Industrial

EV Charging Stations

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Contents

1. Introduction

In the era of electric mobility, the landscape of transportation is rapidly evolving. Electric Vehicle (EV) Charging infrastructure stands at the forefront of this transformation, shaping the way we power our vehicles and navigate our cities. At Nexperia, we understand the pivotal role that EV Chargers play in facilitating this transition.

According to latest forecasts by GlobalData, the production of electric vehicles will surpass traditional combustion engine vehicles towards the end of 2027. From urban streets to highways, EV Charging stations are becoming essential hubs that support the growing fleet of electric vehicles worldwide. Our Application Techbook is designed to offer insights into the application of EV Chargers, analysing different topologies and giving solutions to common challenges.

Discover how Nexperia products can efficiently power AC and DC charging stations which are reshaping the mobility sector, driving progress towards a cleaner, greener future for generations to come.

Fig 1. Electric vehicle powertrain architecture illustration showing the OBC and DCDC Converter

2. EV charging station - description and trends

2.1 Application description

Wallbox charging solutions for electric vehicles

Wallbox charging solutions for electric vehicles are available in both AC (Alternating Current) and DC (Direct Current) variants, offering power ranges from 3.7 kW to 22 kW. AC chargers utilize the vehicle's On-Board Charger (OBC) to convert alternating current to direct current, whereas DC wallboxes handle the power conversion internally.

AC wallboxes:

These are the standard for home charging due to their ease of installation and cost-effectiveness. They provide a convenient solution for EV owners, combining simplicity with efficiency. For instance, a conventional electric vehicle with a battery capacity between 16 and 30 kWh can be fully charged within 2-6 hours, which is ideal for overnight or at-home charging.

DC wallboxes

While not yet widely adopted, DC wallboxes represent a growing trend in the EV charging landscape. This advanced technology enables bi-directional charging, allowing electricity to flow from the vehicle's battery back to the grid, effectively turning the vehicle into an energy storage unit or backup power source. One challenge to broader implementation of DC wallboxes is the limitation imposed by EV battery charging cycles. A typical EV battery supports between 1,500 to 2,000 charge cycles, whereas dedicated energy storage batteries can endure up to 6,000 cycles. The lifecycles of the batteries is expected to improve in the future.

Both AC and DC wallboxes can efficiently charge a conventional EV with a battery capacity between 16 and 30 kWh within 2-6 hours.

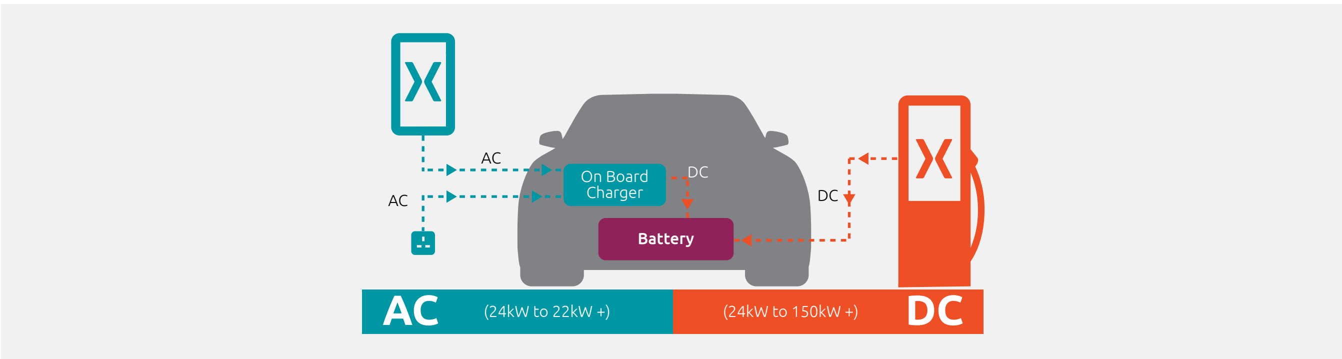


Fig. 2 Types of AC and DC wallbox charging

The integration of electric vehicles (EVs) into residential energy systems introduces a paradigm shift in how energy storage is conceived and utilised within the home. Given the substantial capacity of EV batteries, these mobile storage units can serve dual purposes—powering transportation and supporting domestic energy needs. As a result, the requirement for dedicated stationary battery systems in residential settings can be significantly reduced or even eliminated. By leveraging vehicle-to-home (V2H) and vehicle-to-grid (V2G) technologies, energy generated from renewable sources such as solar photovoltaics can be stored in EV batteries and dispatched intelligently, enabling dynamic load management, peak shaving, and improved self-consumption. The convergence of mobility and energy storage thus fosters a more resilient, cost-effective, and sustainable home energy ecosystem.

2.2 Application trends

DC fast charging stations

DC fast charging stations typically range from 22 kW to 350 kW, significantly reducing charging times compared to AC chargers. Larger batteries with capacities between 20 and 50 kWh can be fully charged within 30 minutes, making them ideal for quick stops. DC charging stations are commonly installed in public areas like car parks or gas stations, and along highways.

State of the art DC Charging stations are comprised of several charging modules with one module ranging from 15 kW up to 50 kW. Modular chargers offer flexibility and scalability since the charging modules can easily be stacked to achieve the desired charging power.

Specification	Level 2 (AC)	Level 3 (DC)	Level 3+ (DC)
Power conversion	Onboard	Offboard	Offboard
Location	Residential & Commercial	Commercial	Commercial
Charging power	3 kW-22 kW	20 kW-350 kW	>350 kW
Power supply	208/240 Vac	300-1000 Vdc	>800 Vdc
	12 A-80 A	Max.500 A	>400 A
	Single Phase/Split Phase	Three Phase	Polyphase
Charging time (50 kWh)	6 hours	30 min	10 min
Standards		IEC 61851-23/24	IEC 62196
		IEC 62196-3	SAE J2836/2 & J2847/2

Table 1: Summary of charging types, times and locations

Megawatt-level charging stations are emerging as a critical infrastructure component to support the electrification of medium- and heavy-duty vehicles. Unlike conventional chargers, MW-level stations require direct connection to the medium-voltage (MV) grid, typically at 34 kV and deliver power at high voltages, often around 1000 V. Manufacturers like BYD are planning over 4,000 MW-class stations across China alone, while broader market projections suggest high-power DC chargers (>200 kW) will grow at a compound annual growth rate (CAGR) of 33%, reaching over 218,000 units globally by 2028 (DC charging for plug in electric vehicles 2021' Yole market report).

Bi-directional charging enabling V2G & microgrid functionality

Bi-directional DC charging stations enable several trends by allowing electricity to flow from the grid into the vehicle and back.

Microgrid is a key concept in modern energy systems - a small-scale, localized power grid that can function independently or alongside the main grid. It typically includes components such as Distributed Energy Resources (DERs), energy conversion facilities, energy storage systems, local active loads, and more.

Additional use cases include utilizing the EV battery as an energy storage system during power outages, reducing electricity costs during peak demand, or integrating it into a smart home grid. Moreover, this bidirectional functionality can support grid stability by feeding excess energy back into the grid, helping create a more resilient and efficient energy infrastructure.

Fig 3. Symbiosis of charging station, energy storage, solar in a smart home/microgrid

Battery swapping and inductive charging

According to recent studies, the biggest deterrent for customers considering electric vehicles is the challenging charging landscape. AC chargers take much longer than conventional refuelling, while DC fast chargers are not yet widely available. Additionally, the lack of standardized charging plugs presents further complications for consumers.

Alternatives to traditional EV charging include Battery Swapping and Wireless (Inductive) Charging. Battery Swapping, common in the two-wheeler segment in Southeast Asia, is gaining popularity for EVs, seeing the first commercial, publicly available swapping stations. In this system, EV owners drive into a station where their empty batteries are replaced with fully charged ones. However, the extracted batteries still need to be recharged, ideally using DC fast chargers, meaning the fast-refuelling issue is resolved for the customer but not eliminated overall.

Wireless (Inductive) Charging allows electric vehicles to recharge without physical connectors by using electromagnetic fields to transfer energy between a charging pad on the ground and a receiver on the vehicle. This technology offers a convenient and hassle-free charging experience, though it requires precise alignment and infrastructure development.

Liquid cooling

Apart from optimizing the power devices and converter topology, liquid cooling technology offers significant advantages. It combines liquid cooling modules with liquid-cooled cables, where coolant (such as glycol or oil) flows through the liquid-cooled cables, directly dissipating the heat generated by internal components. This method not only has high cooling efficiency, allowing small cross-section cables to carry large currents while maintaining low temperature rise, but also greatly improves charging safety. Additionally, the thinner and lighter cables are more convenient to use and reduce safety hazards associated with excessive weight. Moreover, since the liquid cooling system does not need high power fans, it produces less noise, further enhancing the user experience. In summary, liquid cooling is a critical component for ultra-high-power DC charging systems.

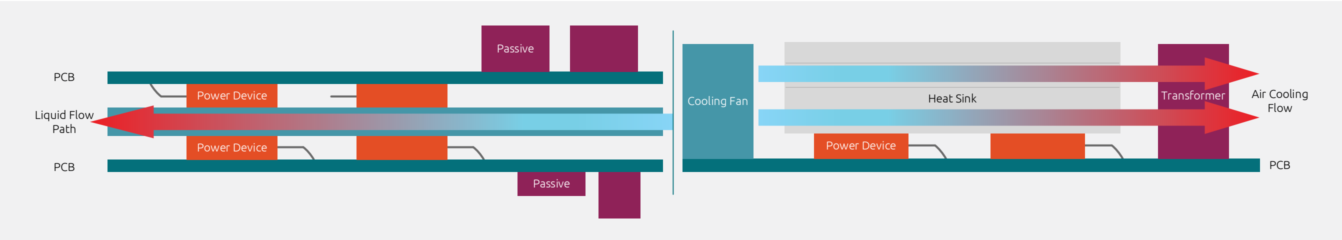


Fig 4. Conventional air cooling & Liquid cooling

Architecture of charging stations

A typical **AC-connected** system uses a line-frequency transformer to connect the distribution network to a three-phase AC bus, which operates at a line-to-line voltage of 250–480 V. This AC bus powers each charger at the station, with each charger incorporating its own AC-DC conversion stage. This setup results in multiple power conversion stages between the distribution network and the EV or RES DC port, increasing system complexity and cost while reducing overall efficiency. Nevertheless, AC-connected systems offer benefits such as mature, widely available technology and established standards, which is why they are the most common configuration for EV charging stations.

DC-connected systems utilize a central AC-DC converter to establish a DC bus, allowing for greater efficiency and power density by reducing the number of conversion stages. More advanced configurations employ solid-state transformers (SSTs), which combine rectification, voltage conversion, and isolation into a single unit. These systems are well-suited for ultra-fast or high-power charging applications but still face challenges, particularly in DC protection. Although current solutions—such as advanced fuses, solid-state circuit breakers, and protective relays—have proven technically viable, the industry must develop standardized protection protocols before DC architectures can become mainstream.

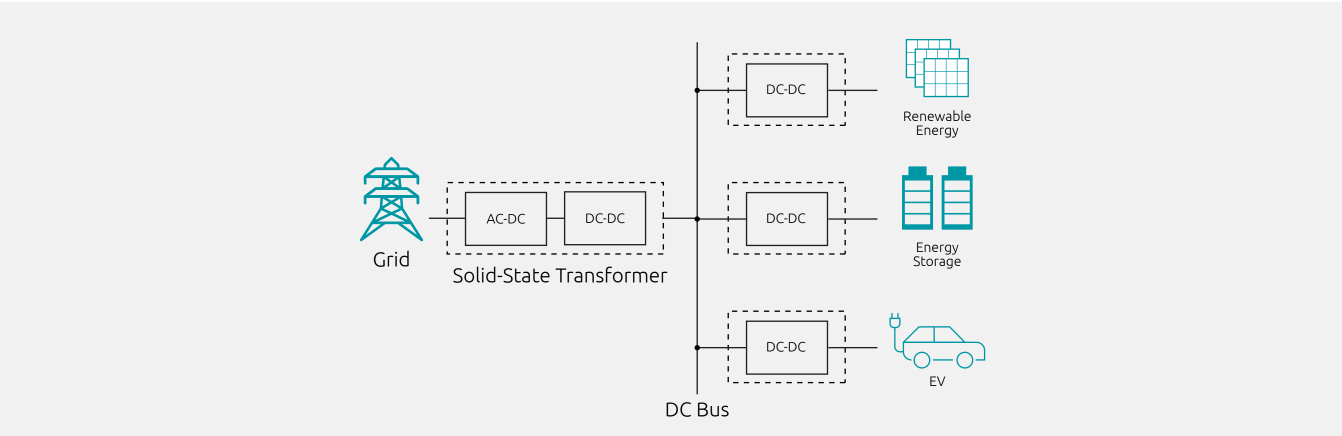


Fig 5. Architecture of DC Charging Station

3. Block diagram

3.1. AC charger

AC charging stations feature communication and metering modules that manage the transfer of AC input power to the On-Board Charger (OBC) within the EV.

Block diagram - AC off-board EV charger

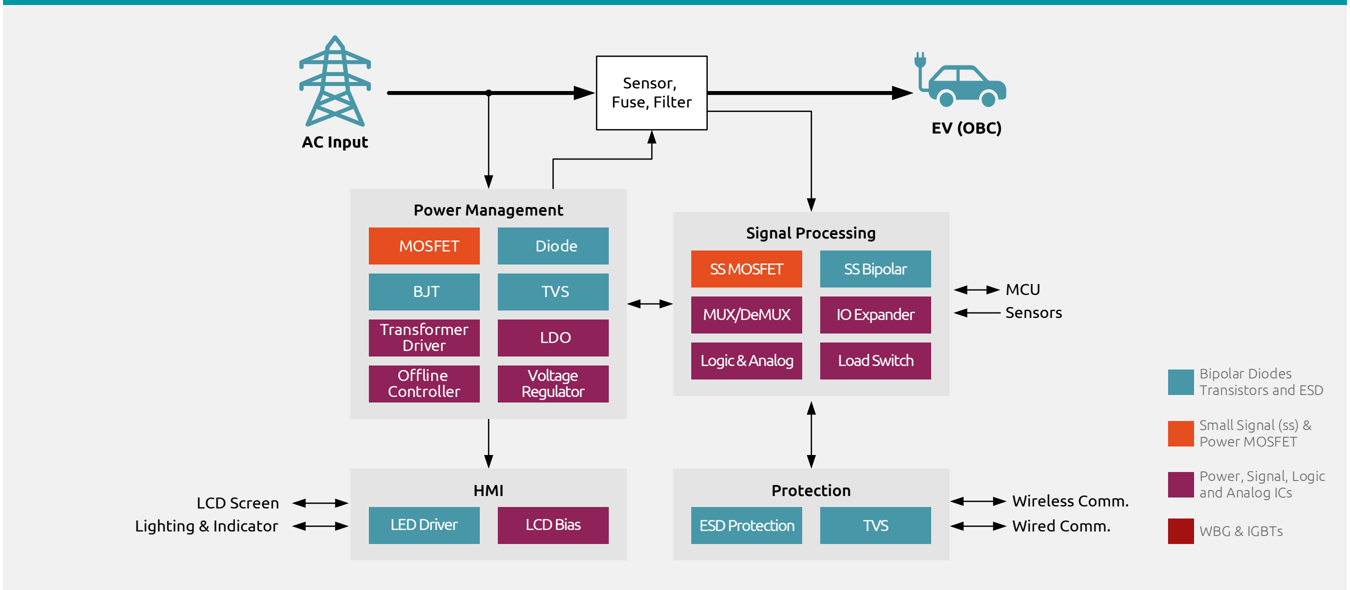


Fig 6. AC EV charger block diagram

AC charging stations feature communication and metering modules that manage the transfer of AC input power to the On-Board Charger (OBC) within the EV.

The **Power Management** block delivers power to sensors, controllers, communication modules, and other low-power electronic components. An offline regulator is often chosen for its compact form factor and high integration, while discrete solutions are used when cost reduction is a priority.

The **Protection** block primarily focuses on ESD (Electrostatic Discharge) protection. With numerous signal interfaces present in an AC charger, ESD protection is essential to safeguard circuits from high-voltage transients. TVS diodes are commonly used to shield low-power systems from these voltage spikes.

The **HMI (Human-Machine Interface)** block enables user interaction with the charger and displays real-time system information. This may include an LCD screen powered by an LCD bias power IC or basic LED indicators driven by bipolar transistors.

Lastly, the **Signal Processing** block handles data transmission and signal conversion, incorporating MCUs, small-signal devices, and logic components. Where signal isolation is necessary, isolators are preferred to ensure safe and reliable operation.

3.2. DC charger

A typical DC charger has two main stages for power conversion: AC-DC (PFC) and DC-DC.

Block diagram - DC off-board EV charger

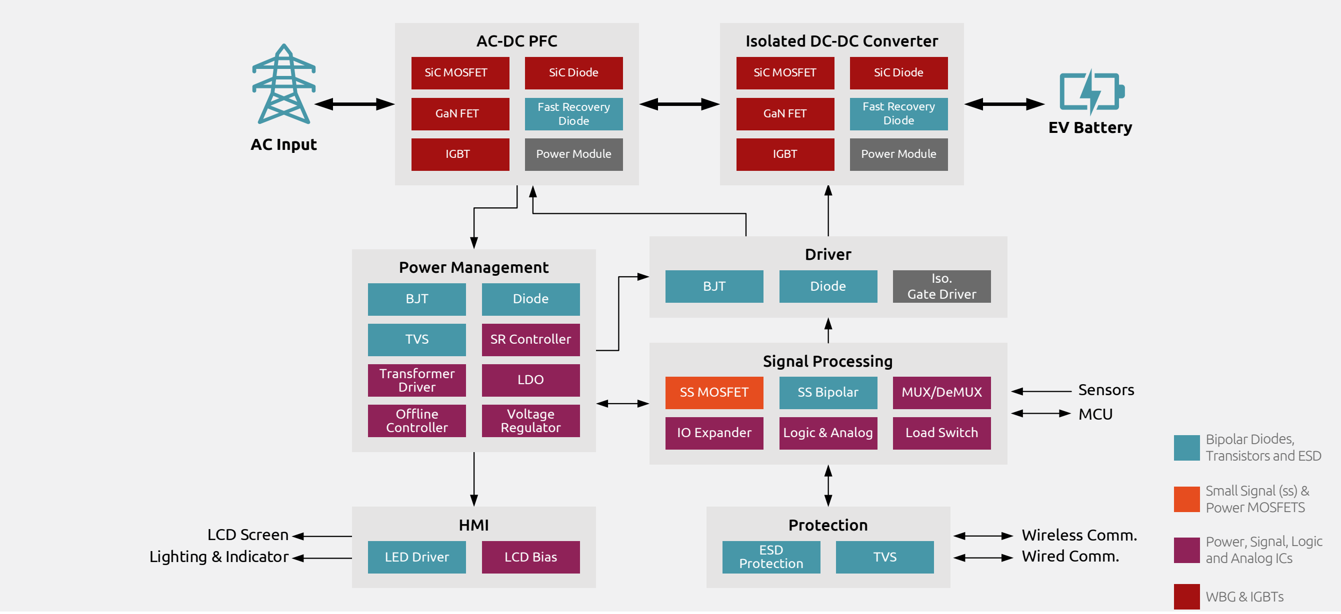


Fig 7. DC EV charger block diagram

The **PFC (Power Factor Correction)** stage improves grid power quality by reducing phase differences and minimizing total harmonic distortion (THD). It also provides stable DC output for efficient DC-DC conversion.

The **Isolated DC-DC Conversion** adjusts the voltage to match the EV battery's requirements, either stepping it up (boost) or down (buck). It also provides isolation to enhance safety. High-voltage power semiconductors play a pivotal role in determining overall efficiency across both stages. The optimal solution should be selected based on specific application requirements—whether that involves choosing between conventional IGBTs and higher-efficiency wide bandgap (WBG) devices or deciding between paralleled discrete components and high-power density power modules.

The **Gate Driver** block provides efficient power semiconductor switching while protecting against issues such as half-bridge crosstalk. While a gate driver IC is typically preferred, external circuits may require additional components like diodes or BJTs for specific functions.

The **Power Management** block is responsible for supplying low-power devices, delivering voltages ranging from 200 V to 1000 V to support both 400 V and 800 V battery architectures. It must be designed to accommodate a more complex low-voltage system, requiring higher power output and multiple voltage rails. Typical components in such compact power supply units include flyback controllers, synchronous rectification ICs, and low-dropout regulators (LDOs). Furthermore, to ensure safe and reliable operation, robust isolation between high-voltage and low-voltage domains must be implemented using digital isolators and transformer drivers.

Other key blocks—**Signal Processing, HMI,** and **Protection**—function similarly to those in an AC charger, though signal processing in a DC charger is more complex and requires additional logic and small-signal components

4. Topologies and Circuit Diagram

4.1. Interleaved boost Power Factor Corrector (PFC)

The Interleaved Boost Converter is a common topology employed in the Power Factor Correction (PFC) stage of DC electric vehicle (EV) chargers. While increasing the number of interleaved channels necessitates additional transistors, diodes, and gate drive signals, this approach effectively scales output power with relative simplicity. By distributing current across multiple phases, it minimizes conduction losses, reduces inductor size, lowers thermal stress, and enhances total harmonic distortion (THD) performance and EMI filter design.

However, as a bridgeless PFC topology, it suffers from rectifier voltage drops that contribute to power losses, particularly in high-power applications, thereby limiting overall efficiency. Moreover, its unidirectional nature makes it incompatible with vehicle-to-grid (V2G) functionality, which is increasingly important for next-generation chargers. Although cost-effective, the additional component count and lack of bidirectional capability may constrain its long-term viability.

SiC diodes are superior to their silicon counterparts in many critical metrics, including switching characteristics and are therefore suggested for this topology. For a comparison of Si and SiC refer to Nexperia Whitepaper.

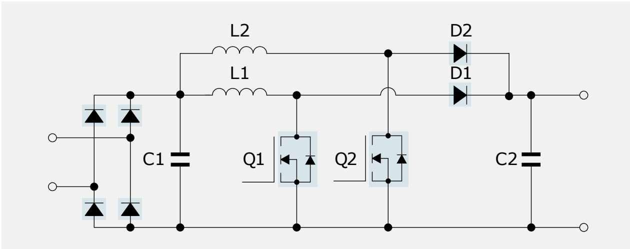
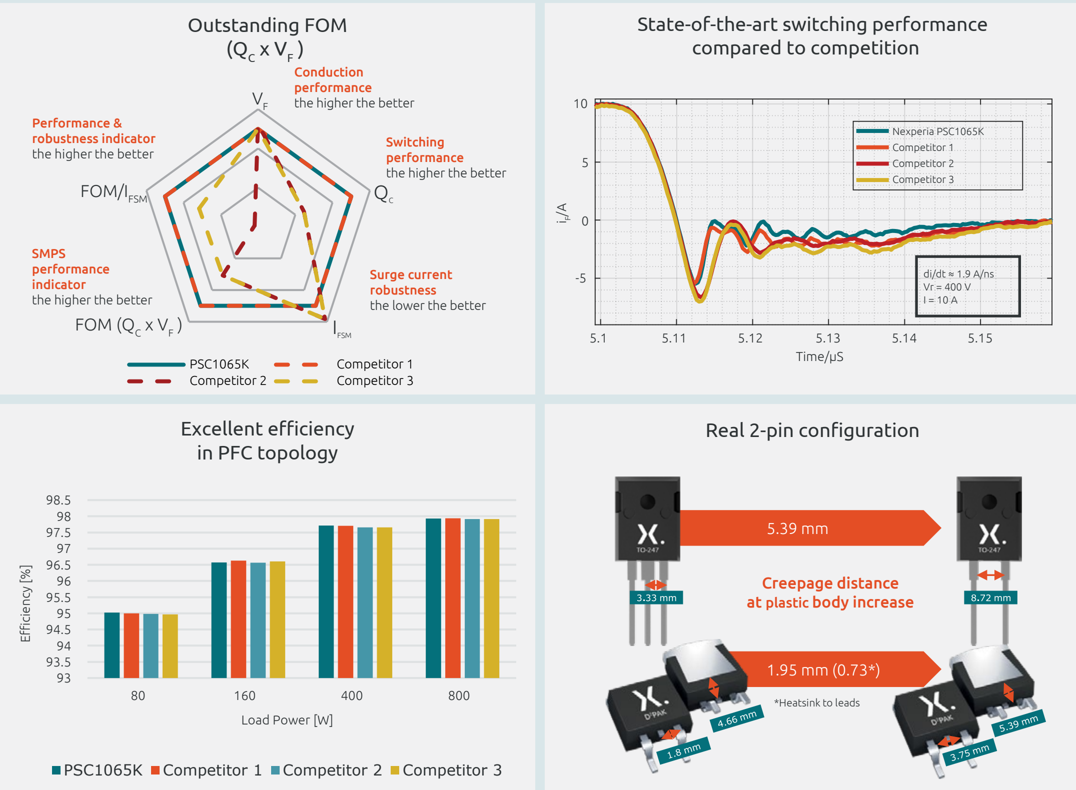


Fig 8. Interleaved Boost PFC power converter topology

Suggested Nexperia SiC rectifier portfolio



4.2. Vienna PFC (T-NPC PFC)

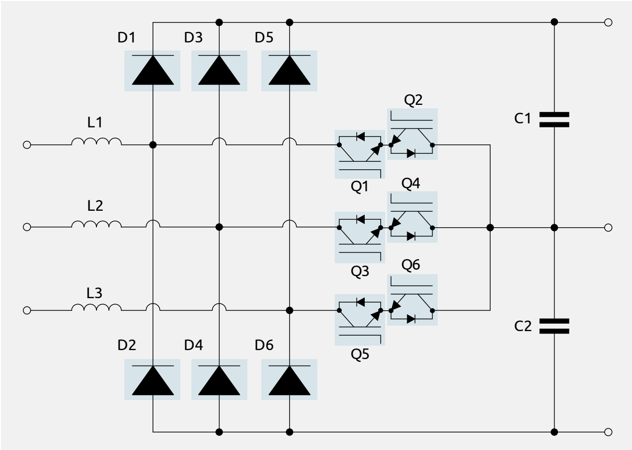


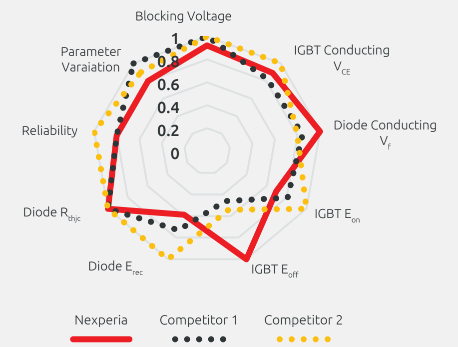
Fig 9. Vienna PFC (T-NPC PFC) power converter topology

The Vienna PFC is ideal for three-phase high-power DC EV chargers with 400/800 V output. Each phase has two rectifier diodes and two transistors, controlled by one gate driver, eliminating dead time issues and reducing cost. It also enables 800 V-1000 V output using 650 V transistors. As a three-level NPC topology, Vienna PFC reduces power loss, improves EMI, and lowers current ripple compared to traditional two-level boost PFC. However, it requires more components and managing neutral point imbalance is challenging. Its unidirectional power flow can be resolved by replacing rectifier diodes with transistors, forming a T-NPC configuration. While this allows bidirectional operation, it also adds complexity and cost, which must be considered against its performance benefits.

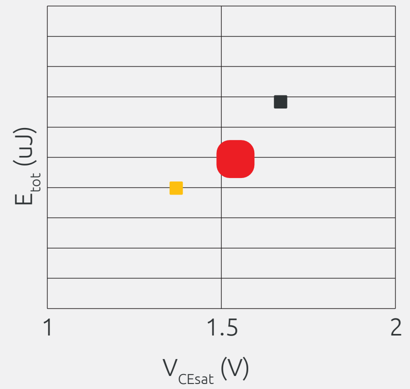
IGBTs are a good alternative to design in here as they are a very mature and reliable technology. Nexperias third generation of IGBTs are introduced in the Application Note AN90042.

Suggested Nexperia IGBT portfolio

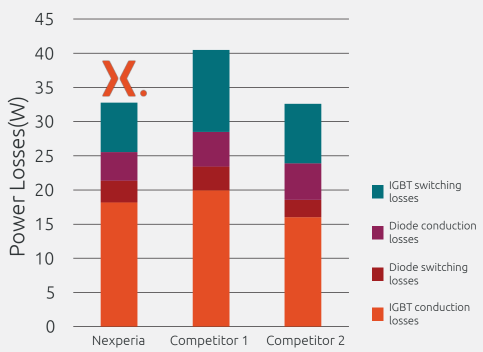
Outstanding performance



State of the art trade off



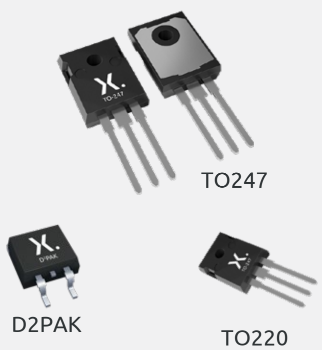
Excellent efficiency in inverter topology



Note: based on simulation

V_{in} = 400 I_{out} = 30 A f_{sw} = 10 kHz

Pin to pin configuration



Nexperia IGBT benefits

- Low conduction and switching losses
- Stable and tight parameters for easy parallel operation
- Fully rated as a soft fast reverse recovery diode
- Ultra-low diode V_f at operation temperature
- 5 µs short circuit capability

4.3. Active Front End (Three-phase six switch boost rectifier)

The three-phase boost rectifier, or Active Front End (AFE), is ideal for the PFC stage in EV chargers due to its simple design as a two-level structure, bidirectional operation, high efficiency, and low THD. It also features fewer switches with an easy control scheme.

However, high conduction losses from current passing through transistors and body diode recovery losses at high switching frequencies are major drawbacks. The best solution is using Wide Bandgap (WBG) semiconductors, such as two 1200 V SiC MOSFETs per channel or a half-bridge SiC power module in 800 V systems. While WBG semiconductors improve efficiency and reduce losses, they need careful thermal management & design consideration on driving circuit. Designers must balance higher upfront costs with long-term performance benefits and design complexity.

To reduce design footprint and increase cooling X.PAK top cooled devices are suggested. Learn more about them in Nexperia Application Note AN90067 . For other SiC MOSFETs from the Nexperia portfolio, check out the Nexperia website or the SiC MOSFETs leaflet.

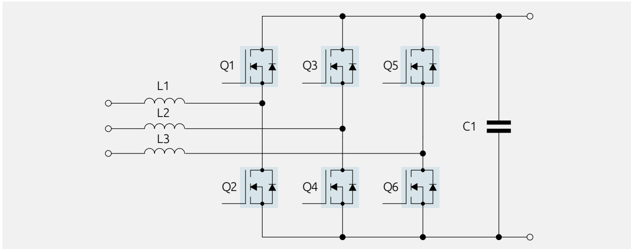
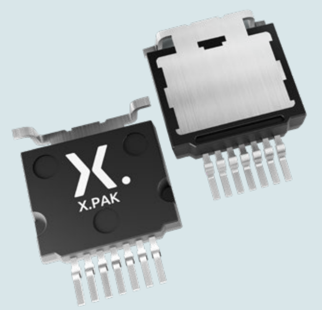


Fig 10. Active Front End (three-phase six switch boost rectifier) power converter topology

Suggested Nexperia X.PAK 1200V SiC MOSFETs



Top-side cooled SMD package for 1200 V SiC MOSFETs

- Combines **high thermal performance**, compact size, and **easy assembly** for high-power applications
- 14 mm x 18.5 mm package size with leads
- Maximize **thermal heat dissipation from the top**, reducing negative impacts of heat dissipation via the bottom (PCB)
- Assembly benefits of SMD merged with cooling efficiency of through-hole technology
- X.PAK packaged devices deliver **class-leading electrical performance** known from Nexperia SiC MOSFETs (excellent $R_{DS(on)}$ temperature stability).

4.4. LLC and CLLC resonant converters

The **LLC** and **CLLC** resonant converters use Zero Voltage Switching (ZVS) on the primary side and Zero Current Switching (ZCS) on the secondary side, improving efficiency and EMI under full load. However, maintaining high efficiency across varying output voltages is challenging. Resonant tank design and complex control strategies add further difficulties.

These converters support unidirectional or bidirectional operation, with CLLC and full-bridge LLC enabling bidirectionality. They require either four transistors with four diodes or eight transistors, along with the corresponding gate drivers. This increases complexity but allows for better control, making them ideal for precise power management applications.

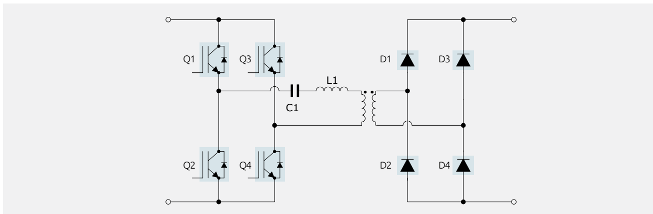


Fig 11. LLC resonant converter (full diode bridge) power converter topology

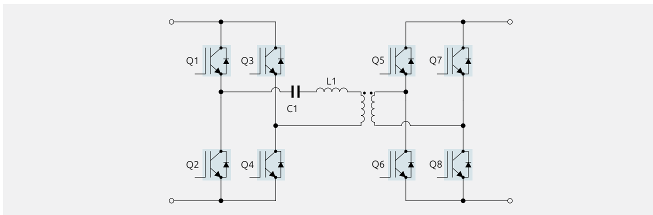


Fig 12. LLC resonant converter (full active bridge) power converter topology

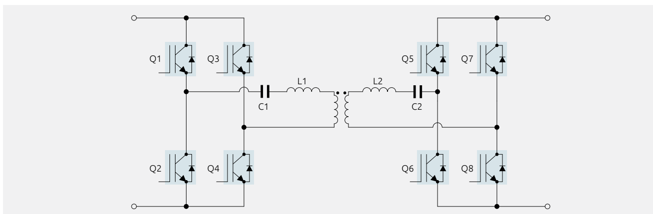


Fig 13. CLLC Resonant power converter topology

4.5. Dual Active Bridge (DAB) converter

The **Dual Active Bridge** converter has gained popularity due to SiC/GaN power devices and advanced magnetic materials, which enhance efficiency and power density. Like LLC, it supports bidirectional power flow, galvanic isolation, and soft switching, but uses phase-shift control instead of a resonant tank, simplifying design. To ease the design in of the GaN devices Nexperia released advanced SPICE models for its GaN portfolio. For and in depth dive in GaN technology consult Nexperias GaN MOSFET handbook.

A DAB converter consists of two full bridges (eight transistors, eight gate drivers). In DC EV charging, where wide voltage gain is needed, reactive power increases and ZVS may be lost, creating design challenges. Modulation techniques help address these issues but require trade-offs based on application needs.

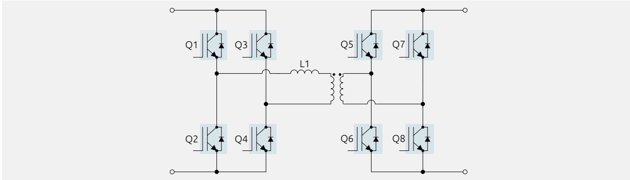


Fig 14. Dual Active Bridge power converter topology

Suggested Nexperia E-mode and D-mode GaN MOSFETs

Our broad portfolio is recognised as the benchmark in efficiency in process & performance

- **E-mode:** simple one chip solution. Best fit for low power applications
- **Cascode/D-mode:** best performance for high power systems
- Wide portfolio from 40 V to 700 V and flexibility in offering customized solutions
- Two decades of expertise in supplying high-volume, high-quality copper-clip packages ushers in a new era of GaN
- Key supplier to the **automotive** industry, in-depth understanding of automotive system requirements and focused technical capability

5. Application design challenges and solutions

5.1. Balancing parallel connection of multiple switches

In high-power applications like DC EV chargers, parallel use of power devices is common due to current capacity limitations. However, improper parallel design can cause uneven stress, accelerating the aging of individual devices and leading to system failures. To ensure reliability, both static and dynamic current sharing must be carefully managed.

Nexperia Solution:

Static current sharing occurs during conduction and is primarily affected by manufacturing variations in device parameters such as $V_{GS(th)}$/$V_{GE(th)}$, R_{DSon}/V_{CEsat}, and body diode V_f. To address this, selecting devices with minimal parameter deviations, screening for matching characteristics or from the same batch is recommended. Using products with a positive temperature coefficient (PTC) helps simplify thermal management and structural design. NGW75T65H3DFP is a 650 V, 75 A IGBT, its PTC characteristic can automatically reach current sharing at conducting.

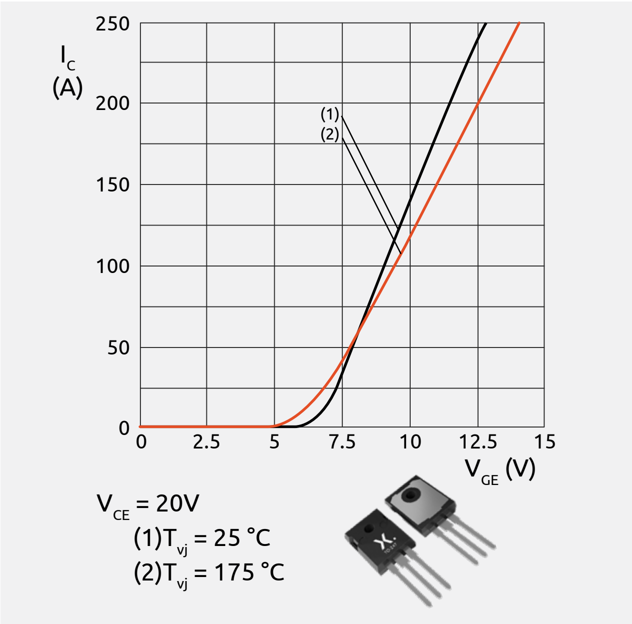


Fig 15. PTC characteristic of NGW75T65H3DFP - $V_{GS(th)}$

Dynamic current sharing refers to the distribution of current among parallel devices during switching events. While it can be influenced by intrinsic factors such as manufacturing variations—particularly the gate threshold voltage $V_{GS(th)}$ —the design of the gate drive circuitry plays a more significant role. To mitigate mismatches, techniques such as mirroring gate drive circuits can help minimize layout-induced parasitic differences. Additionally, when paralleling multiple devices, it is essential to select gate drivers with sufficient current capability or incorporate external current-boosting circuits to ensure balanced and adequate drive strength across all devices.

Advice for a GaN gate driver design can be found in Nexperia Application Note AN90041. Usage of large package devices such as Nexperias CCPAK1212 GaN devices can eliminate the need for paralleling, as a large enough die can already be implemented in the device. However, if paralleling is still needed, follow the advice from Nexperia Application Note AN90030.

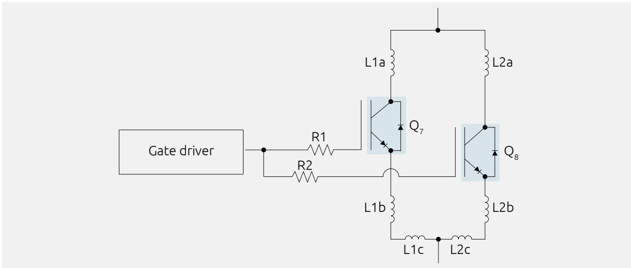


Fig 16. Duplicated layout and parasitic inductance

Suggested Nexperia 650V IGBTs portfolio in TO247-3

- NGW30T65M3DFP – 30A, Medium Speed
- NGW40T65M3DFP– 40A, Medium Speed
- NGW50T65M3DFP– 50A, Medium Speed
- NGW60T65M3DFP– 65A, Medium Speed
- NGW75T65M3DFP– 75A, Medium Speed
- NGW40T65H3DFP – 40A, High speed
- NGW50T65H3DFP– 50A, High speed
- NGW75T65H3DFP– 75A, High speed
- NGW75T65H3DF– 75A, High speed
- NGW40T65H3DHP– 75A, High speed

5.2. Parasitic turn-on & overvoltage spike in half bridge

Wide Bandgap (WBG) devices enable the design of high-frequency switching systems, significantly enhancing power density. This advancement allows for more compact charging modules, paving the way for ultra-fast charging stations with increased output capacity. However, these benefits introduce new challenges in system design.
The half-bridge topology, commonly used in high-power conversion, is particularly sensitive to these effects. The rapid switching transitions of either transistor in the half-bridge can result in high di/dt, which, when combined with parasitic inductance in the devices and power loop, generates voltage overshoots. These transient spikes can overstress the complementary switch, potentially leading to device failure.
Additionally, high dv/dt events can induce displacement currents through the Miller capacitance of the opposing switch. This current flows through the gate resistor, potentially creating a voltage high enough to cause unintended turn-on of the opposite switch. Such false triggering can result in a shoot-through condition, where both switches conduct simultaneously, leading to catastrophic failure.

Nexperia Solution:

We can optimize the design from multiple angles. For example, in the design of the drive circuit, we need to find an appropriate gate resistor (R_G) to balance switching losses and dv/dt or di/dt. A larger R_G will cause a greater voltage drop, increase the risk of parasitic turn-on, but it also reduces V_{DS} spikes as it's slowing down the switching speed. Additionally, setting an appropriate dead-time is essential. While often considered undesirable, dead time plays a critical role in ensuring safe and reliable switching by preventing overlap between the conduction periods of the upper and lower switches.

From a product perspective, devices with lower Q_{GD}/Q_{GS} are less susceptible to parasitic turn-on, as I = C x dv/dt. The NSF040120L4A0 features industry-leading Q_{GD}/Q_{GS} values, and its Kelvin source pin helps separate power and control signals. This separation reduces V_{GS} signal interference during fast switching, effectively minimizing additional switching losses. For more about SiC parameters, check out Nexperia Application Note AN90048.

Adopting additional protection measures from advanced gate driver IC such as negative turn-off voltage and active Miller clamping can effectively reduce V_{GS} spikes, preventing unintended turn-on. Real-time bridge current monitoring or using gate drivers with desaturation protection can quickly rescue the device and system from damages.

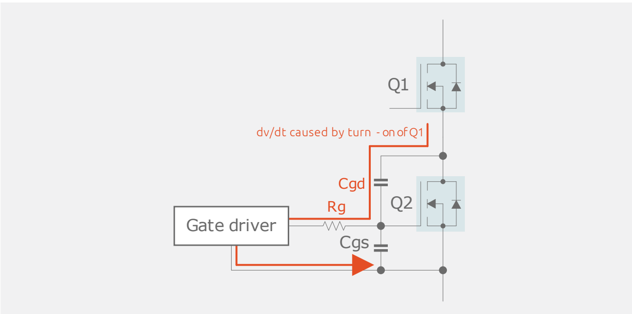


Fig 17. The cause of self-turn-on

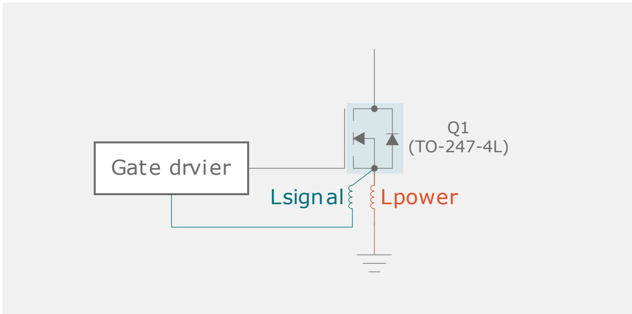
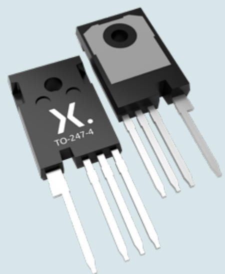


Fig 18. Kelvin source to separate signal & power

Suggested Nexperia 1200 V SiC MOSFETs in TO247-4 with 40 and 80 mΩ

- Excellent R_{DSon} temperature stability
- 65 A and 35 A rated drain current
- Very low switching losses
- Fast reverse recovery
- Fast switching speed
- Temperature independent turn-off losses
- Very fast and robust intrinsic body diode


NSF040120L4A0 / NSF080120L4A0

5.3. Loss calculation during an LLC converter design

The LLC resonant converter has been widely used for over 20 years, proving its value in medium-power applications like LED drivers and PSUs and high-power applications such as DC EV chargers.

A major advantage of LLC converters is soft-switching, which significantly reduces switching losses and EMI. The topology enables Zero Voltage Switching (ZVS) for the input inverter and Zero Current Switching (ZCS) for the output rectifiers, minimizing MOSFET switching losses.

However, loss calculation is still a challenge for thermal design and layout optimization.

Nexperia Solution:

The following aspects need to be paid special attention to in the LLC circuit design.

1. Primary-side MOSFET losses
   - Conduction loss
   - Body diode conduction loss
   - Turn-off loss (Ideally, the MOSFET achieves ZVS turn-on, minimizing these losses)

2. Secondary-side rectifier losses
   - Conduction loss (Since secondary diodes achieve ZCS turn-off, reverse recovery losses are negligible. Devices with lower forward voltage drop should be chosen, such as PNU650200EJ (V_f = 1.55 V) or PSC2065L (V_f = 1.8 V)).

3. Magnetic losses
   - Core losses, hysteresis losses, and eddy current losses from the transformer and magnetizing inductor.

Nexperia's NSF040120L4A0 SiC MOSFET offers excellent R_{DSon} stability through temperature rise, making it ideal for LLC converters, particularly in high power regions. Additionally, due to tight $V_{GS(th)}$ range (1.7 V-2.9 V @ I_d=4 mA) reliable current sharing is enabled even in dynamic switching scenarios. Read more about the performance of Nexperia SiC MOSFETs in this blog post.

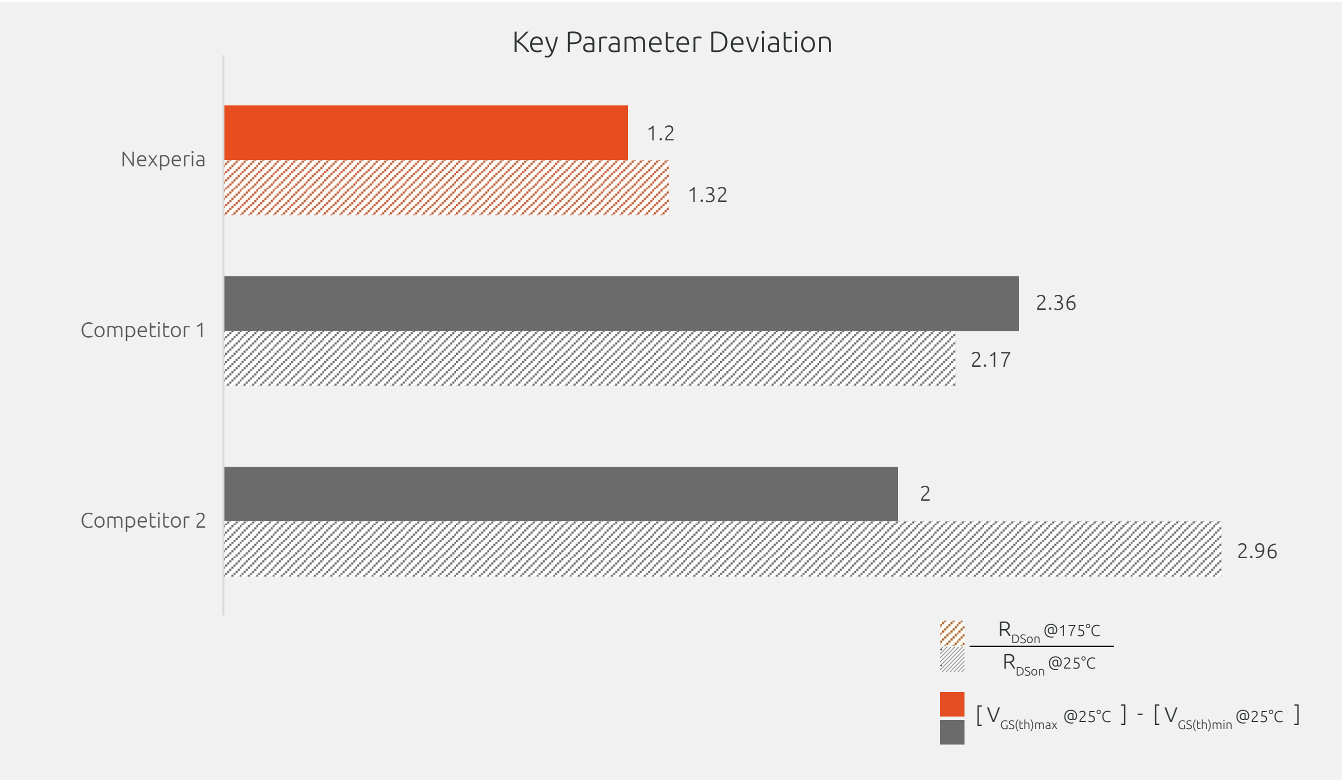


Fig 19. NSF040120L4A0 SiC MOSFET $V_{GS(th)}$ (V) and R_{DSon} (mΩ) deviations compared to leading supplier products

5.4. Insufficient gate driving capability

Gate current plays a critical role in determining switching losses in high-power devices with substantial gate charge, as it directly influences the switching speed. A higher gate voltage increases the total gate charge (Q = C × V), facilitating faster and more efficient turn-on of the MOSFET. However, until semiconductor process advancements significantly reduce gate charge, ensuring adequate gate drive current remains essential—particularly in high-frequency applications or when multiple devices are connected in parallel.

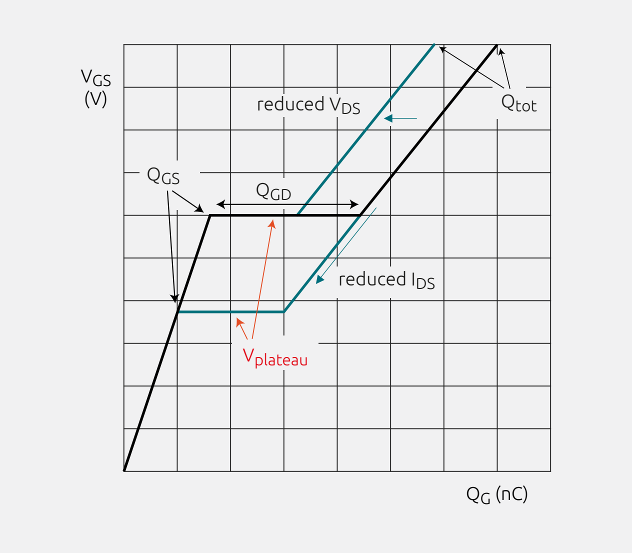


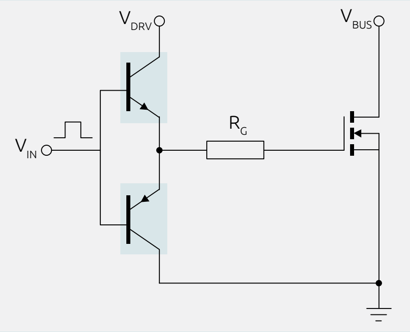
Fig 20. Turn-on Process of MOSFET

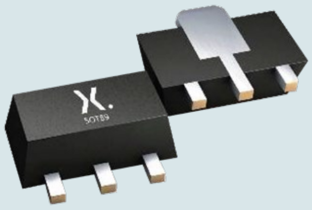
Nexperia Solution:

“Bipolar junction transistors (BJTs) play a significant role in driving power switches. They offer high flexibility in the design of a gate driver, and due to their high peak power capability, they provide advantages in applications where cost performance plays a significant role.” -- Chapter7.71 Bipolar Transistor Application Handbook.

This BJT “booster” is a totem pole driving circuit which consists of NPN and PNP transistors (e.g., PBSS4041PX & PBSS4041NX). These low V_{CEsat} transistors, with a maximum I_C of ±5 A, enable higher sink/source currents, reducing the Miller Plateau duration and minimizing power loss, thereby improving efficiency. The compact package SOT89 allows closer placement to the driver output, further reducing path losses.

Suggested Nexperia Bipolar totem pole driver





PBSS4041PX & PBSS4041NX

5.5. Independent turn-on and turn-off control

When a gate driver provides only a single output, it limits the ability to independently control the turn-on and turn-off switching speeds of the transistor. This constraint becomes particularly critical in high-voltage systems with fast switching transients (high dV/dt). For example, reducing the gate resistance (R_G) can accelerate switching, but excessively low resistance during turn-off may lead to dangerous voltage overshoots and gate oscillations. These effects can compromise device reliability and increase the risk of failure, underscoring the importance of carefully balancing gate drive parameters in such applications.

Nexperia Solution:

Advanced gate drivers typically feature dual outputs, providing greater control, extensive protection functions, and strong current-driving capabilities.
Similarly, as a cost-effective alternative to single output gate driver, adding a Schottky diode in parallel (e.g. BAS40, very low capacitance = 1 pF) with a resistor creates a separate path for the driving current, while the diode's natural forward voltage drop helps to speed up the turn-off process.

As an alternative to BAS40, Nexperia is now offering Schottky diodes in DFN1006BD like BAS40LS. The ultra-small package DFN1006BD can save more than 90% space compared to SOT23 while providing other advantages in terms of soldering and inspection.

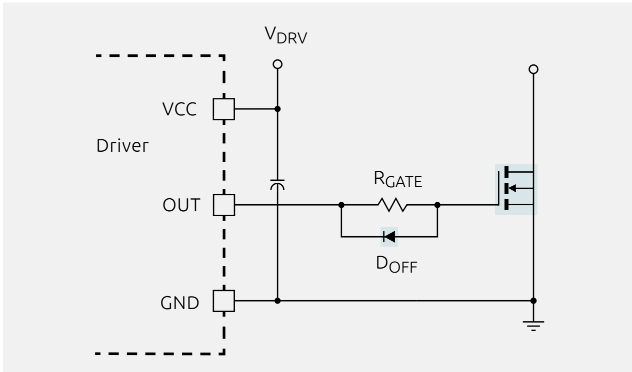


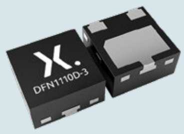
Fig 21. Application of SBD in driving circuit

Suggested advanced Nexperia DFN packages

SOT23AB / SOT457
Occupied PCB area 11.4 mm²

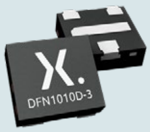
DFN2020MD-6
Occupied PCB area 5.1 mm²
Space saving 55%

SOT323
Occupied PCB area 6.2 mm²



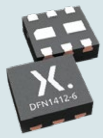
DFN1110D-3
Occupied PCB area 2.5 mm²
Space saving 60%

SOT23
Occupied PCB area 9.9 mm²



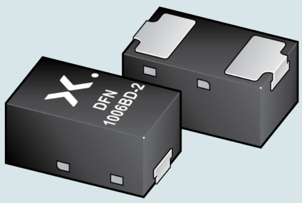
DFN1110D-3
Occupied PCB area 2.5 mm²
Space saving 75%

SOT363
Occupied PCB area 6.2 mm²



DFN1412-6
Occupied PCB area 2.7 mm2
Space saving 55%

SOT23
Occupied PCB area 9.9 mm²



DFN1006BD-2
Occupied PCB area 1 mm2
Space saving ~ 90%

5.6. Unaligned voltage levels in a thorough system integration

AC chargers primarily deliver alternating current directly to an electric vehicle's onboard charger (OBC), with minimal power conversion involved. To support advanced features such as 4G, Bluetooth Low Energy (BLE), and Near Field Communication (NFC), these systems often integrate multiple communication modules operating at various voltage levels - typically 1.8 V, 3.3 V, and 5 V. When devices operating at different voltage levels need to exchange signals, proper level matching is essential to ensure reliable communication and prevent signal integrity issues.

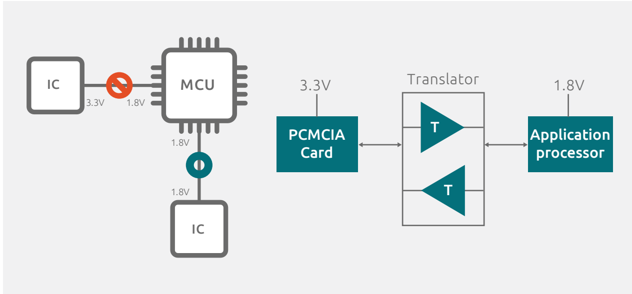


Fig 22. Translating transceiver interface

Nexperia Solution:

Voltage translators or level shifters are used to align these levels. Without proper adaptation, mismatched voltage levels can cause communication failures or even damage chip pins.

Nexperia's voltage translators simplify mixed-voltage system design by delivering a compact, high-performance solution with wide supply voltage support - from as low as 0.9 V up to 5.5 V. Featuring ultra-low propagation delay, low quiescent power consumption, and integrated auto-direction sensing with 3 state outputs, these translators ensure glitch free, efficient level shifting for high-speed interfaces. This innovative solution not only reduces BOM costs and board space but also enhances overall system performance across a broad range of applications. Application note AN90033 details applications of LSF010x auto sense devices.

The following figure shows the H-L and L-H translation between devices of 3 different process families, in this example LVC, AUP and AXP families operate at different supply voltages (5 V, 3.3 V, 1.8 V). To guarantee functionality, the V_{OH} of the driver must be higher than the V_{IH} of the receiver. Similarly, the V_{OL} of the driver must be lower than the V_{IL} of the receiver. For a deep dive into the specifics of logic device families and the translations from one to the other have a look at Nexperia Logic Application Handbook.
For advice on how to achieve level shifting with discrete devices consult Application Note AN10441.

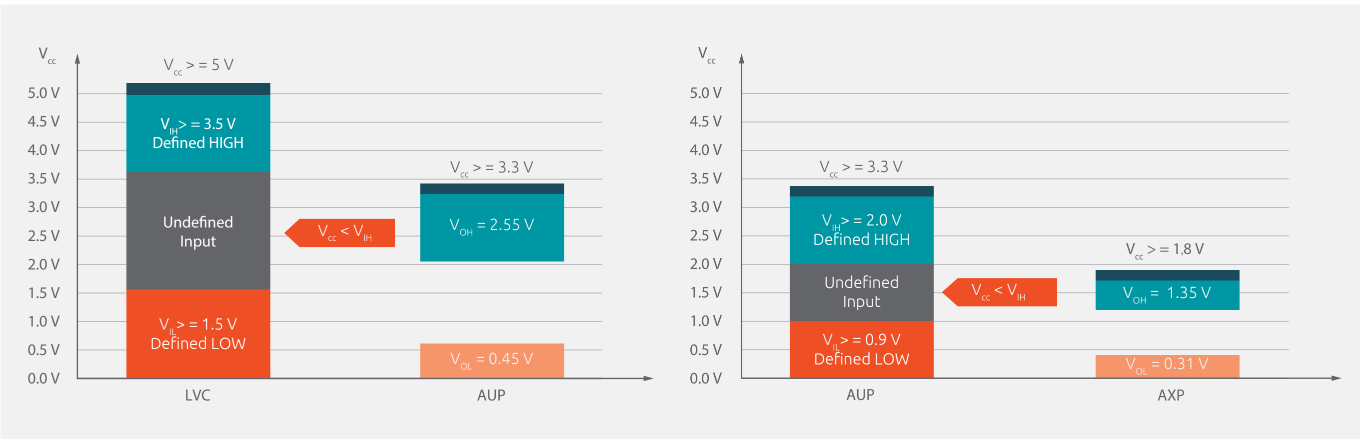


Fig 23. I/O Voltage Level Overview for LVC, AUP, AXP

5.7. Insufficient I/O port demands

The control strategy for power converters in DC EV charging modules is inherently complex, requiring real-time monitoring of multiple sensor signals to ensure optimal performance, efficiency, and safety. For instance, in a Vienna rectifier-based Power Factor Correction (PFC) system, continuous monitoring of parameters such as grid current, output current, DC link voltage, and battery characteristics is essential. This enables precise power factor correction, maintenance of sinusoidal input current, and stable regulation of the DC link voltage.

Moreover, with growing emphasis on system safety and reliability, additional diagnostic features - such as temperature and humidity sensing - are increasingly integrated. These enhancements support early fault detection and contribute to the overall robustness of the charging infrastructure.

Nexperia Solution:

To handle multiple signals efficiently, designers often use multiplexers or I/O expanders to increase I/O capacity, allowing microcontrollers to manage more resources without adding design complexity.

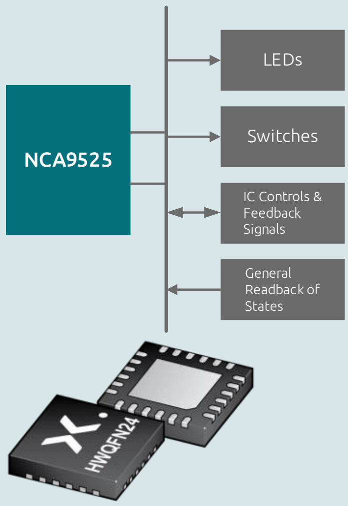
Nexperia's NCA95xx family of General-Purpose I/O (GPIO) expanders provides an elegant solution. Housed in TSSOP24 and HWQFN24, these GPIO expanders are equipped with multiple features: Interrupt, Hardware RESET, Internal pull-up resistors, and configurable pull-ups. As one of the recommendations, NCA9595BY operates within a 1.65 V – 5.5 V supply range, making it compatible with both low-voltage MCUs (e.g., 1.8 V, 3.3 V) and traditional 5 V systems. These GPIO expanders reduces the PCB design complexity through trace reduction and routing simplification thereby reducing the BOM cost.

For expanding the analog to digital conversion (ADC) capability of the controller, multiple analog signals can be relayed to a single ADC pin via analog multiplexers and switches. Read about the advantages of using Nexperia portfolio, including injection current control, back power protection and power-off isolation in Application Note AN90062.

Nexperia provides an industry-leading portfolio of logic devices, including multiplexers and IO expanders, tailored for such high-performance applications. These devices, developed with advanced process technologies, enable scalable and efficient designs for modern DC charging modules.

Suggested Nexperia I2C I/O expander NCA9525

- Single supply GPIO expander supporting 1.65 V to 5.5 V operation
- Serial to parallel and parallel to serial conversion with I2C protocol
- Schmitt-trigger action allows slow input transition and better switching noise immunity at the SCL and SDA inputs
- Low power consumption 2.5 μA max
- 400 kHz operation (FM I2C mode)
- Glitch free Power up with all channels configured as inputs with Pull-ups
- Latched outputs with 25 mA drive maximum capability for directly driving LEDs
- Open-drain active LOW interrupt output (INT)
- Configuration pull-up registers to disable pull-up resistors on GPIOs
- Noise filters on SCL and SDA inputs



5.8. Sensitive components need isolated power supply

Electric vehicle (EV) battery architectures are increasingly transitioning from 400 V to 800 V and beyond to reduce conduction losses associated with high current. DC EV charging modules, which feature complex control systems, often power their low-voltage controllers and sensors directly from the high-voltage DC bus. To safeguard these sensitive components from electrical surges or potential damage, robust isolation mechanisms are essential for ensuring safe and reliable operation.

In compliance with safety standards such as IEC 61851 and GB/T 18487.1, which mandate electrical isolation for both AC and DC EV chargers, proper isolation design is not only a best practice but a regulatory requirement. This includes the use of digital isolators, isolated power supplies, and reinforced insulation techniques to protect low-voltage circuitry from high-voltage transients.

Nexperia Solution:

DC EV charging modules use serial communication buses to transmit data over physical networks such as RS232, RS485, CAN, etc. These transceivers and external IO ports are recommended to use isolated power supplies to ensure electromagnetic interference (EMI) and reliable system operation.

The NXF650x transformer driver family is a critical component of the isolated power supply, enabling galvanic isolation in the DC-DC conversion. Read more about their protection features and EMC performance.

It integrates two low-side switches that operate alternately in a push-pull manner, working together with a center-tapped transformer and diodes to generate the required voltage rails. These voltage rails power components with isolated power demands, such as isolated gate drivers, CAN transceivers, etc.

By integrating these functions, the NXF650x ensures high efficiency, compact design, and reliable operation, addressing the growing demand for advanced isolated power solutions in EV charging systems.

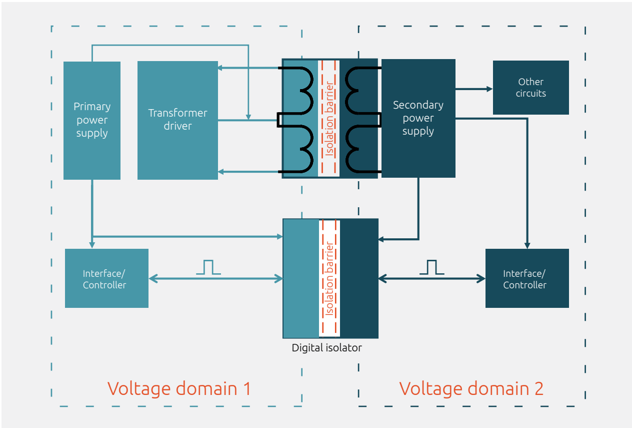
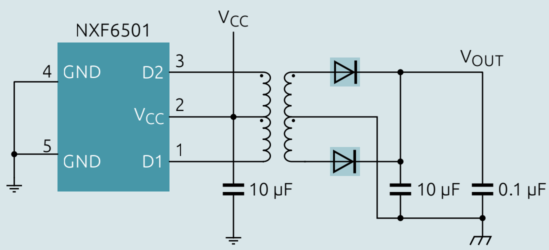
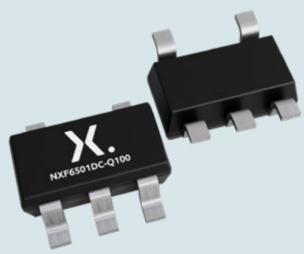


Fig 24. Signal & Power Isolation

Suggested Nexperia NXF6501 transformer driver

- Higher output power delivery at better efficiency
- Up to 6 W at 90 % efficiency in a small, SOT23 package
- Ultra-low radiated emissions that ease system design
- Meets or exceeds CISPR25 class-5 and CISPR32 class-B specifications
- Fail-safe inputs
- Prevent back-powering local supply through inputs and simplifies system design by allowing any order power-up
- Over current protection with hiccup mode, thermal shutdown, soft-start, and undervoltage protection ensures robust power system delivery
- AEC-Q100 at no extra cost
- All devices are automotive qualified and can be used in automotive and industrial applications





5.9. ESD solution to multi-interface system

Today, nearly all charging equipment is designed with system safety and device protection in mind. CAN interface is used for communication between the charging module and BMS in the vehicle. According to communication standards such as GB/T-27930 and IEC 15118, the signalling rate is 250 kbps. It is necessary to implement proper ESD solution without signal distortion.

Nexperia Solution:

For ESD protection of high-speed communication signals, ESD diodes should have low diode capacitance (C_d) to minimize signal attenuation and ensure communication quality. Additionally, placing the ESD diodes as close as possible to the external connection points of the charging module helps rapidly discharge static energy to the ground, enhancing protection. Finally, in the peripheral circuit design of the CAN transceiver, minimizing the routing length reduces the impact of parasitic effects.

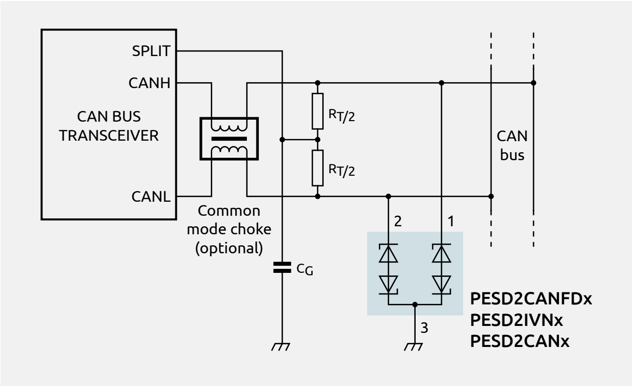


Fig 25. ESD Protection in CAN Interface

For a lineup of commonly found interfaces and suggested protection methods, including example circuits browse to Nexperias ESD protection Applications brochure.

In modern EV charging station construction, many other interfaces, particularly those for communication between chargers and platforms, also require careful ESD protection, such as

Wired
- Ethernet
- RS485, RS232

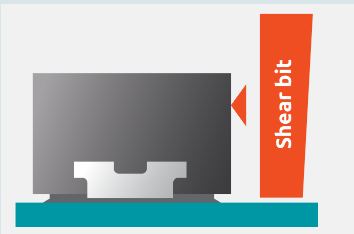
Wireless
- WLAN
- Cellular
- NFC/RFID

The PESD2IVN24-T provides robust ESD protection for CAN communication between the charger and vehicle, as well as between chargers. With an ultra-low clamping voltage of 30 V @ Ipp = 1 A, it effectively shields CAN transceivers from interference and damage. For higher signal integrity, Nexperia also offers the low C_d version PESD2CANFD24L-T, featuring a capacitance of just 9 pF. For in depth technical knowledge about ESD protection devices visit Nexperas ESD device Handbook.

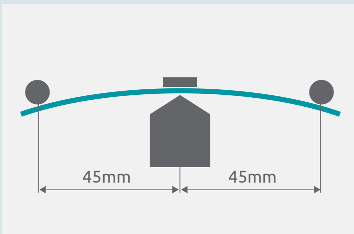
Nexperia offers SOT23 as well as DFN packages with side-wettable flanks (SWF) for ESD protection devices. The main purpose of the SWF is to facilitate a reliable Automated Optical Inspection (AOI) capability for DFN packages. Thus, costly x-ray inspection can be skipped. Another advantage brought by SWF is that the shear force is also improved by about 10 %, resulting in increased robustness.

Improved mechanical robustness

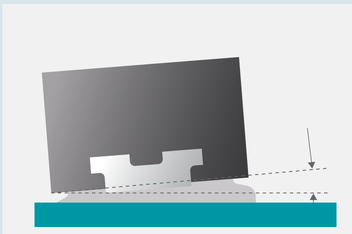
Maximum shear force
Optimized for high shear forces for robust soldering



Maximum board bending
Very high board bending capability for designs with flexible PSBs



Minimum tilting angle
Reduced tilting angle for ultra flat PSB designs



6. Recommended products

6.1. AC charger

Technology	Description	Key part numbers
Power Management		
Power MOSFET	N/P-Channel, ≤60 V, LFPAK/MLPAK	PXN4R7-30QL, PSMN3R3-80YSF
Fast Recovery Rectifier	400 V-650 V, <10 A, CFP/D2PAK	PNS40010AER, PNU65010EP
Schottky Diode	≤100 V, ≥1 A, CFP/DFN	DFN2020D_3 series, PMEG100T10ELR
Power BJT	Low V_{CEsat}, NPN/PNP, ≤100 V, DPAK/DFN/CFP	MJD and MJPE series, BC55PA series
TVS	TVS 400 W/600 W, CFP/SMA,B,C	PTVSxP1UP series
Transformer Driver	Low noise, high output drive 1.2 A@5 V, SOT23	NXF6501DC-Q100
Flyback Controller	QR flyback controller , Wide V_{cc}, TSOT-23	NEX806 series
LDO	150/300 mA, 40 V low Iq low-dropout regulator, SOT23/SOT223	NEX90x30-Q100, NEX90515-Q100
Signal Processing		
Small Signal MOSFET	≤100 V, ultra-low R_{DSon}, DFN	BUK9D120-60P, BUK6D20-40E
Small Signal BJT	NPN/PNP, ≤100 V, 100 mA-500 mA, SOT23/DFN	BC807QBH series, BC806H series
Zener Diode	50 µA, 1.8 V-36 V, ±5 %, SOD323/DFN	BZX8850S-C series, BZX58550-C series
Schottky Diode	≤100 V, <500 mA, SOD323/DFN	BAT46GW, BAS40
Switching Diode	≤300 V, 50-200 mA, SC70/DFN	BAS16L, BAV70
GPIO Expander	Low voltage, 16 bit, I2C & SMBus	NCA9535BY
Voltage Translator (Level-shifter)	Wide supply voltage range, low delay, 3-state output options, QFN/SOT	74AUP1T00 series
Analog Switches	Reduced signal attenuation result and THD, wide supply voltage, QFN/SOT	74HC4067; 74HCT4067 series, 74AHC1G66; 74AHCT1G66 series
Logic	Gates, Buffers, Transceivers, etc., QFN/SOT	74AHC00; 74AHCT00 series
HMI		
LCD Bias	Dual output, 80-220 mA, WLCSP15	NEX10000UB
LED Driver	Resistor-equipped NPN, <1.25 W, <50 mA, SOT/DFN	NCR320U
Protection		
ESD for CAN	30 kV, double-channel, bidirectional, SOT	PESD2CAN24T-Q
ESD for Ethernet	30 kV, 100BASE-T1 & 1000BASE-T1 compliant, DFN/SOT	PESD2ETH1G-T
ESD for High-speed Interfaces	23 kV, low cap, IEC 61000-4-2/5, DFN/WLCSP	PESDxU1UT series

6.2. DC charger

Technology	Description	Key part numbers
AC-DC PFC & DC-DC		
SiC MOSFET	1200 V, 40/80 mΩ, TO-247-3L/4L/D2PAK	NSF030120D7A0, NSF040120L4A0, NSF040120L3A0
SiC Diode	650 V, 10/20 A, TO-220/DPAK	PSC1065H, PSC2065J
Cascode GaN FET	650 V, 39/41/60 mΩ, CCPAK1212/TO-247-3L	GAN039-650NTB, GAN041-650WSB, GAN063-650WSA
Fast Recovery Diode	650 V, 10-30 A, D2PAK	PNE650200AEJ, PNU650300AEJ
IGBT	650 V, 50/75 A, TO-247-3L	NGW75T65H3DF, NGW50H65H3DFP
Driver		
BJT	Low V_{CEsat}, ≤±60 V, NPN/PNP, DPAK/CFP	MJD and MJPE series
Schottky Diode	≤60 V, ≤1 A, SOT23/DFN	1PS70SB10
Power Management		
Power MOSFET	N/P-Channel, ≤60 V, LFPAK/MLPAK	PXN4R7-30QL
Fast Recovery Rectifier	400 V-650 V, <10 A, CFP/D2PAK	PNS40010AER, PNU65010EP
Schottky Diode	≤100 V, ≥1 A, CFP/DFN	DFN2020D_3 series, PMEG100T10ELR
Power BJT	Low V_{CEsat}, NPN/PNP, ≤100 V, DPAK/DFN/CFP	MJD and MJPE series, BC55PA series
TVS	TVS 400 W/600 W, CFP/SMA,B,C	PTVSxP1UP series
Transformer Driver	Low noise, high output drive 1.2 A@5 V, SOT23	NXF6501DC-Q100
Flyback Controller	QR flyback controller , Wide V_{cc}, TSOT-23	NEX806 series
LDO	150/300 mA, 40 V low Iq low-dropout regulator, SOT23/SOT223	NEX90x30-Q100, NEX90515-Q100
Signal Processing		
Small Signal MOSFET	≤100 V, ultra-low R_{DSon}, DFN	BUK9D120-60P, BUK6D20-40E
Small Signal BJT	NPN/PNP, ≤100 V, 100 mA-500 mA, SOT23/DFN	BC807QBH series, BC806H series
Zener Diode	50 μA, 1.8 V-36 V, ±5 %, SOD323/DFN	BZX8850S-C series, BZX58550-C series
Schottky Diode	≤100 V, <500 mA, SOD323/DFN	BAT46GW, BAS40
Switching Diode	≤300 V, 50-200 mA, SC70/DFN	BAS16L, BAV70
GPIO Expander	Low voltage, 16 bit, I2C & SMBus	NCA9535BY
Voltage Translator (Level-shifter)	Wide supply voltage range, low delay, 3-state output options, QFN/SOT	74AUP1T00 series
Analog Switches	Reduced signal attenuation result and THD, wide supply voltage, QFN/SOT	74HC4067; 74HCT4067 series, 74AHC1G66; 74AHCT1G66 series
Logic	Gates, Buffers, Transceivers, etc., QFN/SOT	74AHC00; 74AHCT00 series
HMI		
LCD Bias	Dual output, 80-220 mA, WLCSP15	NEX10000UB
LED Driver	Resistor-equipped NPN, <1.25 W, <50 mA, SOT/DFN	NCR320U
Protection		
ESD for CAN	30 kV, double-channel, bidirectional, SOT	PESD2CAN24T-Q
ESD for Ethernet	30 kV, 100BASE-T1 & 1000BASE-T1 compliant, DFN/SOT	PESD2ETH1G-T
ESD for High-speed Interfaces	23 kV, low cap, IEC 61000-4-2/5, DFN/WLCSP	PESDxU1UT series

7. References

Nexperia handbooks

MOSFET and GaN FET application handbook
ESD Application Handbook
Bipolar Junction Transistor (BJT) Application Handbook
Diode fundamentals, characteristics and applications
Logic product features and application insights

Application notes

AN90030 | Paralleling of Nexperia cascode GaN FETs in half-bridge topology
AN90033 | Bidirectional multi-voltage level translator applications using Nexperia's LSF010x auto-sense devices
AN90041 | Gate drive circuit design for Nexperia 650 V Enhancement-mode (e-mode) GaN FETs
AN90042 | Nexperia 650 V (G3) IGBT product introduction
AN90048 | Understanding of critical SiC parameters for efficient and stable designs
AN90053 | Advanced SPICE models for Nexperia cascode Gallium Nitride (GaN) FETs
AN90062 | Analog multiplexers and switches
AN90067 | X.PAK SiC MOSFETs: A Technical Guide
AN10441 | Level shifting techniques in I²C-bus design

Technical Notes

TN90008 | Reduce radiated emissions in isolated power designs using NXF650x-Q100
TN90009 | Protection features of NXF650x transformer drivers

Other resources

Application page | AC EV wallbox
Application page | DC EV charging station online page
Web page | Nexperia crossing tool
Whitepaper | SiC diodes
Whitepaper | Side Wettable Flanks
Brochure | ESD protection applications
Blog | Discover 4 advantages of Nexperia's SiC MOSFETs
Leaflet | SiC MOSFETs
Leaflet | GaN CCPAK

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