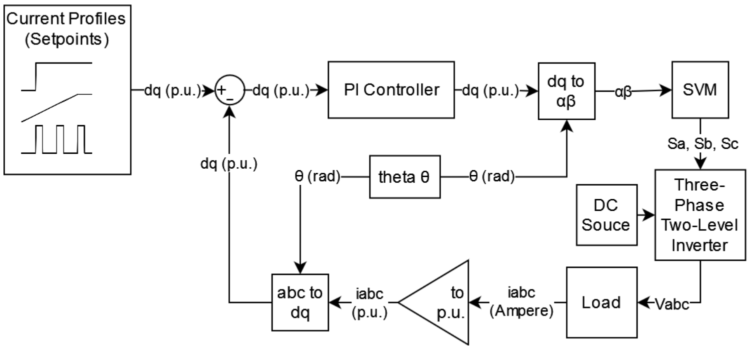
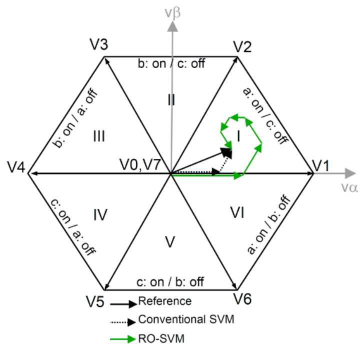
Reliability-Aware Control in an Inverter

This project investigates semiconductor damage in a two-level three-phase inverter, focusing on SiC-FETs and IGBTs in electric vehicle motor control. A control loop was implemented in simulation and reality to assess the impact of current profiles on wear. An optimized Space Vector Modulation (SVM) method showed less damage than the conventional approach.



Overview: Current Control Loop



Conventional SVM versus
Reliability-Optimized SVM

Current Control Loop

This project implements a control loop that includes the setpoints the controller must achieve. The setpoints are current profiles consisting of steps, ramps, pulses, stairs, and rising and falling behaviors. As is typical in controlling synchronous machines, Clarke and Park transformations are applied. The goal of the controller is to minimize the error, which is the difference between the target current and the actual current. A PI controller is used for each dimension of the dq vector. The resulting $\alpha\beta$ vector is used by Space Vector Modulation (SVM) to determine the inverter's duty cycles.

Reliability-Optimized SVM

The Reliability-Optimized Space Vector Modulation (RO-SVM) is a modulation technique designed to improve the reliability and lifespan of semiconductor devices in power converters. Unlike conventional SVM, which causes uneven thermal stress, RO-SVM uses a convex optimization approach to distribute thermal load evenly across switches. In this project, both SVM methods use a switching frequency of 10 kHz.

Conclusion

The analysis of current profiles indicates that gradual changes in current control, such as with a ramp profile, result in minimal damage to semiconductors. In contrast, pulse profiles cause the highest damage. Damage increases when large amplitude changes in current occur at frequencies that allow the semiconductors to cool down but not relax, leading to greater stress from repeated heating and cooling cycles.

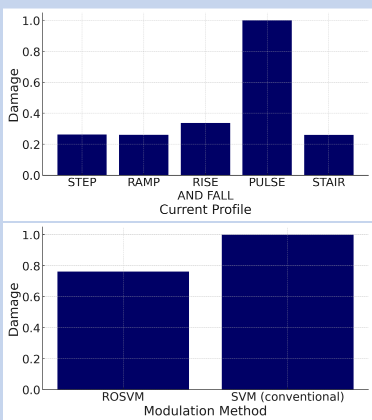
To minimize damage, it is essential to avoid significant changes in the temperature profile and frequencies around 2 Hz. By implementing the RO-SVM, the inverter lifetime can be prolonged by over 20%, as it reduces stress on the semiconductors and optimizes their operation.

Damage Analysis

This section defines damage and explains its estimation. Temperature dynamics were modeled using a fifth-order Foster model. Damage in semiconductors occurs due to temperature fluctuations, causing physical stress. It depends on these variables:

1. Average junction temperature
2. Temperature swings
3. Frequency of temperature changes

The Coffin-Manson equation estimates cycles to failure, and the Rainflow algorithm counts them for damage calculation. The figures illustrate the damage results discussed in the conclusion.



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Repository:
https://github.com/Silas004/P6.git