Converter Topologies Using High-Voltage High-Frequency SiC Devices

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Medium-Voltage Levels and Applications

<table>
<thead>
<tr>
<th>Medium-Voltage Range [V]</th>
<th>Major Applications</th>
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</thead>
<tbody>
<tr>
<td>2,400</td>
<td>Medium-Voltage Industry Drives (1-10 MW)</td>
</tr>
<tr>
<td>(3,300)</td>
<td>Micro-grid Applications (1-10s MW)</td>
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<tr>
<td>4,160</td>
<td>Distribution System Applications (1s-100 MW)</td>
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<tr>
<td>4,800</td>
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<tr>
<td>(6,600)</td>
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<tr>
<td>6,900</td>
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<tr>
<td>13,800</td>
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<tr>
<td>23,000</td>
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<td>34,500</td>
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<tr>
<td>46,000</td>
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<td>69,000</td>
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New Devices Needed in Microgrids

- Phase Shifter
- Phase Balancer
- Power Regulator
- Impedance Compensator

Architectures of Smart Power Distribution Systems: HVDC & FACTS

- HVDC
  - HVDC standard
  - VSC / HVDC light
- FACTS
  - SVC TCSC
  - STATCOM SVC light
1. Cascade Multilevel Converters (Both Star- and Delta-CMI): STATCOM, ESS, UPFC, ...

2. Modular Multilevel Converter (MMC): HVDC

3. Emerging Multilevel Converters (2-Port CMI, nX Converter, ...)
Example 1: Power Flow Controller at 13.8 kV

42 Modules per phase

13.8 kV, 2 MVA PROTOTYPE
INVERTER MODULES (12 SERIES)
SHUNT (30 SHUNT)

BASE MODULE
(100A / 200A)
Si IGBT based VSC for HVDC and FACTS:

- Consider the case of Trans-Bay Cable, CA for example
- Built on modular multi-level converter topology

- Two Converters
- Each converter consists of 6 legs
- Each leg consists of ~200 modules*

Example 1: How many modules are required to achieve the needed performance?

Only 10 CMI modules are needed, however 42 are used due to voltage ratings of Si devices.
Example 2: Today’s Si-based HVDC MMC converter

- Typical Service life of an overall system is 30 years*.
- All modules in a leg are in series.
- Without redundancy for 200 modules in series, each module has to be designed for an impossible lifetime of $200 \times 30 = 6,000$ years!
- Redundant modules are needed to make 30-year service time possible and to improve reliability.
- Large redundancy is needed to achieve 30-year lifetime.

*Peter Kohnstam, Siemens High Voltage DC Conversion Systems- 22 April 2013, United States Department of Energy
Benefits Of SiC Power Devices

Today’s Si IGBT voltage ratings*:

• 1700 V/ 3600 A to 6500 V/ 750 A

With wide band gap devices, high current, high voltage devices are possible.

• 20-kV device are possible, which leads to reduction in the number of series modules for the same CMI or MMC rating.

• Low redundancy is needed to achieve 30-year lifetime, thus the number of total modules becomes significantly lower.

• Higher efficiency, simpler system, longer lifetime.

*Ultra High Voltage Semiconductor Power Devices for Grid Applications – M. T. Rahimo IEDM, December 2010, San Francisco, USA
Benefits Of SiC Power Devices -cont

SiC power device

• Improves reliability of operation due to lesser number of redundant sub-modules.
• Reduces component costs.
• Increases efficiency of CMI and MMC converters.
• Reduces cooling requirement, potentially making natural convection air cool possible –A utility company’s dream!
New Converter Topologies and Applications Become Feasible Because of SiC’s High-Frequency Switching

- Solid-State Variable Inductor
- Solid-State Variable Capacitor
- Solid-State Variable Transformer
- DC Transformer, nX DC-DC Converter
- DC Capacitor-less Inverters
- Z-Source Converters
For Solar Power Generation

For example: MW MV solar power based on cascade multilevel and quasi-Z-Source Inverter

- High switching frequency \(\rightarrow\) small inductors
- High temp. \(\rightarrow\) minimum cooling
Ideal Grid Converters/Inverters

Grid Needs for Converters to be:

- Scalable to any grid voltage levels without excessive # of modules
- DC capacitor-less or minimized L & C
- Highly efficient (>99%)
- Reliable and maintenance-free
- Natural-convection air-cooled

SiC Attributes:

- High Voltage
- High Frequency
- High Temp.