2.3kV Si and SiC devices development for renewable energy system

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Outline

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- Technology of 2.3kV Si device
- Technology of 2.3kV SiC-MOSFET device
- Static characteristics: I-V curves of IGBT/MOSFET devices
- Static characteristics: I-V curves of FWD/MOSFET devices
- Switching waveforms of 2.3kV Si device
- Switching waveforms of 2.3kV SiC-MOSFET device
- Power dissipation comparison
- Conclusion

Motivation

DC-link voltage ~1500V is required for renewable energy applications.

- 2-level topology with 3.3kV devices:
  Large switching losses due to the high blocking voltage device.
- 3-level NPC topology with 1.2kV devices:
  Large number of devices and gate drives
  Bigger commutation inductance

Our Proposal

New 2.3kV devices for renewable energy systems.

- Advantages of 2-level topology with 2.3kV devices:
  - ✓ Smaller footprint size
  - ✓ Smaller number of gate drivers
  - ✓ Lower on-state losses
  - ✓ Lower commutation inductance

Technology of 2.3kV Si IGBT

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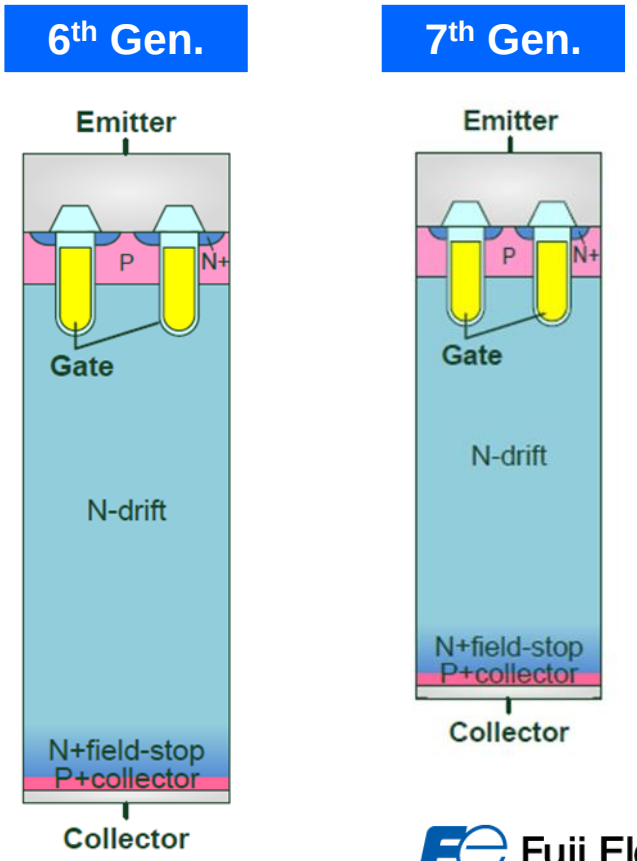
- 2.3kV Si-IGBT device based on the 7th Gen technology
- Thinner drift layer
- Low on-state voltage and low conduction loss

Technologies of 7G IGBT

- Thinner drift layer
  - Reduce $V_{CE(sat)}$ and E_{off}
- More fine pattern of trench pitch
  - Reduce $V_{CE(sat)}$ and E_{off}
- Optimized Field-Stop layer
  - Secure breakdown voltage
  - Low leakage current at high temperature

Cross section view of Si-IGBT chip



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Technology of 2.3kV SiC-MOSFET

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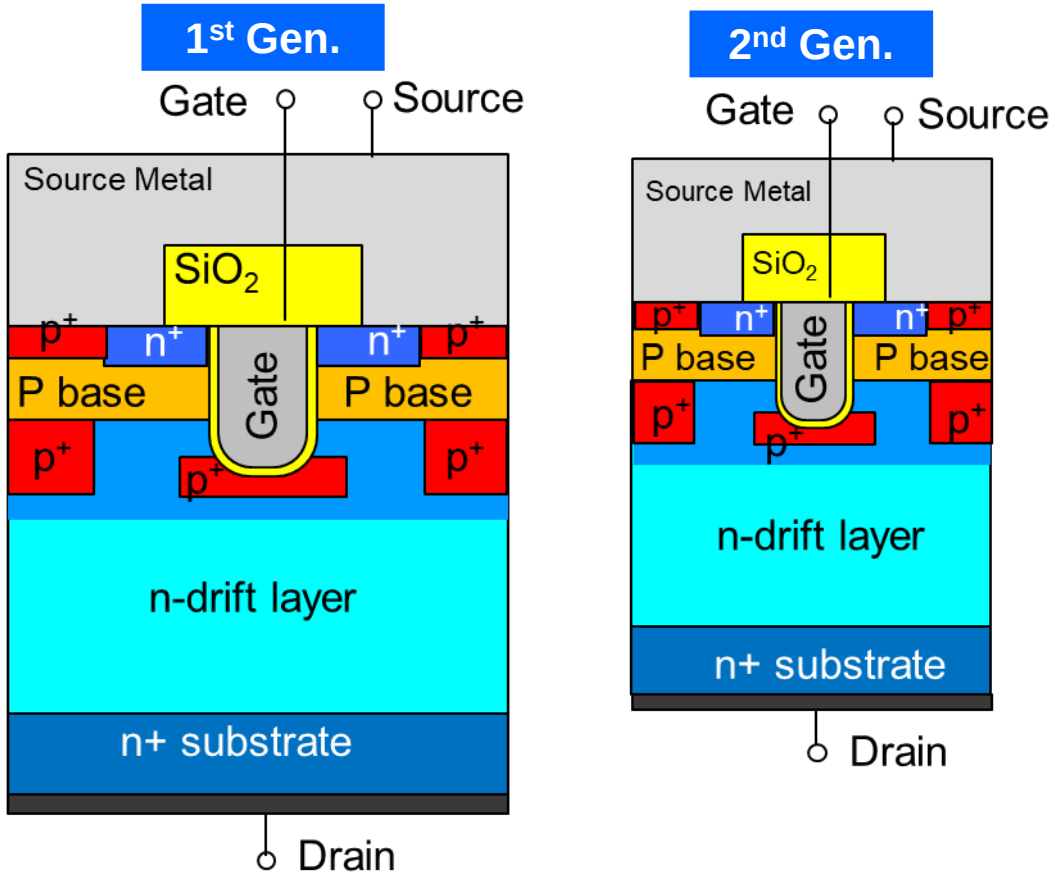
Fuji 2nd Gen SiC-MOSFET has 23% lower R_{on} than Fuji 1st Gen SiC-MOSFET by shrinking the cell pitch.

Technologies of Low R_{on}

- Narrow cell pitch
- Thin N+ substrate
- Trench gate structure

Cross section view of SiC-MOSFET



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On-state Voltage of Si IGBT / SiC MOSFET

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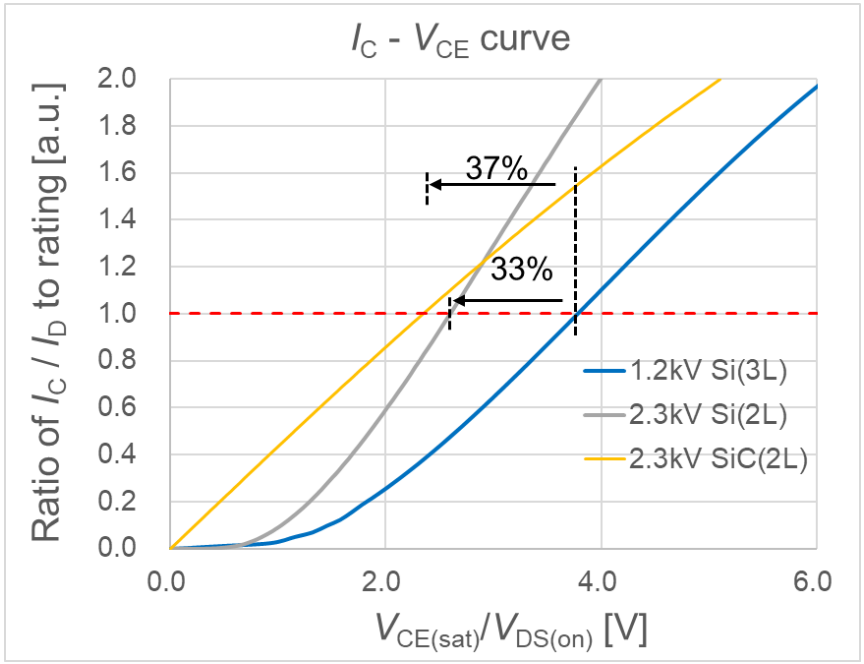
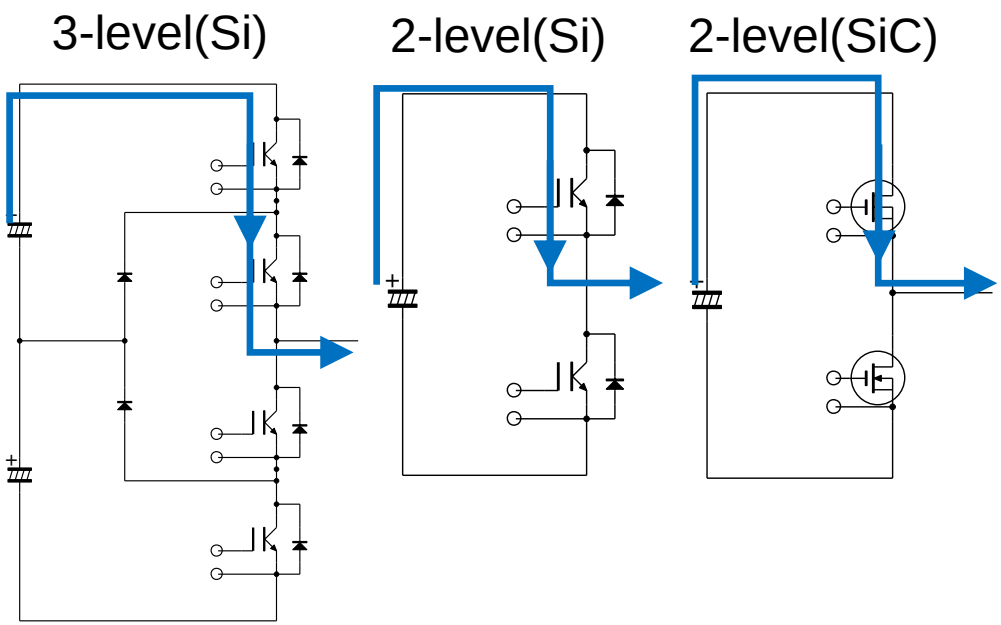
Compared to 1.2kV Si IGBT in 3-level NPC circuit,

- 2.3kV Si IGBT in 2-level circuit is 33% smaller.
- 2.3kV SiC-MOSFET in 2-level circuit is 37% smaller.





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On-state Voltage of Si FWD / SiC MOSFET

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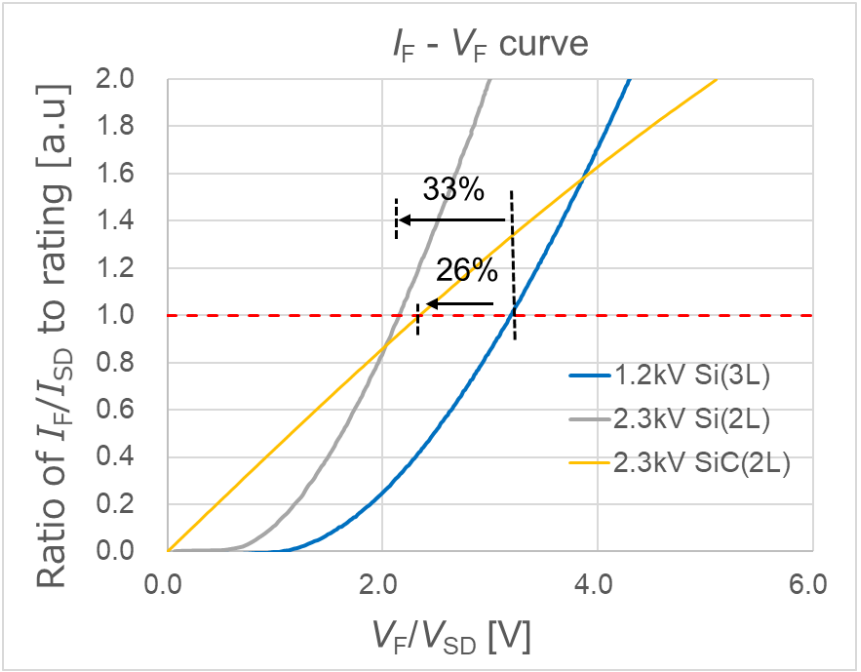
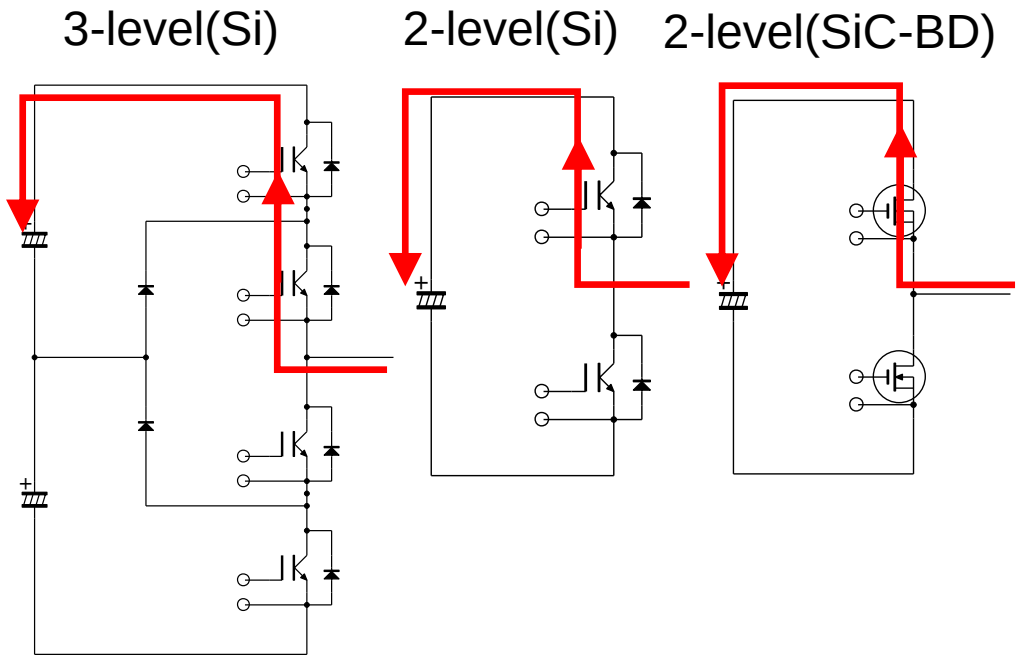
Compared to 1.2kV Si FWD in 3-level NPC circuit,

- 2.3kV Si FWD in 2-level circuit is 33% smaller.
- 2.3kV SiC-MOSFET (Body Diode) in 2-level circuit is 26% smaller.





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Switching Waveforms of 2.3kV Si-IGBT

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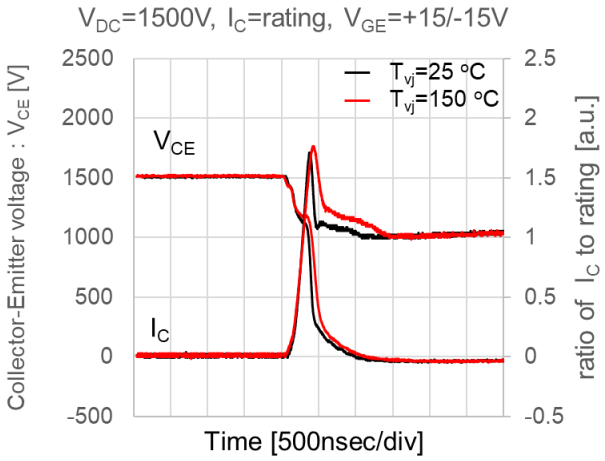
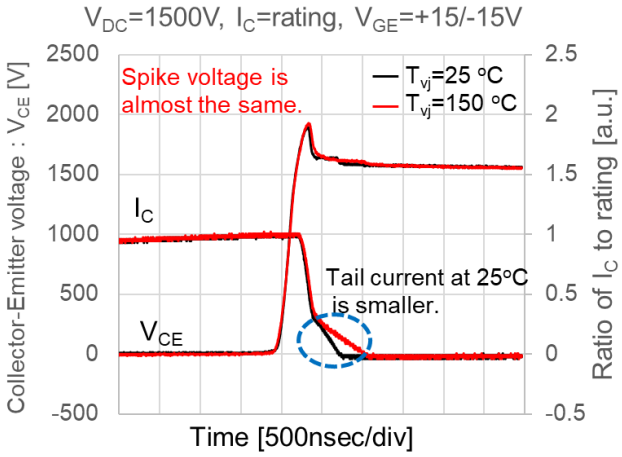
- Larger turn-off and reverse recovery tail current at higher temperature
- Smaller di/dt at higher temperature
- Larger switching losses at the higher temperature

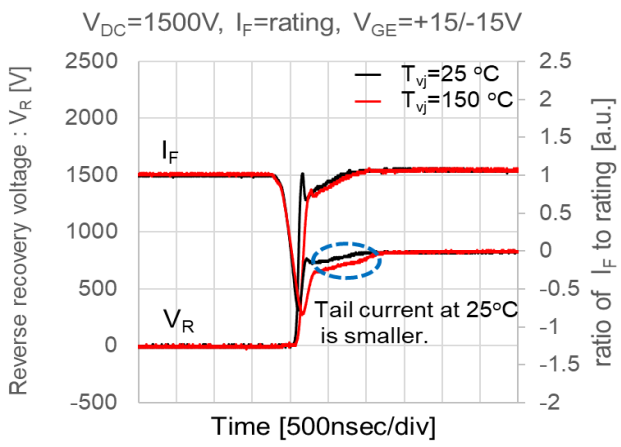
Turn-on waveform



Turn-off waveform



Reverse recovery waveform



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Switching Waveforms of 2.3kV SiC-MOSFET

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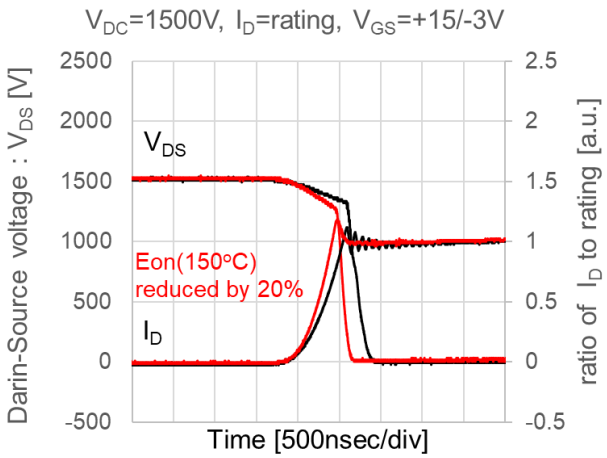
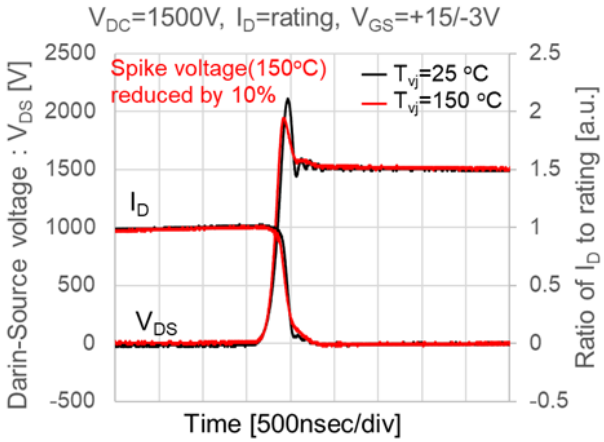
- No tail current and small spike
- Smaller spike voltage at higher temperature

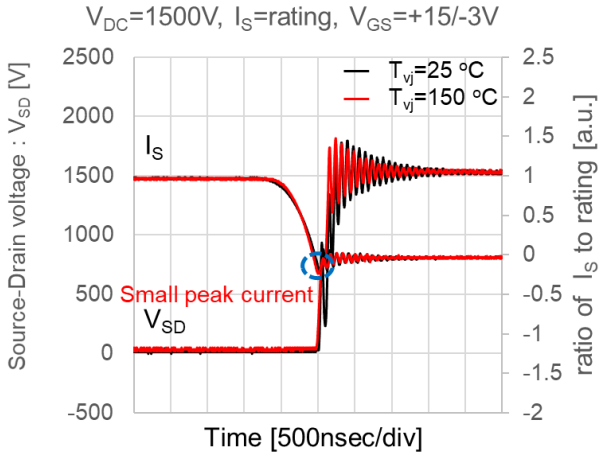
Turn-on waveform



Turn-off waveform



Reverse recovery waveform



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Power Dissipation Comparison

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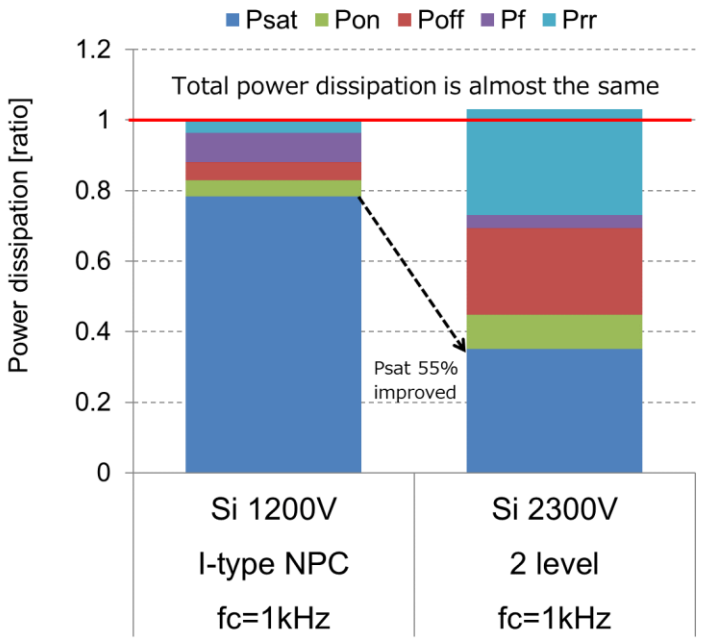
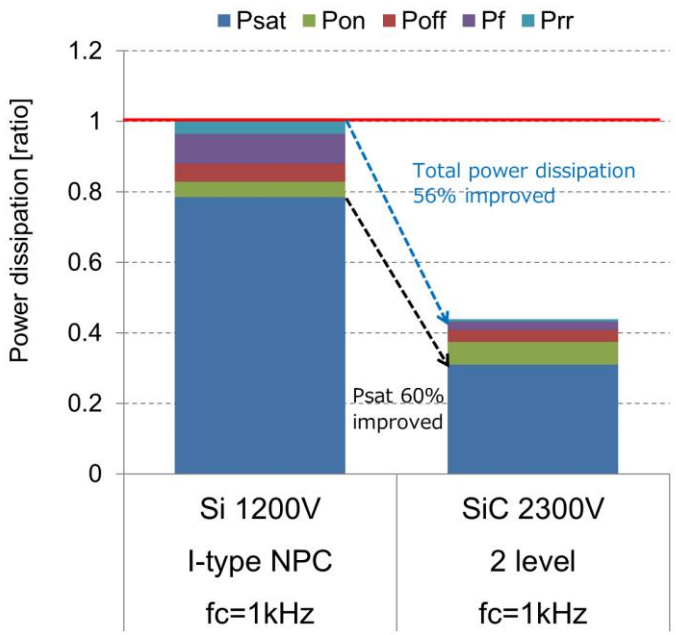
Conditions of I_o=600Arms, V_{DC}=1500V, cosφ=1, λ=1.0, f_c=1 kHz, T_{vj}=150 degC.

2-level topology with 2.3kV Si IGBT and
3-level NPC topology with 1.2kV Si IGBT



The total power dissipation is almost the same.

2-level topology with 2.3kV SiC MOSFET and
3-level NPC topology with 1.2kV Si IGBT



SiC device has better performance.

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Benefits of 2.3kV device in 2-level topology

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✓ Simplified circuits and drives, reduced dissipation losses

	3-level (Si)	2-level (Si)	2-level (SiC)
Number of devices	30 ☹ (IGBT x12, FWD x18)	12 ☹ (IGBT x6, FWDx6)	6 ☺ (MOSFET x6)
Footprint	100% ☹	33% ☺	33% ☺
Number of gate drivers	12 ☹	6 ☺	6 ☺
Total loss	100% ☹	103% ☹	44% ☺
On-state loss	100% ☹	45% ☺	38% ☺
Switching loss	100% ☹	487% ☹	80% ☺

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Conclusion

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- Newly developed 2.3kV Si-IGBT and 2.3kV SiC-MOSFET with trench gate structure have been introduced.
- The 2.3kV devices are suitable for renewable energy applications with ~1500VDC bus voltage.
- The 2.3kV SiC-MOSFET has low power dissipation, and it can operate at higher switching frequency.
- The 2.3kV devices have the following benefits:
  - Simplified inverter design with a small number of gate drives
  - Low commutation inductance
  - Low on-state loss

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