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# Multiphysics Modeling of Power Electronic Devices

This work will model the power electronic devices in two steps: loss modeling and thermal modeling for IGBTs, MOSFETs, and power diodes. There will be no specific devices used; just general device parameters found from a market survey at different voltage/current ratings. This section covers how these modeling methods are designed for each respective device.

### Relevant Converter Topologies in WEC Applications

***Updated:*** *12/16/2024*

H-Bridge voltage source converters are the most common in WEC systems, especially when arranged in an AC-DC-AC or BTB topology. The rectification stage can be of active or passive rectification, and the rectification/inversion stages can be controlled independently with the presence of a DC link capacitor. The downsides of these topologies include: switching losses, low reliability of the DC link capacitor, and EMI issues [1]. Authors in [2] present a traditional 3-phase active rectifier for the front-end converter (connected to the generator) with a DC-link capacitor, followed by a DC-DC buck converter to step down the DC link voltage.

Multi-level converters (MLCs) have become more prevalent. MLCs are often used in a BTB configuration, with MLCs replacing both the rectification and inversion stages in the conventional H-bridge topologies. The three key topologies include diode-clamped converters (DCC), flying-capacitor converters (FCC), and cascaded H-bridge (CHB) converters [1]. The advantages of these topologies include lower switching losses and EMI [1] as well as higher allowable DC bus voltages which leads to reduced phase currents and lower I2R losses. Some of the disadvantages include voltage imbalances between submodules/levels [1], more complex control, and higher component counts which may have a negative impact on converter reliability.

Matrix converters are a single-stage AC-AC converter topology, where any generator input phase can be connected directly to one or more output phases, allowing for flexible switching configurations and accurate control of voltages/currents [1]. These systems are more compact than H-bridge or MLC-based BTB converters as there is no DC link and a low number of switching components [1]. Without a DC link, the reliability of the matrix converter is also improved compared to H-bridge and MLC topologies. One of the primary limitations of matrix converters is that they should not be used systems with linear generators as phase voltages in linear generator-based systems drop to 0 as the velocity decreases [1].

As presented by [3], many applications use SVPWM to generate switching signals to activate the semiconductor devices. We should, therefore, consider both an SPWM and SVPWM method for each module developed (if applicable).

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[1] J. K. H. Shek, D. E. Macpherson and M. A. Mueller, "Power conversion for wave energy applications," *5th IET International Conference on Power Electronics, Machines and Drives (PEMD 2010)*, Brighton, UK, 2010, pp. 1-6, doi: 10.1049/cp.2010.0019.

[2] E. A. Amon, A. A. Schacher and T. K. A. Brekken, "A novel maximum power point tracking algorithm for ocean wave energy devices," *2009 IEEE Energy Conversion Congress and Exposition*, San Jose, CA, USA, 2009, pp. 2635-2641, doi: 10.1109/ECCE.2009.5316277.

[3] J. Burhanudin, A. S. A. Hasim, A. M. Ishak, J. Burhanudin and S. M. F. B. S. M. Dardin, "A Review of Power Electronics for Nearshore Wave Energy Converter Applications," in *IEEE Access*, vol. 10, pp. 16670-16680, 2022, doi: 10.1109/ACCESS.2022.3148319.

### Accounting for Device Sensitivity to Junction Temperature

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It is common for high-level models of power semiconductor devices to be made of a series combination of ideal switches, diodes, and resistors. With this considered, it is intuitive that the characteristics of the device change with its operating temperature. Knowing that general resistors are positive temperature coefficient devices, we can expect the on resistance of these semiconductors to increase with .

#### MOSFETs

The electrical parameters of MOSFETs are highly sensitive to . Of most importance, this includes the values for , , .

Modeling the impact has on the conduction losses can be done in a linear fashion, as presented in [1]. The general equation is shown below, where is the general value for the device resistance at 25C. The value of can be derived simply by picking two resistance values at two different junction temperatures (obviously simplest to choose one resistance value to be defined at 25C) .

Many manufacturers will provide data for modeling switching energies as a function of , and should be used when considering these thermal effects.

#### IGBTs

[2] presents a linear model to estimate the impacts of junction temperature on IGBT on-resistance.

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[1] D. D. Graovac, M. Pürschel, and A. Kiep, “MOSFET Power Losses Calculation Using the Data- Sheet Parameters,” *Infineon Application Note*, pp. 1–23, 2006.

[2] <https://assets.danfoss.com/documents/latest/444047/AB501641682475en-000201.pdf>

### MOSFET Loss Modeling

#### Loss Modeling in Two-Level Voltage Source Converter Topologies:

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Modeling of the MOSFETs will be done largely using the examples in the application note by Graovac et al., 2006. This method also considers the losses of the body diode, so for MOSFET applications, no extra parallel diode will be included. Table 1 lists all input/output information for the MOSFET loss block. For inputs, , , , and are used to calculate the amplitude of . The switch location information is required for timing of the power pulse relative to the instantaneous phase current value.

Table 1: Inputs and outputs used for device modeling.

|  |  |
| --- | --- |
| **Input** | **Output** |
| RMS Phase Current () | Sine Wave Pulsed Power Output () |
| Electrical Frequency () |
| Modulation Index () |
| Power Factor () |
| Switch Location |

From Graovac et al., the average device losses over a fundamental period in three-phase motor drive applications can be defined as follows:

Where is used to find switching loss estimates for the MOSFET and Diode from an LUT derived from datasheet parameters.

In total, these losses are summed together to determine the periodic average losses of the device with respect to the fundamental frequency,

As presented in the IPOSIM documentation from Infineon, the periodic average is then used to create a half-sine wave pulsed power waveform with amplitude

This half-sine pulse should be applied in-phase with the RMS phase current through the MOSFET. For example, for a high-side MOSFET, this pulse should be applied in-phase with the positive half-cycle of the phase current. For a low-side MOSFET, the pulse should be applied in the negative half-cycle.

**NOTE:** This method is limited in that it is only valid for SPWM switching methods. Other loss calculations will need to be done for other switching methods such as SVM.

#### Loss Modeling in Modular Multilevel Converter (MMC) Topologies

The paper by Zhang et al., 2019 presents a new loss modeling method that is more suitable for MMC topologies considering the DC arm current bias.

### IGBT Loss Modeling

### Diode Loss Modeling