Scalable and Accurate Modelling of a WBG-based Bidirectional DC/DC Converter for Electric Drivetrains

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Power Electronics Drives: Demand

Size reduction

Cost reduction

Efficiency improvement

Weight reduction

Reliability

Power Electronics Drives: Challenges

Contents

- ❑DC/DC Topology Selection for EVs
- ❑High Fidelity (HiFi) Modelling Approach
  - ✓Device Modelling
  - ✓Passive Components Modelling
- ❑Scalability & Accuracy
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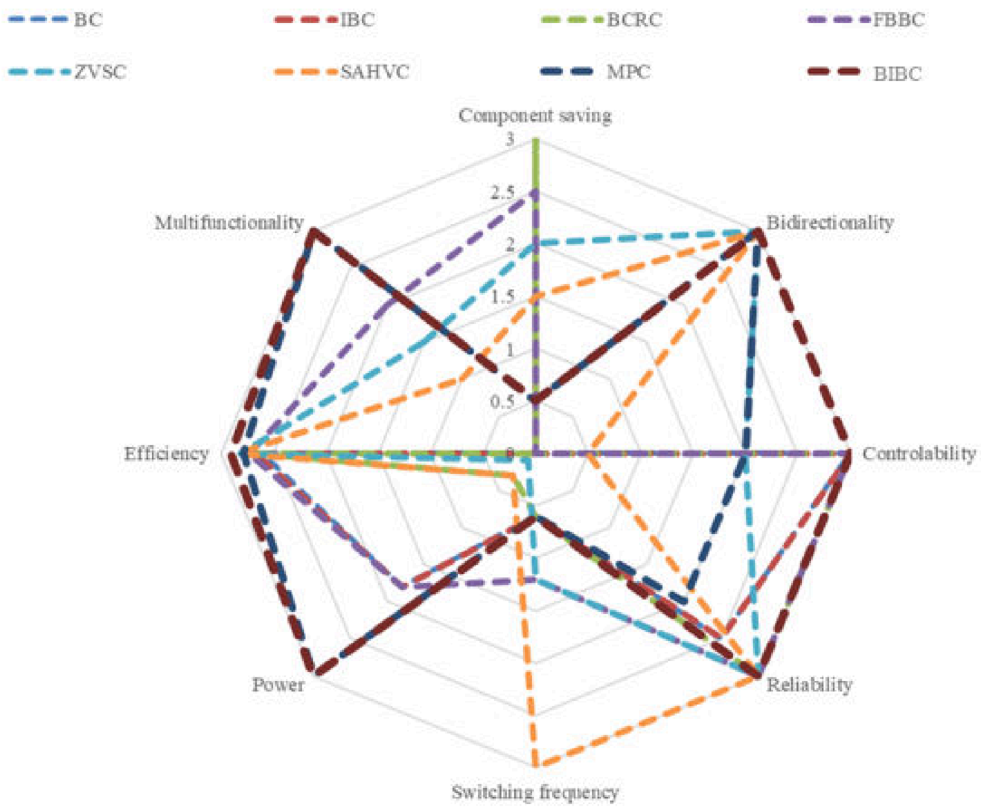
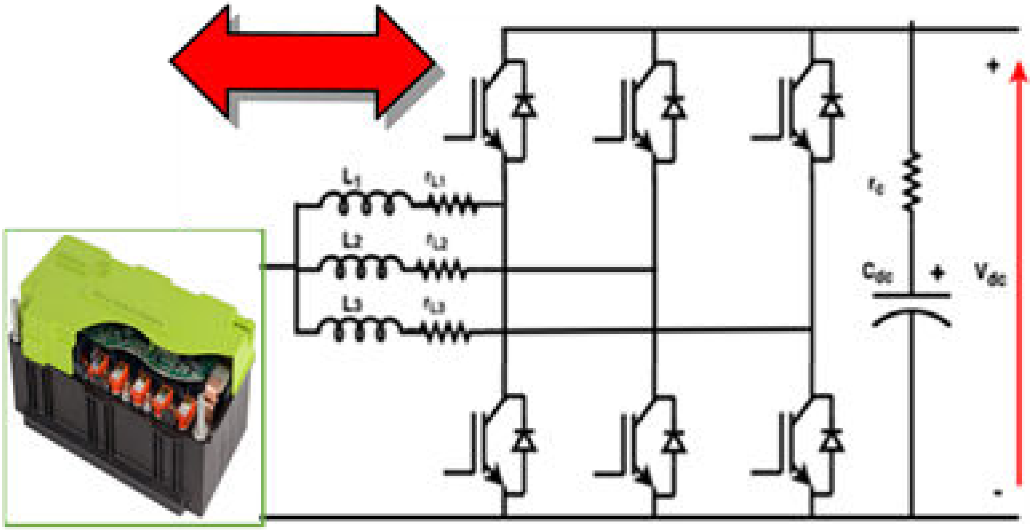
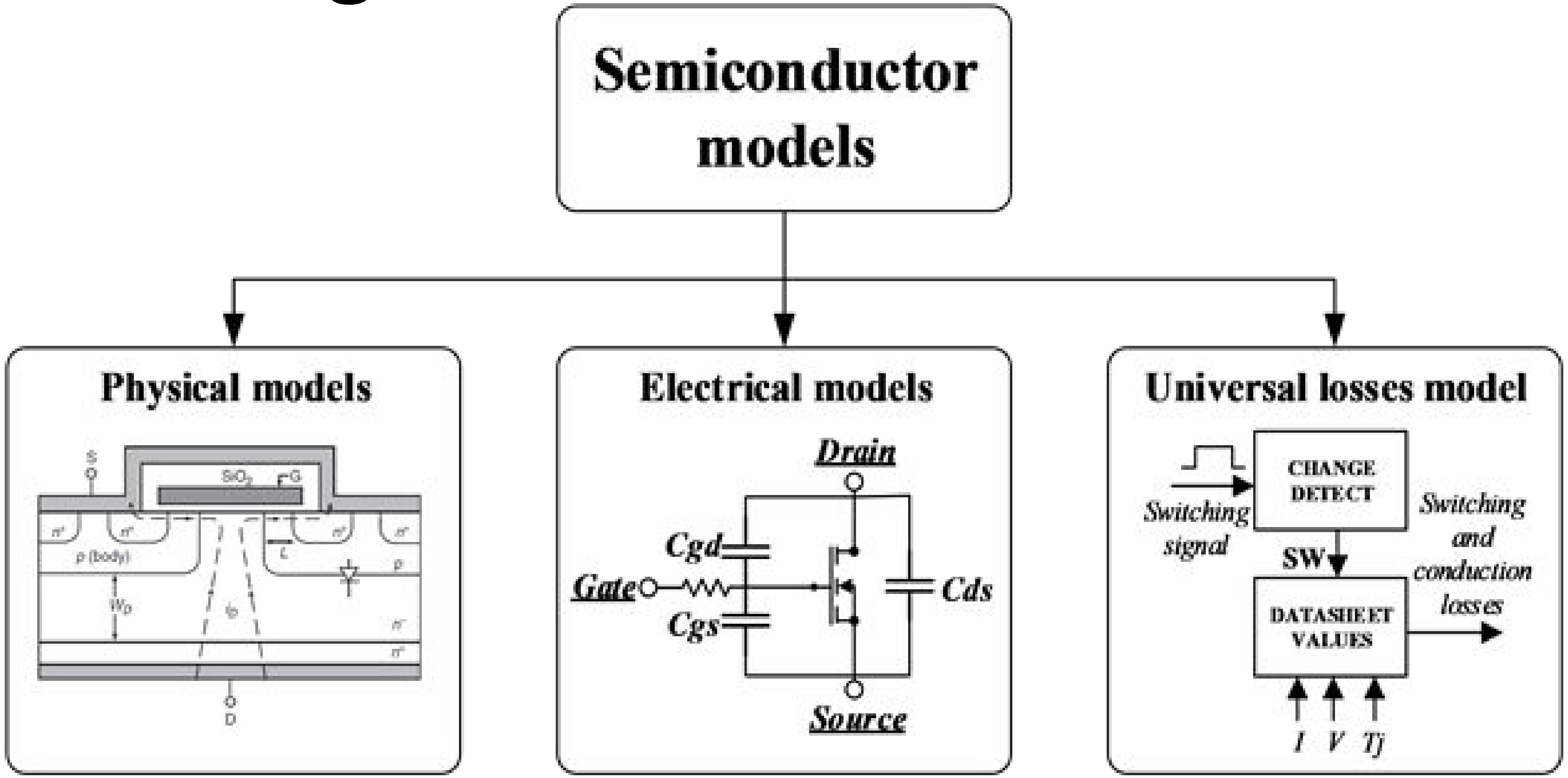
- ❑Conclusion

HV DC/DC Topology Selection for EVs





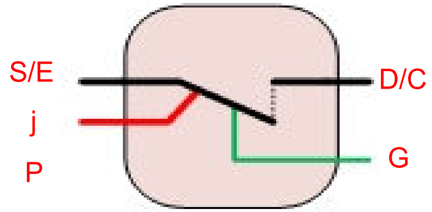
Device Modelling

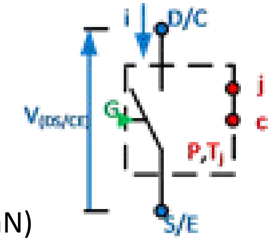


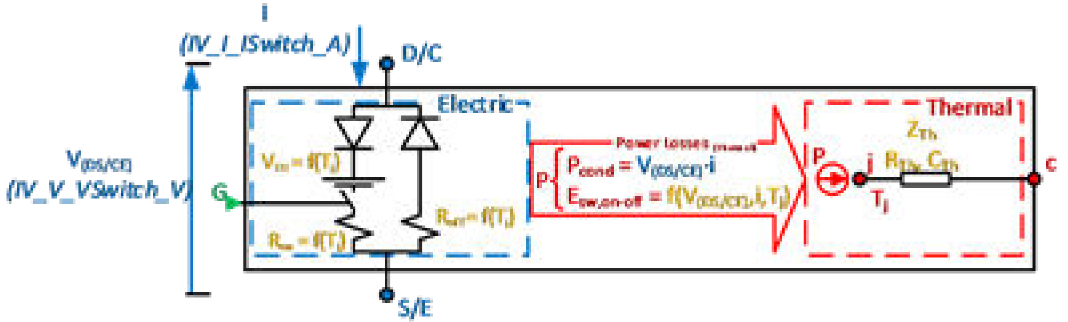
HiFi Switch Modelling

Electrical and thermal variables integration

- **Multiphysical Nodes**
  - Control: Gate (G)
  - Electric: Drain/Collector (D/C) – Source/Emitter (S/E)
  - Thermal Node: Junction (j)
- **Main Internal Variables**
  - Electric: {v, i}
  - Thermal: $\{T_j,\ Q \equiv P_{Loss} \rightarrow [E_{Sw,On}, E_{Sw,Off}, P_{Sw,On}, P_{Sw,Off}, P_{cond}]\}$
- **Main Parameters**
  - Electric: $\{R_{DS,ON}(T_j), V_{th}(T_j), R_{OFF}\}$
    - Adaptable to any switch technology (Si, SiC, GaN)
  - Thermal: $\{E_{Sw,On\,(LUT)}(T_j, i, v), E_{Sw,Off\,(LUT)}(T_j, i, v)\}$ - By means of LookUp Tables (LUT)
- **Output**
  - $P \equiv P_{Loss}$



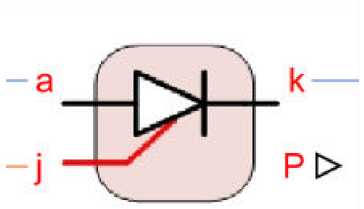


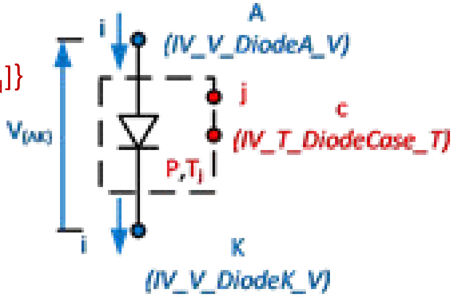


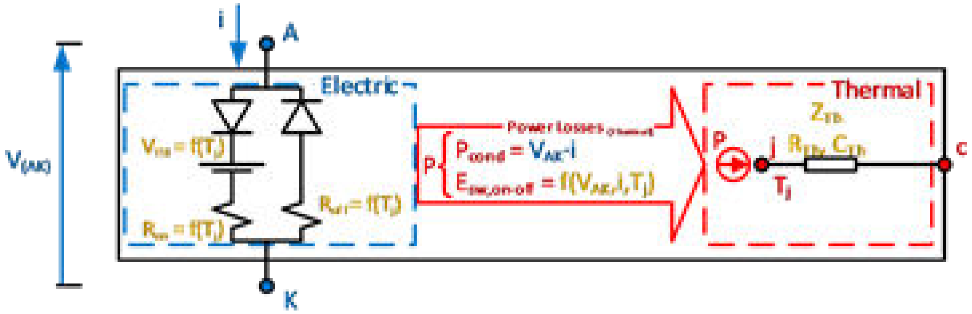
HiFi Diode Modelling

Electrical and thermal variables integration

- **Multiphysical Nodes**
  - Electric: Anode (a) – Cathode (k).
  - Thermal: Junction (j).
- **Main Internal Variables**
  - Electric: {v, i}
  - Thermal: $\{T_j, Q \equiv P_{Loss} \rightarrow [E_{Sw,On}, E_{Sw,Off}, P_{Sw,On}, P_{Sw,Off}, P_{cond}]\}$
- **Main Parameters**
  - Electric: $\{R_{ON}(T_j), V_{th}(T_j), R_{OFF}(T_j)\}$
    - Adaptable to any switch technology (Si, SiC)
  - Thermal: $\{E_{Sw,On\,(LUT)}(T_j, i, v), E_{Sw,Off\,(LUT)}(T_j, i, v)\}$ - By means of LookUp Tables (LUT)
- **Output**
  - $P \equiv P_{Loss}$







HiFi Passive Component Modelling

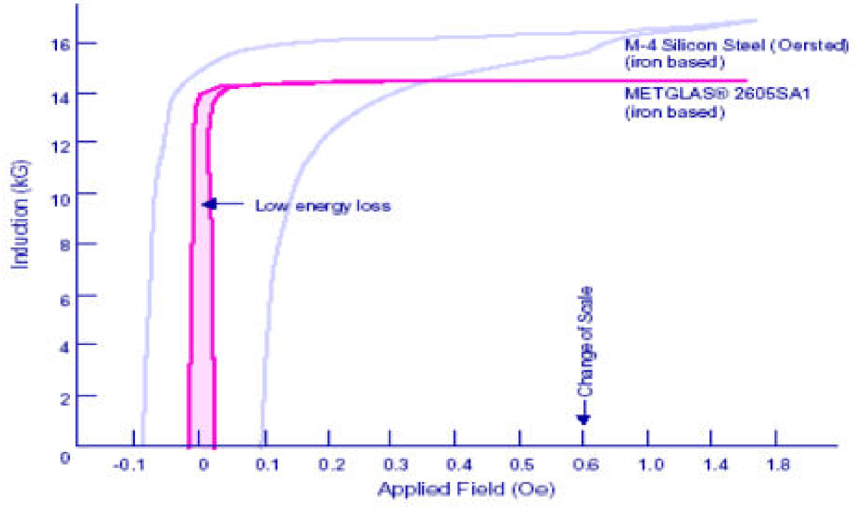


Fig: Selection of high-performance material

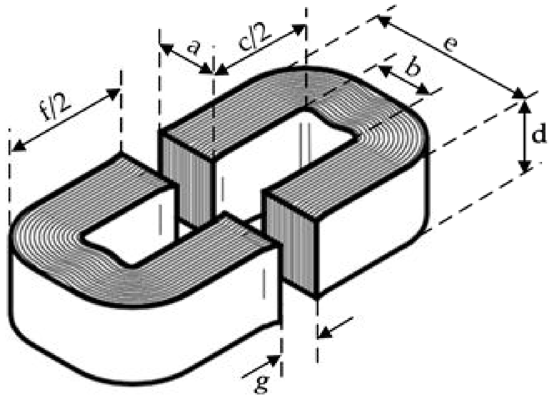


Fig: Geometry parameters of selected core

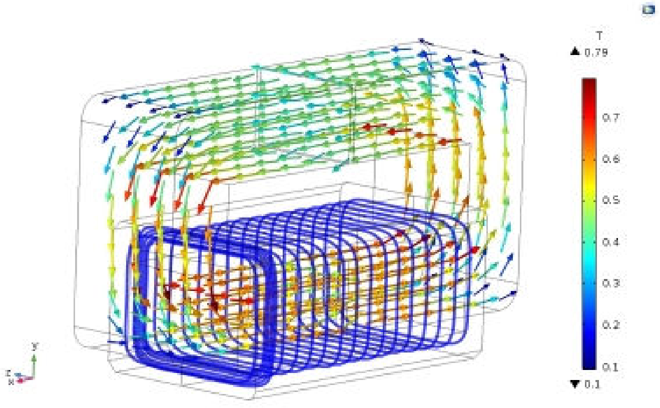


Fig: FEM Analysis of selected Inductor

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$$\mathrm{ESR} = \frac{R_2}{1+(2\pi f)^2 C_2^2 R_2^2} + R_1 + R_0$$

Fig: Polypropylene, DC Link Capacitors

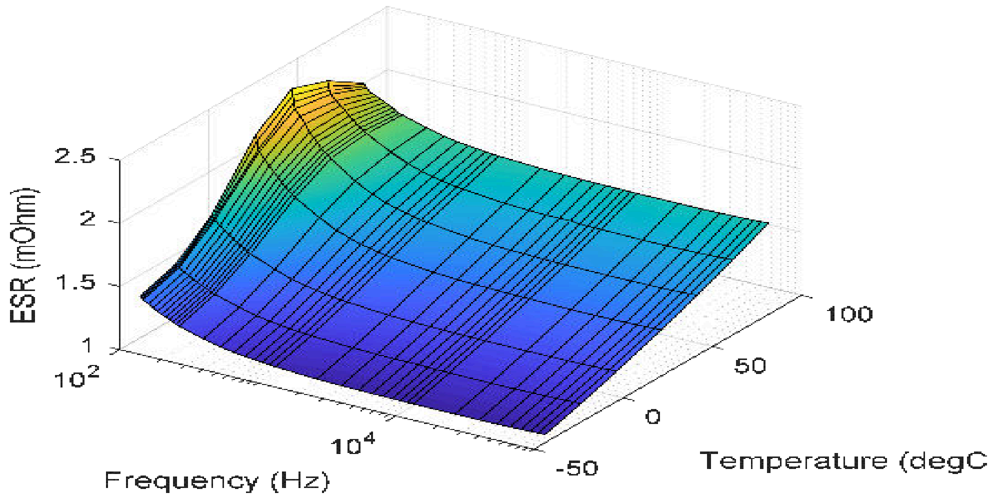
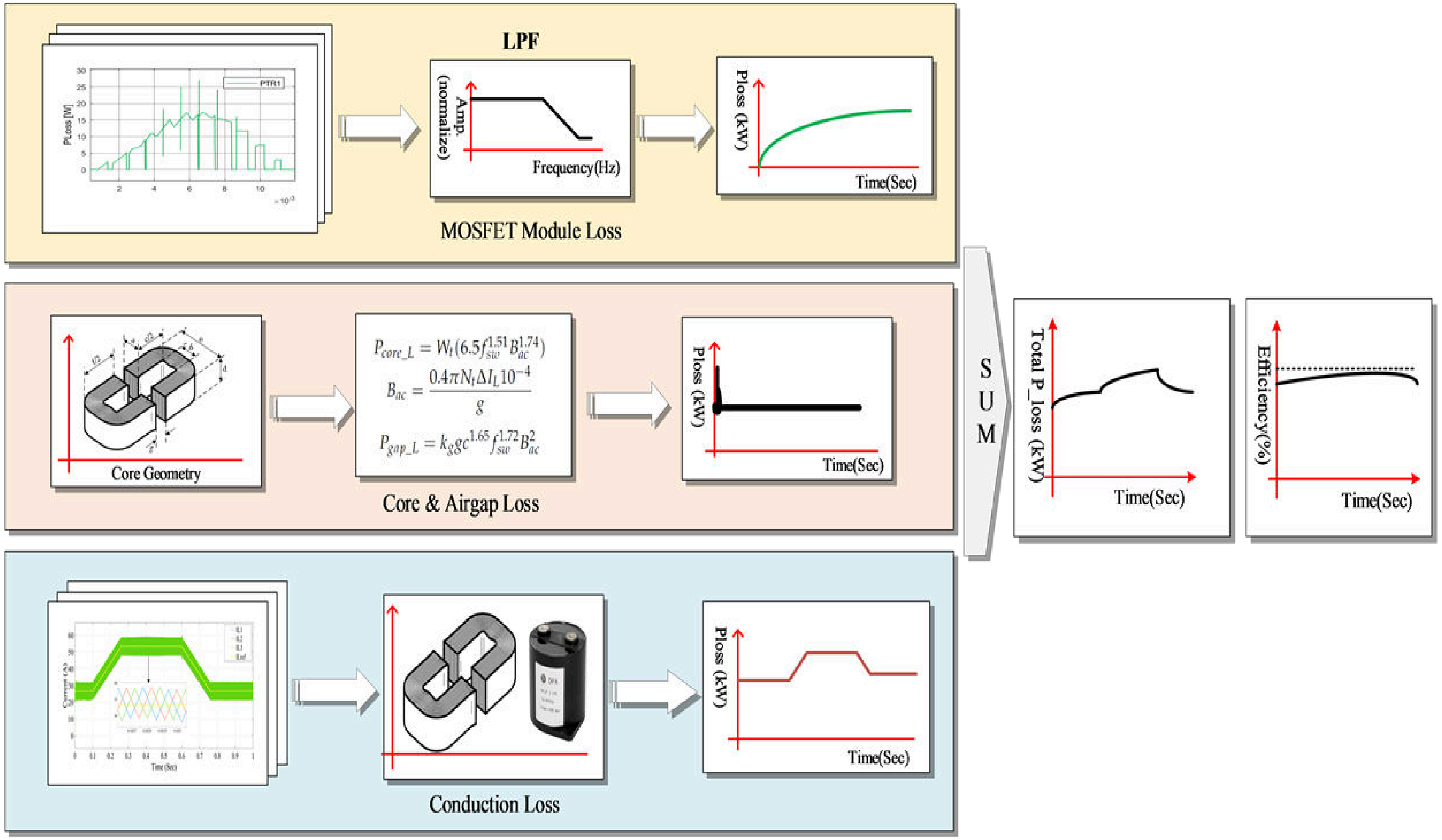


Fig: ESR model of capacitors

HiFi Loss Modelling



Scalability

Description	Special HiFi	HiFi	LoFi
Model Type	Simscape + Simulink	Simulink	Simulink
Step size	1e-6	1e-6 or 1e-7	1e-2
Variants type	15×3 (45)	3×6×5×5 (450)	15×3×3 (135)
Sensor Type	HiFi	Ideal	Ideal
Loss model	Instantaeous	Instantaeous	Average
Thermal model	HiFi	HiFi	Map based
Safety functionalities	Yes	Yes	Yes
xMOD compatibility	No	Yes	Yes
HiL capacity	No	Yes	Yes
Characteristics	✓ Accurate physics ✓ Dual-loop lead-lag control ✓ Discrete control ✓ Short-circuit simulation ✓ dv/dt analysis ✓ Detail parameterization ✓ Complex final integration	✓ Accurate physics ✓ Dual-loop lead-lag control ✓ Discrete control ✓ dv/dt analysis ✓ Less simulation time that Special HiFi ✓ Detail parameterization	✓ Map based ✓ Fater than RT ✓ Device selection
Limitations	✓ High simulation time	✓ No Short-circuit simulation	✓ No semiconductor physics

Accuracy

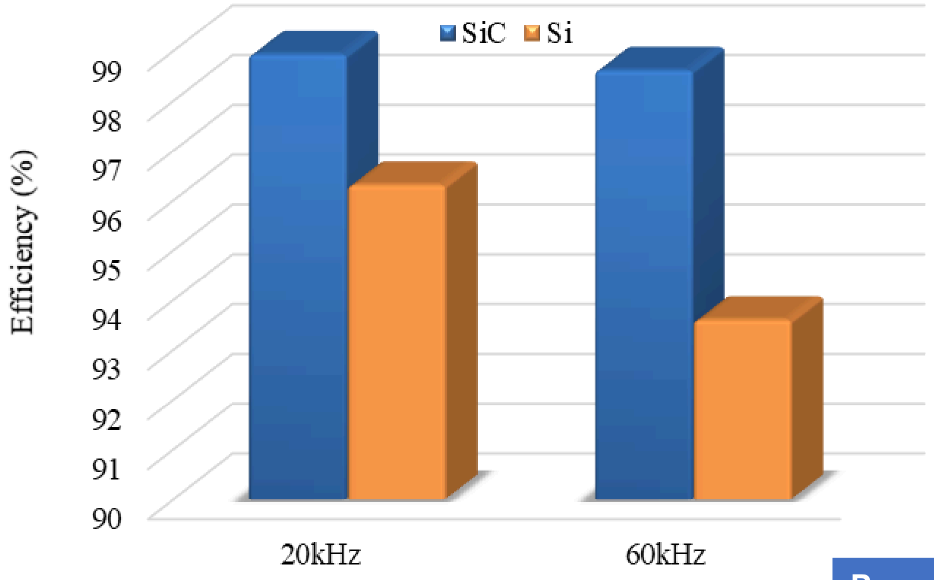
Error between different model

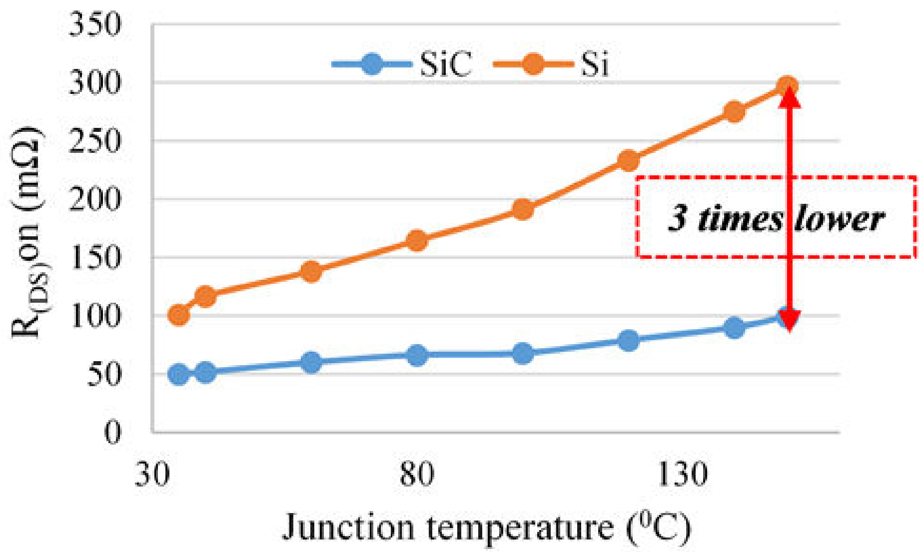
Model	Average Power Losses	Average Junction Temperature	Average DC Link Current
Special HiFi	0%	0%	0%
HiFi	2.03 %	0.55 %	0.55 %
LoFi	5.29 %	0.61 %	3.49 %

FEM and Experimental result

AMCC50	FEM (μH)	Experimental (μH) Prototype	Error
Number of turns=19; Airgap=0.8mm	155.49	164.8	5.65%
Losses	10.37	10.50	1.23%

Impact of WBGs on Converter Performance





Parameter	Value
Rated Power, P_{nom}	30kW
DC Link Voltage, V_o	400V
Input Voltage, V_{BAT}	200V
Input current, I_{in}	150A

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Conclusion

- High Fidelity simulations use for system characterizations & validation
- Improve scalability, modularity and real-time use of simulations
- Achieve time reduction in model to model calibration
- Targeting reduction in co-simulation toolchain
- High potential using WBGs

Future work

- Validate regarding experimental result

Thank you for your attention