Benefits of 3-level power modules in Automotive traction inverters

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Bodo's Wide Bandgap Event 2025

Making WBG Designs Happen

SiC

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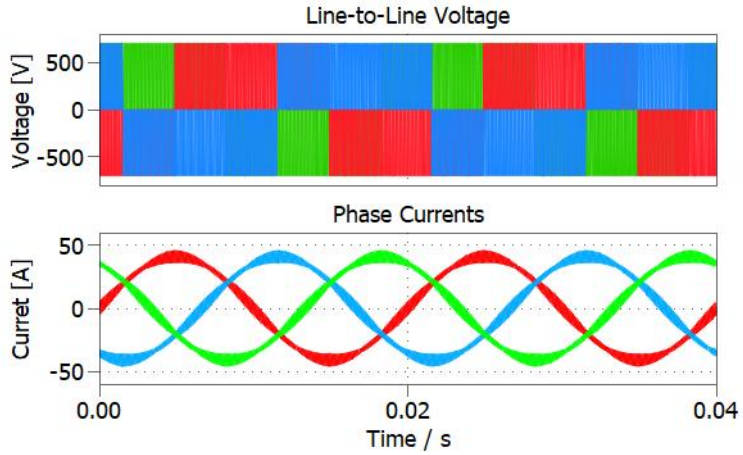
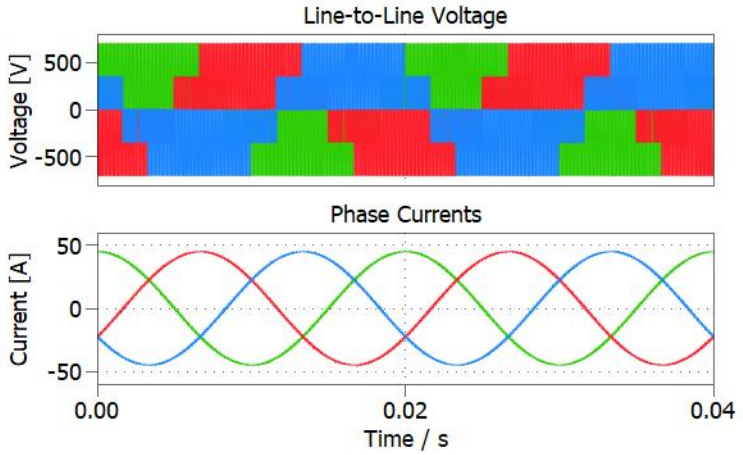
1. Limitations of existing 2-level inverters

- Today's BEVs predominantly use 2-level Voltage Source Inverters for traction, moving from IGBT based inverters to SiC-MOSFET based inverters.
- Inverter efficiency has greatly improved with the use of SiC, but system losses, EMI emissions and dV/dt can still be improved.
- PWM harmonics from 2-level inverters add copper, iron (hysteresis and eddy) and rotor stray losses, causing heat in the electric machine which limits the constant output power.
- For most motor types used in traction, PMSM, ASM and even EESM, their efficiency is limited when using 2-level inverters.
- Continuous increase in battery voltage and faster devices increase common mode disturbance and dV/dt, causing insulation and bearing stress.

2. Benefits and trade-offs of 3-level inverters

- 3-level T-type inverters halve device switching voltage per step, enabling lower switching losses or higher switching frequency.
- Their output waveform closer resembles a sinusoidal waveform, lowering THD and current ripple at the electric machine.
- Halving switching voltage lowers dV/dt and common mode voltage, therefore lowering insulation stress and EMI emissions.
- Lower current ripple on the machine side contributes to lower hysteresis, eddy currents and core losses, among others.

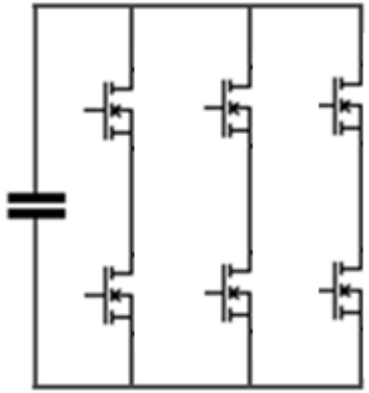


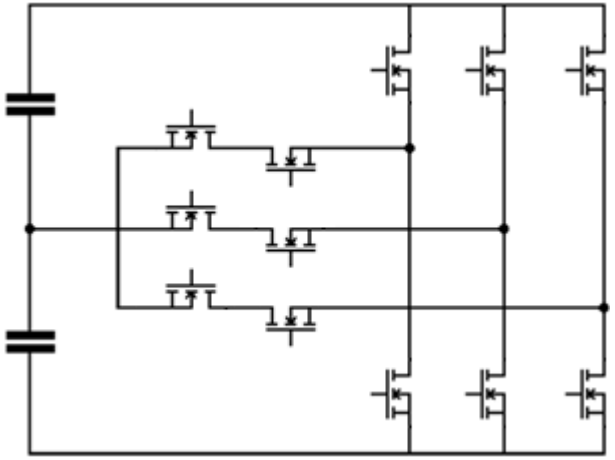


2. Benefits and trade-offs of 3-level inverters

These improvements come with trade-offs, but the advantages can be worth it in the right applications.

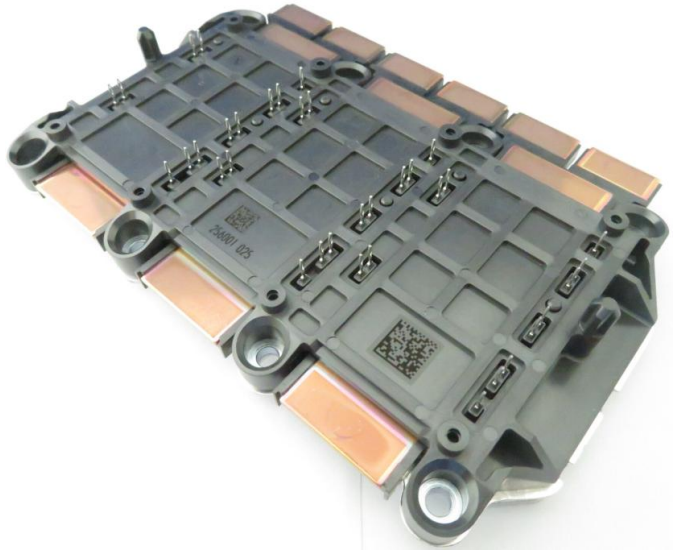
- Extra devices per phase: 3-level T-type inverters require 2 extra devices and their corresponding driving control per phase, making the inverter more expensive than the respective 2-level.
- Larger conduction losses: Having extra series devices slightly increases the conduction path losses, although partially offset by SiC's low Rds on.
- Higher control complexity: The balance of each dc-link capacitor and the extra devices make 3-level inverters more difficult to control.





3. Fuji Electric's solution

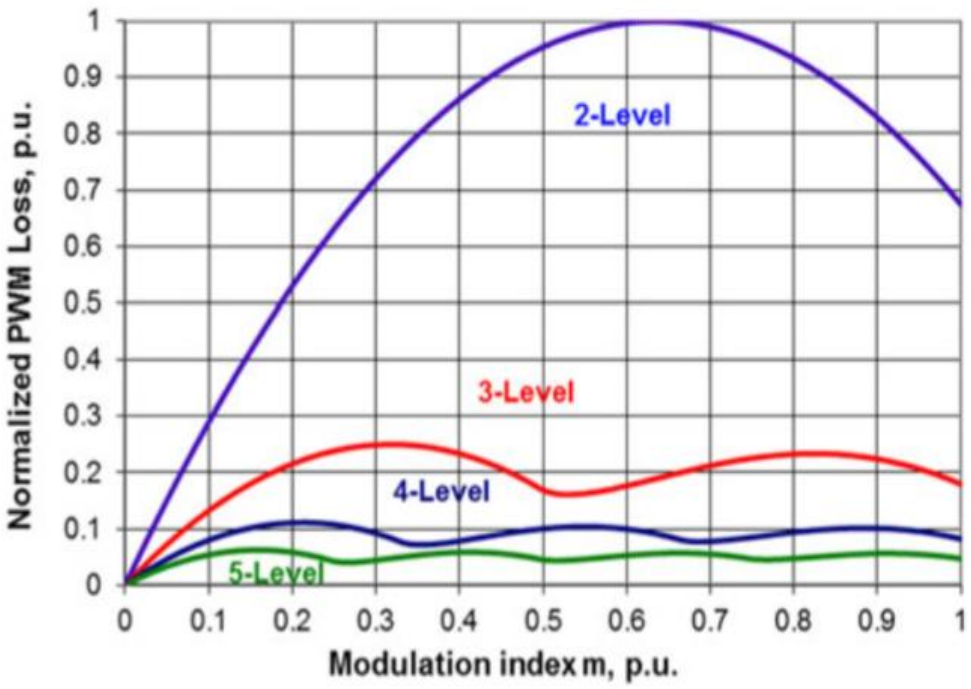
- Fuji Electric has developed a convenient, state of the art 3-Level T-type SiC module for 800 V battery systems, the M1206.
- Up to 300 kW power per module.
- Low stray inductance.
- Laser welding main terminals.
- Press-fit pin auxiliary terminals.
- Molded package with revolutionary 3D wiring internal structure.
- AQG324 approved.
- Flexible design (Future plan):
  - Half-bridge design with customizable adapter frame.
  - Available with or without water cooler.
  - Al or Cu coolers, pin-fin or closed water jacket.

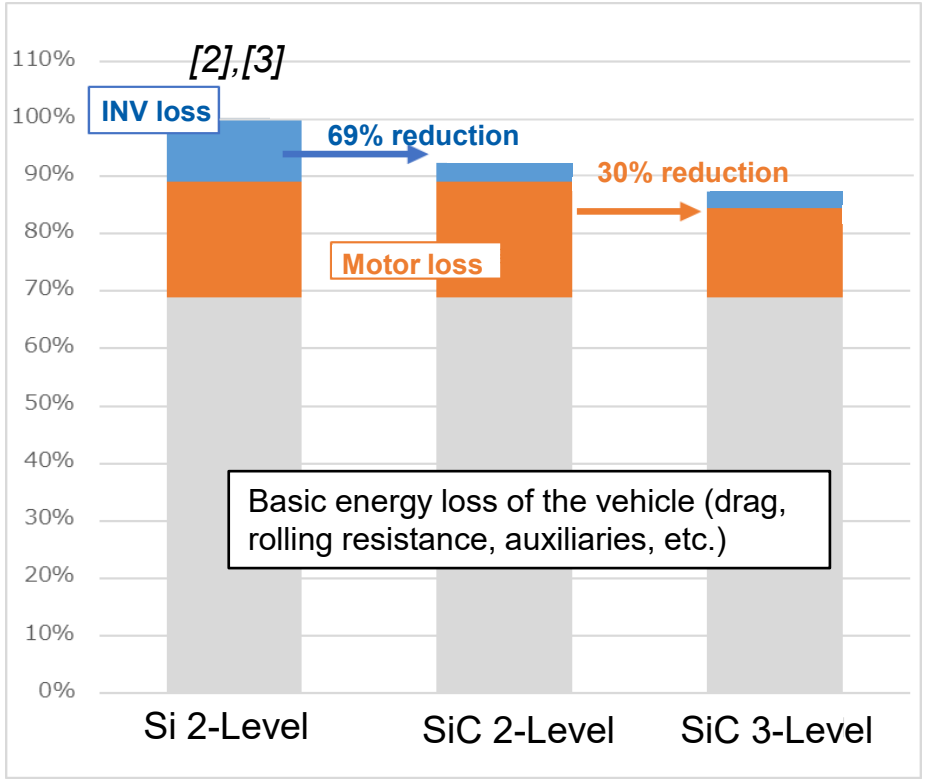


4. Evaluation results

Evidence

[1] **Normalized PWM Eddy Current Loss**

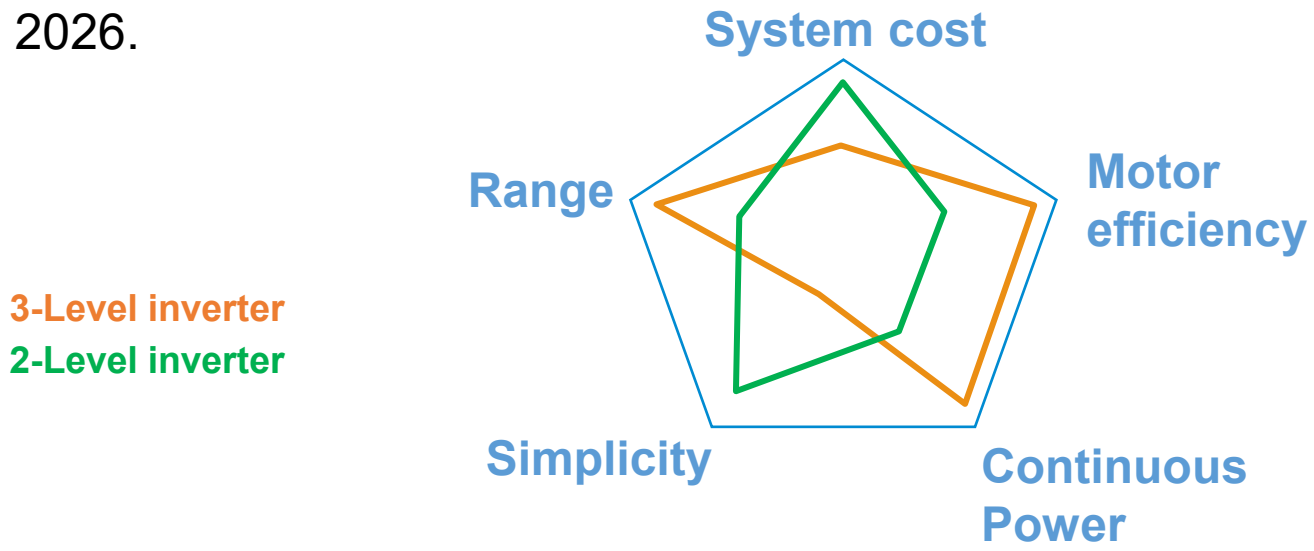




Real world tests show the previously studied loss reduction clearly. For reference, the change from Si to SiC gave BEV an approximate increase in efficiency by 7%. A similar result is expected with the change from 2 to 3-level inverters.

5. Summary

- The change from Si to SiC brought great improvements to powertrain efficiency. Further improvements can be achieved by using 3-level topology.
- Lower voltage steps allow for lower losses and higher efficiency at the electrical machine level, allowing for a higher constant power output.
- Fuji's M1206 SiC 3-Level T-type module offers extremely high power density with low leakage inductance.
- Market ready in 2026.



THANK YOU

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Innovating Energy Technology

Annex

[1] *A.Ruderman, Effect on Multilevel Inverter Supply on Core Losses in Magnetic Materials and Electrical Machines, IEEE 2015*

[2] *A. Nisch et al,"Effects of a SiC TMOSFET tractions inverters on the electric vehicle drivetrain", Proc. Int. Exhib. Conf. Power Electron, Intell. Motion Renewable Energy and Energy Manage., pp. 95-102,Nuremberg,Germany(2018)*

[3] *P. Panchal et al,"An Innovative 3-level Solution for Automotive Applications:eMPack", Proc. Int. Exhib. Conf. Power Electron, Intell. Motion Renewable Energy and Energy Manage., pp. 315-321, Nuremberg, Germany (2024)*