & light commercial vehicles report, Yole Intelligence.

About The Authors

Milan Rosina is the principal analyst for Power Electronics and Battery at Yole Intelligence (Yole) within the Power and Wireless division. Rosina has twenty years of scientific, industrial, and managerial experience in equipment and process development. He also has experience in due diligence, technology, and market surveys in the fields of renewable energies, EVs/HEVs, energy storage, batteries, power electronics, thermal management, and innovative materials and components.

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