Residential energy storage systems (ESS) and multi-modular topology for 2\textsuperscript{nd} life batteries
Infineon’s energy storage system designs

Energy storage has been an integral component of electricity generation, transmission, distribution and consumption for many decades. Today, with the growing renewable energy generation, the power landscape is changing dramatically. This shift to renewable sources also makes delivering power reliably, where and when it’s needed, a bigger challenge than ever before.

Energy storage systems provide a wide array of technological approaches to manage our supply-demand situation and to create a more resilient energy infrastructure and bring cost savings to utilities and consumers.

Infineon’s unique expertise in energy generation, transmission, power conversion, and battery management makes us the perfect partner to advance energy storage solutions (ESS) in terms of efficiency, innovation, performance, as well as optimal cost.

Typical structure of energy storage systems

Battery-based ESS technology can respond to power drop-outs in under a second, making use of clean energy, sourced from collocated solar or wind plants. In such before-the-meter cases, ESS functions as bulk storage coupled with either renewables generation or transmission and distribution systems. In residential and commercial situations, ESS plays a role in behind-the-meter systems.

Infineon’s distinctive expertise and product portfolio provide state-of-the-art solutions that reduce design effort, improve system performance, empower fast time-to-market and optimize system costs.

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Trends in energy storing systems (ESS)

Multi-modular approach

**Promising solution to 2nd life batteries**
Innovative approach paving the way of 2nd life batteries in ESS applications

**Solutions for:**
- Reuse of increasing number of 2nd life batteries
- Battery pack connected to own bi-directional power converter
- Output of converters connected to create high voltage DC bus
- Current drawn from battery does not need to be equal
- Voltage output is controllable
- More flexibility

**Silicon carbide (SiC)**

**Value of SiC in ESS**
Improved system efficiency at high current and temperature conditions enabling smaller size and weight → lower cost per Watt

**Solutions for:**
- Smaller size and weight of systems
  - Enables higher frequencies → smaller magnetics
  - Less losses and better thermals (smaller heatsink)
- High power density
- Simplified bi-directional topologies
- Higher efficiency
- Less bill of material content (BOM)
- Robustness and higher system reliability

**Battery management system (BMS)**

**Efficient and safe batteries**
BMS fulfills two main functions
- Battery protection
- Battery monitoring

**Solutions for:**
- Wider safe operating area (SOA)
- Short circuit protection with higher peak current rates
- Turn-on and turn-off solutions tailored to applications needs
- Cheaper solutions with more compact bill of material and more effective parallelization solutions

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SiC in energy storage systems

Infineon’s latest addition to its SiC portfolio, the CoolSiC™ MOSFET 650 V family, is the product of a state-of-the-art trench semiconductor process, optimized to allow no compromises in achieving both - the lowest losses in the application and the highest reliability in operation. While leveraging the strong material characteristics of silicon carbide, Infineon’s experts managed to add unique features that increase the device performance, robustness, and ease of use.

Full CoolSiC™ portofolio, consisting of 1200 V and 650 V:
www.infineon.com/coolsic

*Recommended for CoolSiC™ MOSFETs

www.infineon.com/energy-storage-systems
Multi-modular approach

In times of increasing popularity of e-mobility solutions (particularly electric cars) it can be expected that in the future the world will have to cope with a significant number of used EV-batteries. A major advantage of modularly cascaded, multilevel architectures is the ability to enable 2nd life of batteries – applicable for example to batteries that have reached the end of their lifecycle and cannot be used in EVs any longer.

To overcome this limitation, modularly cascaded, multilevel architectures that utilize the benefit of highly efficient, low-voltage MOSFETs like Infineon’s market leading OptiMOS™ family have been developed. Each battery pack is connected to its own bi-directional power converter and the outputs of these converters are then connected in series to create the high-voltage DC-bus. By doing so, an equal current can be supplied from the outputs of each of these stages. The current drawn from each battery to the contrary must not be equal. The voltage output for each stage becomes controllable. It is possible to bypass stages should their battery state of charge (SOC) drop below the minimum level. With this added flexibility it is now possible for advanced control schemes to balance the SOC of different batteries among all the packs by placing a heavier load on those packs with higher SOC.

Value of SiC in ESS

**Challenges and requirements**

- Smaller size and weight reduction → power density
- Improved system efficiency
- Cost reduction → lower costs per Watt
- Bi-directionality and reliability

**Benefits and value added**

- CoolSiC™ doubles the power density (W/Kg) compared to silicon (IGBT)
- Overall system cost reduction
  - Higher switching frequency enables smaller transformers / inductors → smaller magnetics
  - Same power can fit in a smaller box size
- Simpler topologies with less control effort
- Higher robustness and better system reliability
- Loss reduction and increase in efficiency at high operating temperatures, i.e. less losses and better thermals (smaller heatsink)

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**Enabling 2nd life of batteries**

Expensive testing, analysis, and matching of batteries diminishes the economic advantages of the 2nd life approach.

Economical approach of reusing ranted out batteries and no need of battery matching.

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Battery utilization – IGBT based systems vs. multi-modular approach

Solutions of a modular multi-level system

Cascaded, modular, multi-level three-phase inverter (100-250 kW)

Half-bridge

Full-bridge

<table>
<thead>
<tr>
<th>Product type</th>
<th>Battery module voltage</th>
<th>Product</th>
<th>Part number*</th>
<th>$R_{\text{DS(on)}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOSFET</td>
<td>48 V</td>
<td>OptiMOS™ 5 80 V</td>
<td>IPT012N08N5</td>
<td>0.7 mΩ</td>
</tr>
<tr>
<td></td>
<td>60 V</td>
<td>OptiMOS™ 5 100 V</td>
<td>IPT015N10N5</td>
<td>1.5 mΩ</td>
</tr>
<tr>
<td></td>
<td>&gt; 60 V</td>
<td>OptiMOS™ 5 150 V</td>
<td>IPB048N15N5</td>
<td>4.8 mΩ</td>
</tr>
<tr>
<td>Driver IC</td>
<td></td>
<td>Isolated EiceDRIVER™</td>
<td>2EDF7275F</td>
<td>–</td>
</tr>
</tbody>
</table>

*more products available:
www.infineon.com/optimos
www.infineon.com/gatedrivers

www.infineon.com/energy-storage-systems
Battery management system

Infineon’s battery management product family and reference designs help you layout your battery management system to perfectly fit your application. Careful considerations of charging and discharging processes in battery protection and cell monitoring will support you throughout your design. With our solutions and design resources for battery management systems you will overcome design challenges and succeed in developing more efficient, longer-lasting, and more reliable battery-powered applications.

In ESS a battery management system fulfills two top level functions, namely:

› Battery protection
› Battery monitoring

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(A) MOSFETs are used for <60 V ESS and contactors are used for high-voltage and grid-scale ESS
(B) Isolation required only in high-voltage / grid-scale ESS
(C) SPI UART interface is required for communication between the battery modules in rack
Battery protection
A battery needs to be protected against possible external faults that would put the system in danger. Protecting the battery from damage during the normal function of the system (charging and discharging process) is one of the main functionalities of a battery management system (BMS). Within Infineon's product portfolio you will find the right devices to disconnect the battery system in case a fault is detected, thereby protecting its value. They will also help to detect system faults like overcurrent/short circuits.

<table>
<thead>
<tr>
<th>Product type</th>
<th>Battery voltage</th>
<th>BV(DSS)</th>
<th>Product</th>
<th>Part number</th>
<th>( R_{\text{gs}} ) (mΩ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOSFET</td>
<td>12-24 V</td>
<td>40 V</td>
<td>StrongIRFET™ 40 V</td>
<td>IRL40T209</td>
<td>1.1 mΩ</td>
</tr>
<tr>
<td></td>
<td></td>
<td>60 V</td>
<td>StrongIRFET™ 60 V</td>
<td>IRF7748L1 L1</td>
<td>2.2 mΩ</td>
</tr>
<tr>
<td></td>
<td>40-60 V</td>
<td>100 V</td>
<td>OptiMOS™ 100 V</td>
<td>IPT015N110N5</td>
<td>1.5 mΩ</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>OptiMOS™ LinearFET 100 V</td>
<td>IPB017N10N5</td>
<td>1.7 mΩ</td>
</tr>
<tr>
<td></td>
<td>60-100 V</td>
<td>150 V</td>
<td>OptiMOS™ 150 V</td>
<td>IPT059N15N3</td>
<td>5.9 mΩ</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>OptiMOS™ LinearFET 150 V</td>
<td>IPB048N15N5</td>
<td>4.8 mΩ</td>
</tr>
<tr>
<td></td>
<td>100-150 V</td>
<td>200 V</td>
<td>OptiMOS™ LinearFET 200 V</td>
<td>IPB110N20N3L5</td>
<td>11.0 mΩ</td>
</tr>
<tr>
<td></td>
<td>150-400 V</td>
<td>600 V</td>
<td>600 V CoolMOS™ S7</td>
<td>IPT69022S7</td>
<td>22.0 mΩ</td>
</tr>
<tr>
<td>Sensor</td>
<td>12-400 V</td>
<td>–</td>
<td>Current sensor</td>
<td>TLI4970</td>
<td></td>
</tr>
</tbody>
</table>

Cell monitoring and balancing
In order to protect the battery pack, each cell must be monitored accordingly. The battery management system is in charge of monitoring each of the cells included in a battery pack and ensuring that they are operated within the safe-operating range. Various parameters, such as cell voltage, state of charge (SOC), state of health (SOH), and also the temperature have a decisive impact on the performance, safety, and lifetime of batteries. Additionally, the cell balancing function ensures an optimization of the energy included in the battery pack. Operating a battery outside of its specifications causes damages to the battery cells and leads to a failure of the battery. This is not only causing maintenance efforts, it is also a major cost factor. That explains why batteries must be closely monitored during charging and discharging cycles.

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Transceiver and sensing ICs

The TLE9012AQU is a multi-channel battery monitoring and balancing system IC designed for Li-Ion battery packs used in automotive, industrial and consumer applications. TLE9012AQU fulfills four main functions: cell voltage measurement, temperature measurement, cell balancing and isolated communication to the main battery controller. Additionally, TLE9012AQU provides the necessary diagnosis tools to ensure proper function of the controlled battery.

The TLE9015QU is a general-purpose transceiver IC to be used in multi-cell battery systems to enable the communication between the main host microcontroller and the slaves in the battery. Besides other applications, the IC has been designed to fit ESS either having one or more cell modules in series.

<table>
<thead>
<tr>
<th>Device</th>
<th>Product</th>
<th>Part number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery monitoring unit</td>
<td>isoUART/UART transceiver IC</td>
<td>TLE9015QU</td>
</tr>
<tr>
<td>Cell supervisory circuit</td>
<td>12 ch sensing IC</td>
<td>TLE9012AQU</td>
</tr>
</tbody>
</table>

Small signal MOSFET

The term Small Signal MOSFET at Infineon refers to standard SOT packages, TSOP-6 and SC59. The product portfolio covers N-channel and P-channel enhancement mode MOSFETs as well as N-channel depletion mode products:

- 20 V – 250 V P-channel enhancement mode
- 20 V – 600 V N-channel enhancement mode
- -20V/20V and -30V/30V complementary (P + N channel) enhancement mode
- 60 V – 600 V N-channel depletion mode

Most products are qualified to AEC-Q100. The portfolio includes products in super logic level (SLL, 2.5 V rated) and ultra logic level (ULL, 1.8 V rated) that allow direct driving by a microcontroller without the need for a driver. However, it also includes products in logic level (4.5 V rated) and normal level (10 V rated).
Small signal MOSFETs offer full functionality by saving printed circuit board space.

<table>
<thead>
<tr>
<th>Device</th>
<th>Product</th>
<th>Part number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single P-channel MOSFET, SLL</td>
<td>SOT-23, -20 V, Super Logic Level</td>
<td>BSS315P</td>
</tr>
<tr>
<td>Single N-channel MOSFET, ULL</td>
<td>SOT-23, 20 V, Ultra Logic Level, ESD protected</td>
<td>BSS806NE</td>
</tr>
<tr>
<td>Dual N-channel MOSFET, ULL</td>
<td>SOT-363, 20 V, Ultra Logic Level</td>
<td>BSD840N</td>
</tr>
</tbody>
</table>

Find full portfolio of Infineons small signal MOSFETs: www.infineon.com/smallsignal

www.infineon.com/energy-storage-systems
**Parameter** | **Specification**
--- | ---
Input voltage | 350 V<sub>dc</sub> ~ 415 V<sub>dc</sub>
Output voltage | 40 V<sub>dc</sub> ~ 60 V<sub>dc</sub>
Output power | 3300 W
Efficiency | 98% peak
Topology | - Bi-directional mode
- Novel integrated magnetics concept
- Novel SMD cooling concept
HV devices | IPL60R075CFD7 (75 mΩ, 600 V)
LV devices | 16x BSC093N15NS5 (9.3 mΩ, 150 V)
Driver | 2x 2EDS8265H (4 A/8 A source/sink)
| 2x 2EDF7275F (4 A/8 A source/sink)
Schottky diode | 2x IDH08G65C6 (650 V)
| 4x BAT165 (40 V)
Controller | XMC4200-F64K256AB
AUX | ICESQ5AG CoolSET™
| IPU80R4K5P7 (4.5 Ω, 800 V)

For more details on the product, click on the part number.

www.infineon.com/energy-storage-systems
### Demoboards

#### Parameter Specification

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input voltage</td>
<td>176 V_{AC} - 265 V_{AC}</td>
</tr>
<tr>
<td>Output voltage</td>
<td>400 V_{DC}</td>
</tr>
<tr>
<td>Output power</td>
<td>3300 W</td>
</tr>
<tr>
<td>PF</td>
<td>&gt;0.95 from 20% load</td>
</tr>
<tr>
<td>Target efficiency</td>
<td>99% at 50% load</td>
</tr>
<tr>
<td>Power density</td>
<td>~72 W/inch³</td>
</tr>
<tr>
<td>HV devices</td>
<td>2x IMZ66R048M1H CoolSiC™</td>
</tr>
<tr>
<td></td>
<td>2x IPW60R017C7 CoolMOS™</td>
</tr>
<tr>
<td>Driver</td>
<td>2x 2EDF7275F EiceDRIVER™</td>
</tr>
<tr>
<td>Controller</td>
<td>XMC1404-F064X0200</td>
</tr>
<tr>
<td>QR-flyback</td>
<td>ICEQ5SAG</td>
</tr>
<tr>
<td></td>
<td>IPU95R3K7P7 CoolMOS™</td>
</tr>
</tbody>
</table>

#### Diagram

![Diagram of EVAL_3K3W_TP_PFC_SIC](image_url)

For more details on the product, click on the part number.

www.infineon.com/energy-storage-systems
Infineon powerful support
Useful links and helpful information

**General support**
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- [www.infineon.com/wheretobuy](http://www.infineon.com/wheretobuy)
- [www.infineon.com/quality](http://www.infineon.com/quality)
- [www.infineon.com/packages](http://www.infineon.com/packages)
- [www.infineon.com/green](http://www.infineon.com/green)
- [www.infineon.com/opn](http://www.infineon.com/opn)

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We commit
We partner
We innovate
We perform

Our mission
We make life easier, safer and greener.

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Infineon offers its toll-free 0800/4001 service hotline as one central number, available 24/7 in English, Mandarin and German.

› Germany ..................... 0800 951 951 951 (German/English)
› China, mainland .......... 4001 200 951 (Mandarin/English)
› India ............................ 000 800 4402 951 (English)
› USA ............................ 1-866 951 9519 (English/German)
› Other countries .......... 00* 800 951 951 951 (English/German)
› Direct access .............. +49 89 234-0 (interconnection fee, German/English)

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