Energy Storage System Solutions

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Understanding the Energy Storage System in Residential and Commercial Systems

More and more countries and companies have announced their strategies for achieving a low-carbon, sustainable world. The global installed renewable energy capacity reached 1600 GW in 2021[1], which shows an incredible growth rate. However, the current generation of clean energy has limitations, and unlike traditional energy, it is dynamic and unstable. For example, a solar inverter's output power dramatically depends on sunshine, which is beyond our control. And such uncontrollable energy might not help when dealing with the pressure on the grid due to increased power demand during lousy weather. As a result, energy storage should not be neglected on the path to net zero.

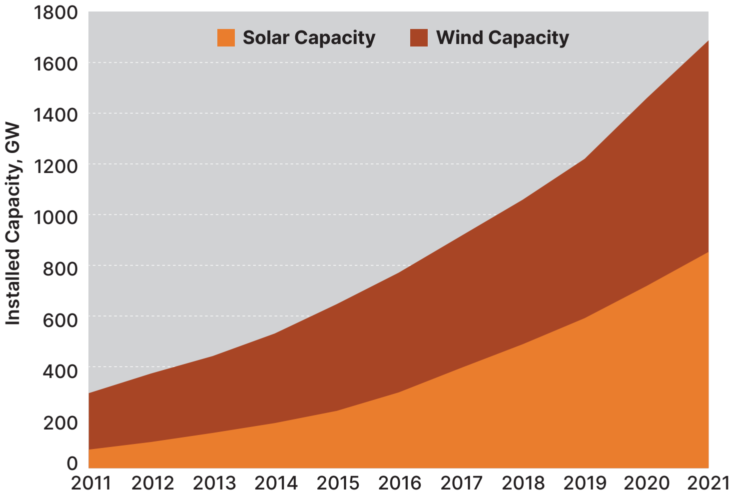


Figure 1. Global Installed Capacity of Renewable Energy

Battery Energy Storage Systems

There are currently four energy storage system types: electrochemical, chemical, thermal, and mechanical. Pumped storage hydropower (PSH) is still the most well-developed mechanical storage system, covering more than 90% of grid-scale energy storage capacity globally. But such colossal facilities have strict geographic requirements for installation.

The global battery energy storage system market size, according to MarketsandMarkets, is expected to grow from USD 4.4 billion in 2022 to USD 15.1 billion by 2027[2] at a CAGR of 27.9%. Around 86% of this market consists of Li-ion batteries.

Lithium-ion batteries, the most well-known electrochemical storage system, have high power and energy density, high roundtrip efficiency, compact footprint, and flexibility for expansion. The Li-ion battery is a relatively mature technology that has benefited from more than three decades of commercial development, which makes it a reliable and low-cost solution. The continuous cost-down of Li-ion batteries is strongly accelerating the development of energy storage[3].

On/off-grid solar inverter systems with storage batteries for residential and commercial use offer several benefits:

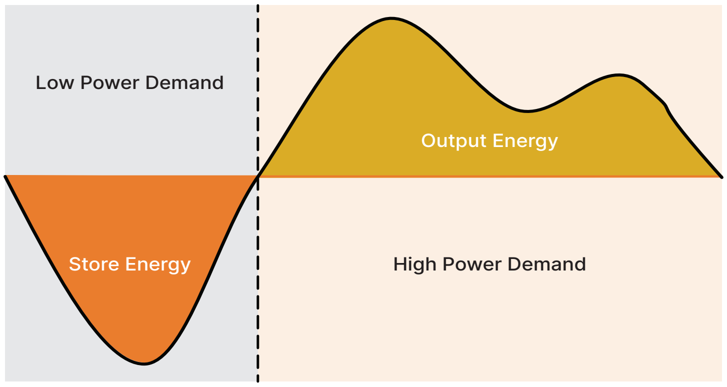


Figure 2. Energy Arbitrage

- **Energy arbitrage** – Storing energy for later use can reduce electricity costs when prices vary.
- **Self-generation and consumption** – Installing storage devices with solar inverters can reduce or eliminate dependence on the grid by storing excess solar power generated during the day.
- **Backup power supply** – Like UPS (Uninterruptible Power Supply), stored electricity can provide emergency power to a load when the input power source or mains power fails.

Four elements to build a BESS include:

- **Battery module/bank –** A battery module comprises battery cells and might be integrated into a rack/bank for higher capacity to establish a commercial-level system. So, charging/discharging voltage depends on the battery capacity ranging from 50 V to over 1000 V.
- **BMS –** A battery management system protects and manages rechargeable batteries, preventing them from operating outside safe operating parameters. A BMS monitors its state, calculates secondary data, reports that data, controls its environment, authenticates it, and balances it.
- **PCS –** Power conversion systems are another vital subsystem for the bidirectional conversion of electrical energy that connects between the battery pack and the grid and load. It largely determines the system's cost, size, and performance.
- **EMS –** Energy management systems are software-based computer-aided tools to monitor, control, and optimize the performance of the generation or transmission system used by operators of electric utility grids.

Applications and Topologies

PCS, a crucial part of an energy storage system, controls bidirectional power conversion. Similarly, like other high-power energy infrastructure applications, higher power is always expected, whether residential or commercial, to match the high growth rate of electricity demands. Meanwhile, a smaller size can significantly reduce transportation and installation costs. Lastly, mass production of wide bandgap semiconductor components like silicon carbide can bring the system efficiency and thermal performance to the next level.

There are two energy storage systems segments: AC-coupled or DC-coupled, and power level.

AC-Coupled and DC-Coupled

AC-coupled energy storage is a separate system that can be added to an existing solar/energy generation system. It's an easy upgrade; however, it involves an additional step of power conversion to charge/discharge the battery, which means more power loss.

A DC-coupled system, or hybrid (solar) inverter, requires only one power conversion step, but it must be designed initially.

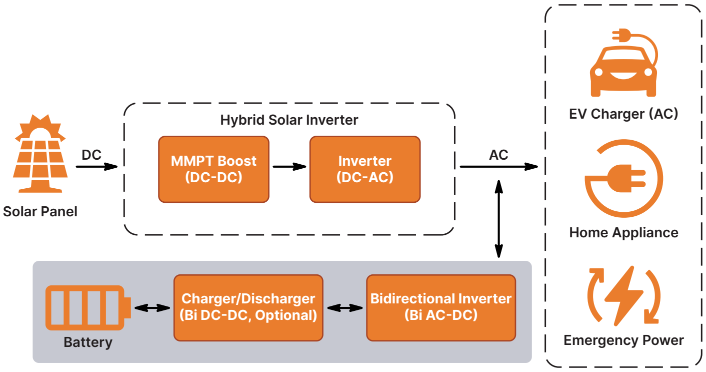


Figure 3. Residential AC-Coupled ESS
(Gray Block)

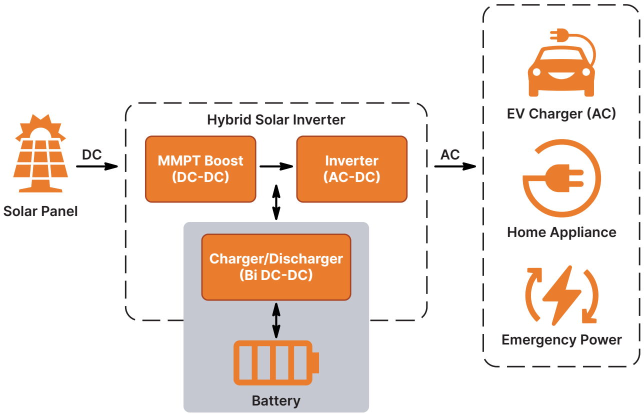


Figure 4. Residential DC-Coupled ESS
(Gray Block)

Residential BESS

A residential power conversion system is either added to an existing solar inverter system or designed together with the solar inverter as a hybrid inverter. The stored energy can charge the battery as backup or the electric vehicle and home appliances to save costs.

The bidirectional DC-DC converter connects between a battery pack and DC-link. Regarding safety and use cases, the bus voltage of a single-phase system is usually less than 600 V, while the charging and discharging power will not exceed 10 kW. Buck-boost is considered the most common bidirectional DC-DC configuration with merits like fewer components and easy control. Two 650 V IGBTs/MOSFETs with parallel diodes with good IF values are sufficient for this bidirectional system.

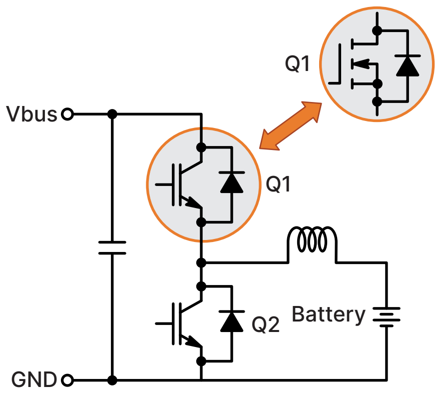


Figure 5. Buck-Boost Configuration for Bidirectional DC-DC

650V FS4 IGBT with Co-Pack SiC Diode, TO247-4

Features

- Using the novel field stop 4th generation IGBT and 1.5 generation SiC Schottky Diode technology
- Low $V_{ce(sat)}$
- Low E_{on} and E_{off}
- Kelvin source

Application

- Solar Inverter
- UPS
- Energy Storage System

FGH4L75T65MQDC50

FGH4L75T65MQDC50 is a newly released 650 V FS4 IGBT with an integrated SiC diode; it offers optimum performance with low conduction and switching losses for high-efficiency applications.

Isolation is another aspect when considering battery safety. The Dual Active Bridge converter (DAB) or CLLC becomes an isolated bidirectional DC-DC converter solution for EV and ESS. A cascaded front-end buck-boost circuit can achieve a wide range of voltage input/output in the case of battery voltage variation. Meanwhile, it reduces reactive power circulating current and expands the soft-switching zone.[4]

150 V Power MOSFET, N-Channel Shield Gate PowerTrench®, TO220-3

Features

- Shielded Gate MOSFET Technology
- Max $R_{DS(on)}$ = 5.0 mΩ at V_{GS} = 10 V, I_D = 97 A
- 50% Lower Qrr than other MOSFET Suppliers
- Lowers Switching Noise/EMI

Application

- ATX / Server / Telecom PSU
- Motor Drives and Uninterruptible Power Supplies
- Micro solar inverters

NTP5D0N15MC

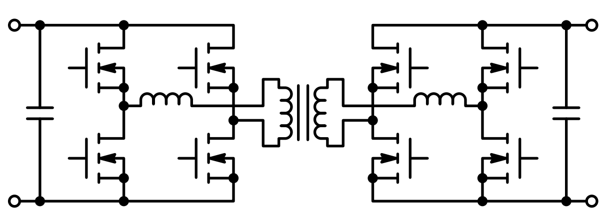


Figure 6. Dual Active Bridge DC-DC Converter

Three-phase power is the standard power supply method in commercial and business cases. The technology is much more reliable now and can be used in homes with higher power demands. Switches should be capable of withstanding higher operating voltage and current to handle the increased power of up to 15 kW and the increased DC-link voltage (close to 1000 V).

Replacing the 650 V switches with the 1200 V series can easily solve the problem, while a three-level symmetric buck-boost can also be considered. This three-level configuration offers reduced switching losses as only half of the output voltage is applied to switches and diodes, and such characteristic leads to smaller inductors and better EMI performance. However, doubling the number of components will inevitably increase the BoM complexity, control difficulty, and total cost.[5]

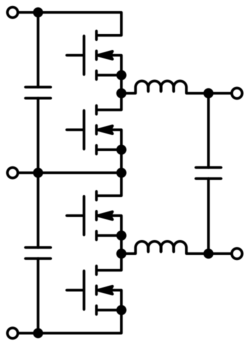
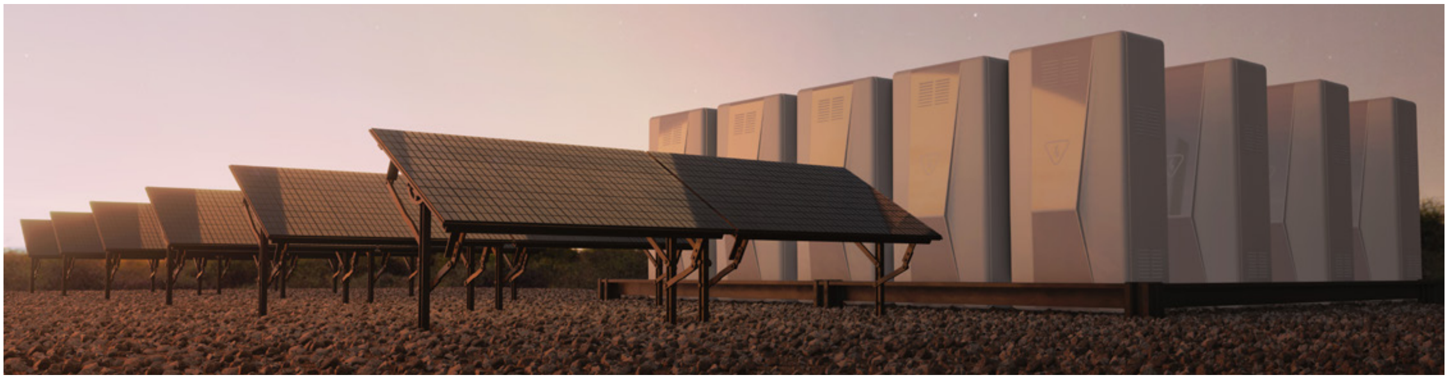


Figure 7. Symmetric Buck-Boost Converter



Commercial BESS

A commercial energy storage system's input/output power ranges from 100 kW to 2 MW. Such a giant system can consist of three-phase subsystems ranging from dozens of kilowatts to over 100 kW.

One of the crucial specifications is the maximum DC voltage, which depends on the bus voltage of existing solar systems or the battery voltage. Commercial solar inverter's standard DC bus voltage is 1100 V and 1500 V, sometimes for utility-scale systems. As an apparent trend for this application, increasing DC-bus voltage will reduce the cable cost of the interconnection for a given power because the current is lower.

AC-coupled systems are more commonly found in energy storage projects because they can be added to the pre-existing system. Moreover, a centralized energy storage unit is much easier to manage and deploy. In contrast, DC-coupled systems require a larger space and more costs to handle the distributed battery banks.

Three-level I-NPC is a common topology in high-power industrial applications, especially inverters. It has four switches, four inverse diodes, and two clamping diodes with a breakdown voltage lower than the actual DC-link voltage; for example, 650 V switches are sufficient in an 1100 V system.

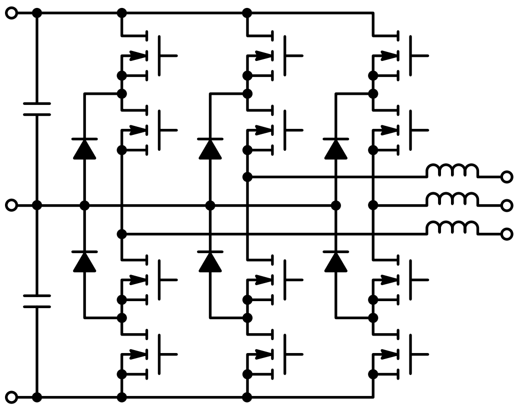


Figure 8. Three-Phase I-NPC

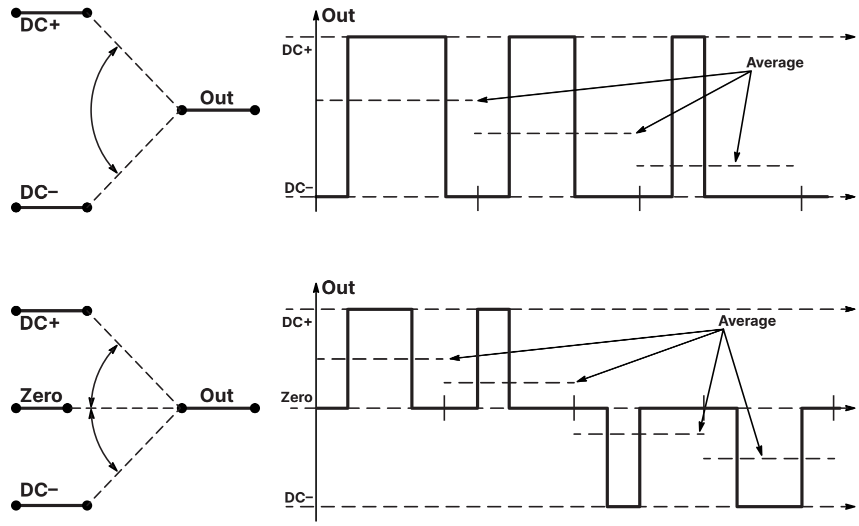


Figure 9. Two-Level & Three-Level Switching Principles

There are three advantages to using three-level topologies. First, they offer more minor switching losses. Generally, switching losses are proportional to the voltage applied to switches and diodes to the power of two (switching losses $\alpha\ V^2_{\text{switch or diode}}$). In three-level topologies, only half of the total output voltage is applied to (some) switches or (some) diodes. Second is a lower current ripple in the boost inductors. For the same inductor value, the peak-to-peak voltage applied to the inductor is also half of the total output voltage in three-level topologies. This leads to less current ripple, making it easier to filter and with a smaller inductor, which allows for more-compact inductor designs and reduced cost. Third, there is reduced EMI. Conducted EMI is mainly linked to the current ripple. As noted, three-level topologies reduce the current ripple, making filtering easier and producing lower conducted EMI. Meanwhile, there is also a benefit regarding radiated emissions.[5]

As an upgraded version, the A-NPC system provides even higher performance because two clamping diodes are replaced by two active switches, which has a clear loss advantage. But the driver pairing and delay matching is critical and can be considered a disadvantage.

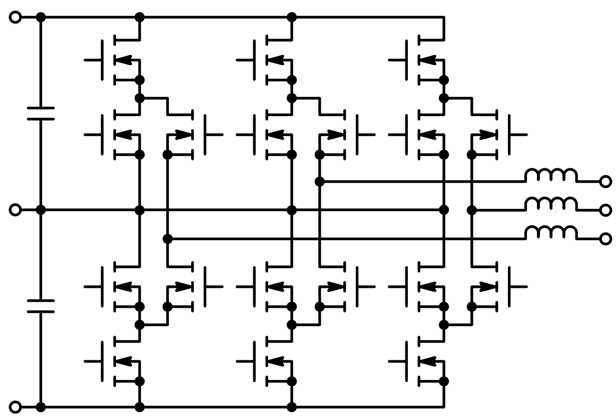


Figure 10. Three-Phase A-NPC

IGBT Module, A-Type NPC 1000 V, 800 A, Q2

Features

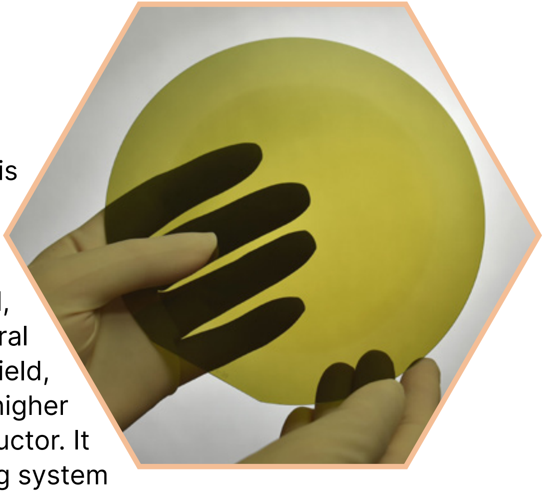
- Extremely efficient trench with Field Stop technology
- Low switching loss reduces system power dissipation
- High power density
- Low inductive layout
- Internal NTC

Application

- 1500 V Solar inverter
- 1500 V Energy Storage

NXH800A100L4Q2

Use Silicon Carbide to Improve the Efficiency



Six-switch is another option for high-power industrial applications, which is a 2-level topology with six switches and easy control; however, it brings poor EMI performance and high switching losses.

Silicon carbide, a next-generation wide band gap semiconductor material, can significantly improve performance issues. Silicon carbide offers several superior performance characteristics, such as band energy, breakdown field, thermal conductivity, etc. These features allow a SiC system to run at a higher frequency without losing output power to reduce the dimension of the inductor. It can also optimize the cooling system, which replaces the forced air-cooling system with natural cooling. Sometimes, the removal of the heat sink can save money and weight.[6]

Even diode replacement (replacing Si SBD with SiC SBD) is highly recommended to balance the cost and performance. SiC SBD has much lower t_{rr} and I_{rr} than Si SBD, leading to a lower E_{rr} and better system efficiency.

Material Properties

Properties	Si	SiC
Breakdown Filed (MV/cm)	0.3	3
Band Energy (eV)	1.12	3.26
Electron Mobility (cm2/Vs)	1400	900
Hole Mobility (cm2/Vs)	600	100
Thermal Conductivity (W/cm°C)	1.5	4.9
Maximum Junction Temperature (°C)	150	600

→

Application Benefits

Effect on Device	Effect on System	Effect on End Application
High Voltage Low R_{SP}	High F_{SW} + Small Passives	System with • Small Size • Light Weight • High Efficiency • Cost Benefits
Low Conduction Losses	Cheaper Heatsink	

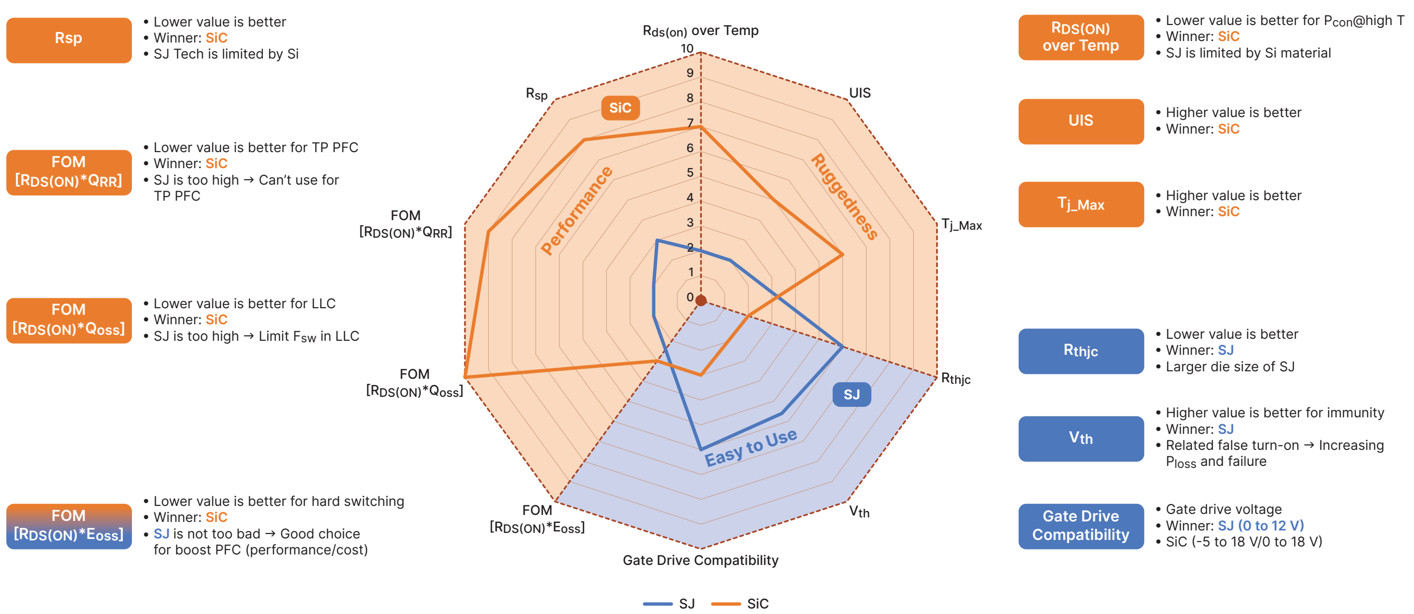


Figure 11. Si vs. SiC MOSFET

SiC MOSFET, EliteSiC, 12 mohm, 650 V, TO247-4

Features

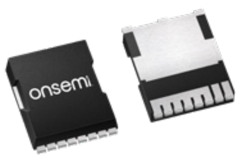
- Typ. $R_{DS(on)}$ = 12 mΩ @ V_{GS} = 18 V
- Typ. $R_{DS(on)}$ = 15 mΩ @ V_{GS} = 15 V
- Ultra-low gate charge ($Q_{G(tot)}$ = 283 nC)
- High-speed switching with low capacitance (C_{OSS} = 430 pF)

Application

- Solar inverters
- Uninterruptible power supplies
- Energy storage

NTH4L015N065SC1

SiC MOSFET, EliteSiC, 33 mohm, 650 V, TOLL



NTBL045N065SC1

Features

- Typ. $R_{DS(on)}$ = 12 mΩ @ V_{GS} = 18 V
- Typ. $R_{DS(on)}$ = 15 mΩ @ V_{GS} = 15 V
- 30% PCB saving over D^2PAK (9.9 mm × 11.68 mm)
- 60% Volume saving over D^2PAK (H = 2.3 mm)
- Ultra-low package inductance (2 nH)
- 60% E_{ON} reduction with kelvin source

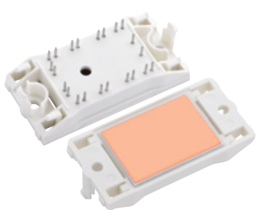
Full SiC MOSFET Module, EliteSiC, Two Channel Boost, Q0

Features

- 2 × 1200 V/40 mΩ SiC MOSFET
- 2 × 1200 V/40 A SiC Diode, 2 × 1200 V/50 A Bypass SiC Diode
- Low Inductive Layout
- Internal NTC

Application

- Solar inverters
- Uninterruptible power supplies



NXH40B120MNQ0

Replace with PIM (Power Integrated Module) to Enhance Power Density

Considering a Power Integrated Module solution could maximize system efficiency and power density. SiC modules cost more; however, the advantages can outweigh the cost, including:

- Improved parasitic effect caused by pins and undesirable layout
- Improved production efficiency for fewer components and easy mounting
- Improved die consistency to contribute to current sharing
- Improved thermal performance

NTH4L020N120SC1 (Discrete SiC)		NXH020F120MNF1PTG (SiC Module)	
E_{ON}	E_{OFF}	E_{ON}	E_{OFF}
0.49 mJ	0.39 mJ	0.24 mJ	0.24 mJ
T_{thjc}	R_{thjh}	T_{thjc}	R_{thjh}
0.3 °C/W	3.3 °C/W with 5 kV Isolation*	0.45 °C/W	0.8 °C/W with 5 kV Isolation

*If a TIM with a thermal impedance of 3°C/W is used

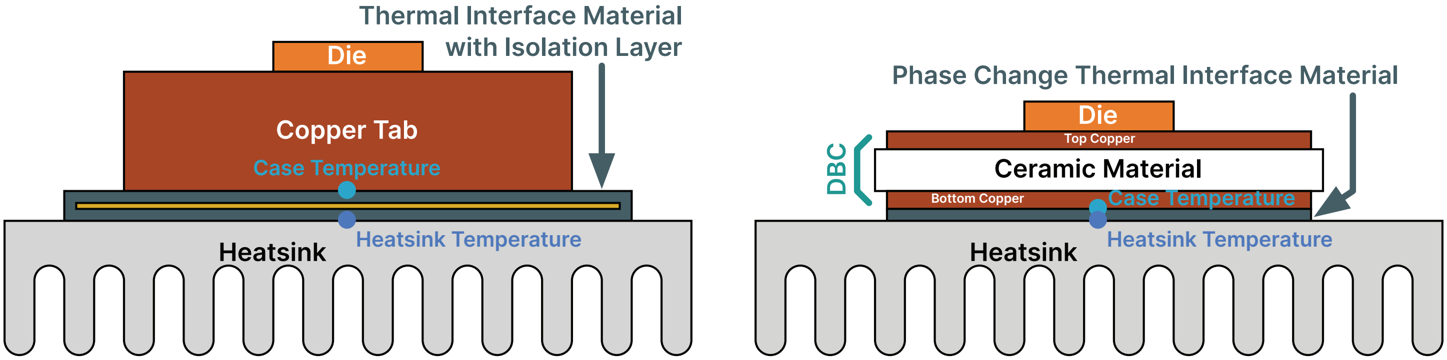


Figure 12. Thermal Comparison: Discrete vs. Module

2-Pack Half Bridge, EliteSiC, Power Integrated Module, F1

Features

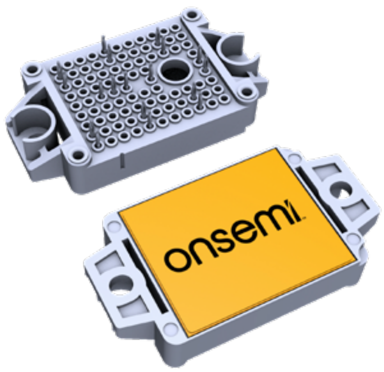
- 2 × 1200 V SiC MOSFET, $R_{DS(ON)}$ = 10 mΩ
- Low thermal resistance
- Internal NTC thermistor

Application

- 3-Phase solar inverter
- Energy storage system

Benefits

- Improved $R_{DS(ON)}$ at higher voltage
- Improved efficiency or higher power density
- Flexible solution for high-reliability thermal interface

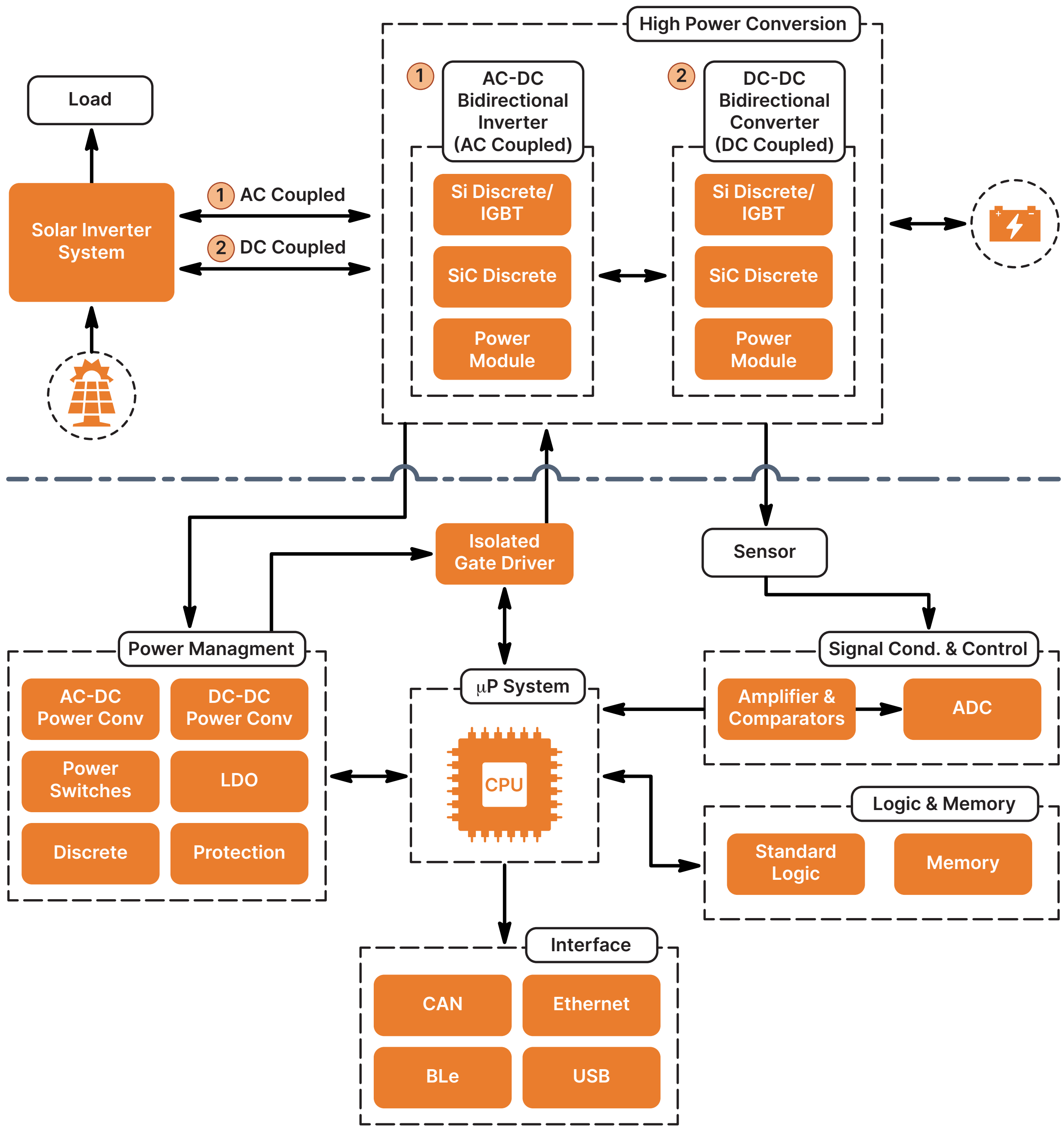


NXH010P120MNF1

Applications and Topologies

onsemi has a wide product coverage for energy storage systems and solar string inverters, click the links below or visit our website at www.onsemi.com/energy-storage for more product information.

- Power Modules
- SiC MOSFETs
- SiC Diodes
- IGBTs
- Gate Drivers
- Power Conversion Management
- Signal Conditioning and Control
- Logic and Memory
- Interface



Gate Driver

To drive SiC MOSFETs quickly and safely, a reliable SiC MOSFET driver is necessary. Three performance characteristics are important when choosing a SiC MOSFET to increase the robustness of a SiC power implementation:

- **High current capability** – High peak current at turn–on and turn–off can quickly charge/discharge the C_{GS} and C_{GD} capacitances.
- **Strong immunity** – SiC gate drivers in systems with fast switching of SiC MOSFETs must consider immunity related to fast dV/dt and induced noise. In particular, the maximum and minimum voltages allowed represent immunity to positive and negative surge events.
- **Matched propagation delay** – Propagation delay is the time delay from 50% of the input to 50% of the output, which is crucial in high–frequency applications; a delay mismatch will cause switching losses and heat generation.

Gate Driver, Dual Channel

Features

- 4.5 A Peak Source, 9 A Peak Sink Output Current Capability
- Propagation Delay Typical 36 ns with 8 ns Max Delay Matching per channel
- Common Mode Transient Immunity CMTI > 200 V/ns
- 5 kV_{RMS} Galvanic Isolation

Application

- Isolated Converter
- Silicon Carbide Driver

NCP51561

Current Sense Amplifier

Accurate voltage and current measurements in ESS require reliable and precise OpAmps or current sense amplifiers. **onsemi** provides amplifiers with high precision, low power, and current sense (integrated resistors) in different supply currents, gain bandwidth products, and packages to facilitate the feedback of voltage and current signals for close-loop control.

Current Sense Amplifier, Single/Dual Channel

Features

- Integrates precision, ratio-matched resistors, with 0.1% accuracy
- Wide common mode input: -0.1 to 40 V
- Low offset voltage: ±100 μV
- Low offset drift: ±1 μV/°C max
- Low gain error: ±1% max
- Low current consumption: 300 μA max per channel

Application

- High/Low-side current sensing

NCS2167x

Ethernet Controller

10BASE-T1S MACPHY Ethernet Controller

Features

- Exceeds noise immunity levels specified in IEEE 802.3cg, enabling up to 50 m reach with 8 nodes
- Enables more nodes per 25 m segment, which lowers cabling, connector, and installation costs
- Connects multiple devices on a single-pair cable using one MACPHY per port
- Connect to controllers, sensors, and other devices that do not have an integrated MAC
- Further increases noise immunity in pure PLCA networks
- Exceeds noise immunity levels specified in IEEE 802.3cg, enabling up to 50 m reach with 8 nodes

Application

- Industrial Automation
- Sensor and Control Interfacing
- Security and Field Instrumentation

NCN26010

System-Level Simulation Tools

The **onsemi** online-based Elite Power Simulator provides meaningful insights for complex power electronic applications through system-level simulations at an early stage of the development cycle. The Elite Power Simulator delivers an accurate representation of how designed circuits will work using our EliteSiC family of products, including manufacturing corner cases of the EliteSiC technology.

Features

- Industry-first PLECS model valid for hard and soft switching simulation
- Covering DC-DC, AC-DC, DC-AC applications, including 32 circuit topologies in industrial and automotive
- Loss and thermal data plotting
- Flexible design and fast simulation result
- Product recommendation feature that is based on application and topology

Figure 13. Elite Power Simulator: Simulation Results and Waveforms

The Self-Service PLECS Model Generator grants electronics engineers the power and freedom to create custom high fidelity system level PLECS models. Engineers can use a model directly in their own simulation platform or upload it to the **onsemi** Elite Power Simulator to simulate.

Features

- Industry-first PLECS model valid for hard and soft switching simulation
- Custom application parasitics tailored to the user-specified application circuit parasitics which significantly influence conduction and switching energy losses
- High-density broad table tailored to user-specified electrical bias and temperature conditions for conduction and switching energy loss data
- Corner models valid at typical and corner conditions for the product, enabling users to track application performances in worst, nominal, and best-case fabrication conditions of the conduction and switching energy losses

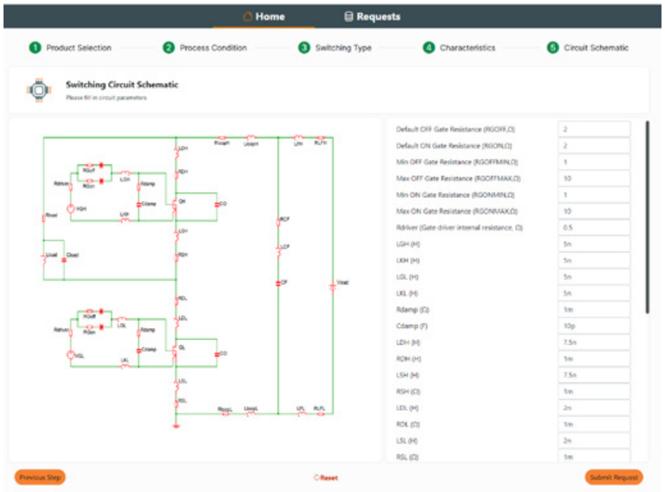


Figure 14. Self-Service PLECS Model Generator

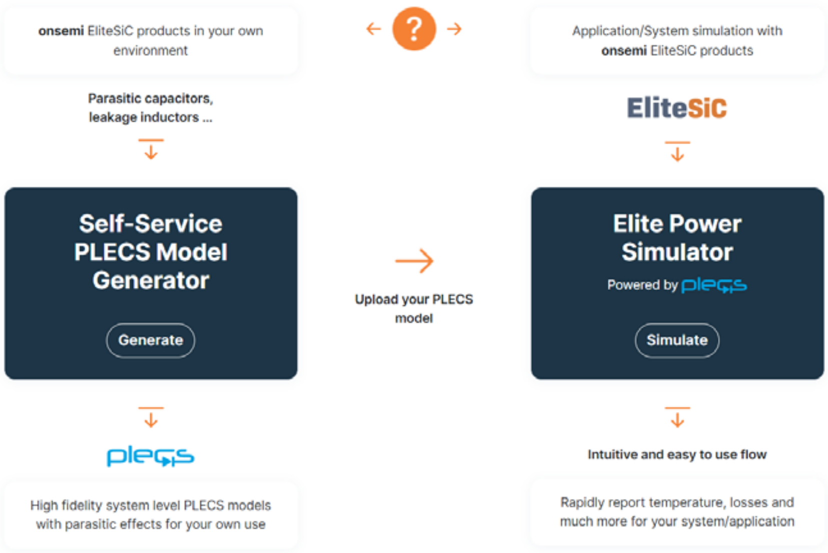


Figure 15. How to Choose Elite Power Simulator and Self-Service PLECS Model Generator

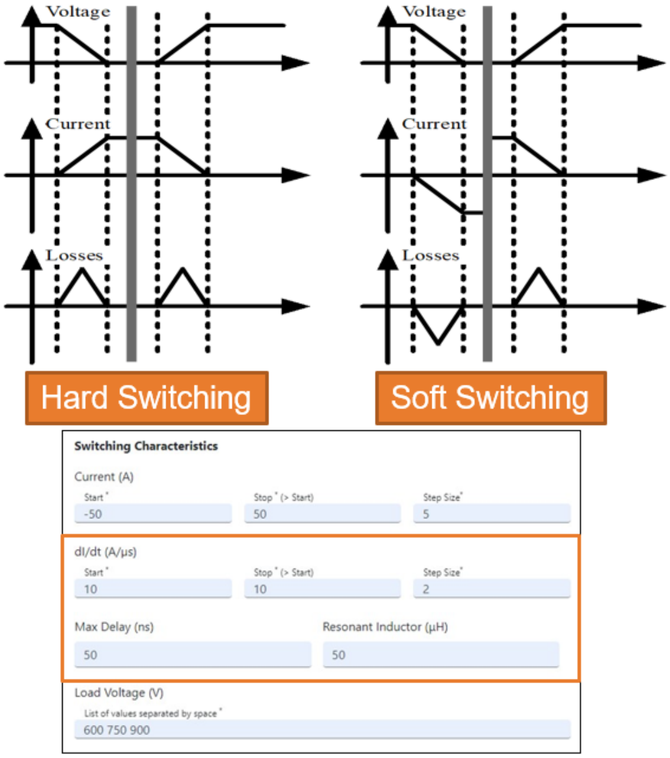


Figure 16. Self-Service PLECS Model Generator – Hard and Soft Switching Selection

Figure 17. Self-Service PLECS Model Generator - Dense Loss Tables

Learn more about "Novel Industry-First Self-Service PLECS Model Generator and Elite Power Simulator Accurate For Soft and Hard-Switching".

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