Concept for a GaN-Based Intelligent Motor Controller with Integrated Failure Prediction for the Inverter and the Drive

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Topic number and topic name: E05 (fits also E06/J05/S01)
>>> Fits the new track on "Intelligent Motion" <<<

Preferred presentation form: Oral presentation

Abstract

Power electronics based on gallium nitride (GaN) or silicon carbide enable more efficient and compact drives for industry and mobility - with particularly demanding requirements for dynamics and reliability. In the joint research project "PowerCare", three Fraunhofer institutes combine their expertise to research a novel, miniaturized motor controller with integrated real-time failure prediction, yielding increased time-to-market for novel power electronics in mission critical applications. The custom controller combines integrated fault prediction for both the inverter electronics and the motor, utilizing a domain-specific RISC-V processor.

This paper gives an insight into the system concepts for modelling the degradation of power electronics and the motor in electrical drive systems. Additionally, opportunities and application scenarios of vertical GaN MOSFETs and intelligent motor controllers are highlighted, and initial development results are provided.

Synopsis

1. Motivation

To get closer to the requirement for absolute reliability of electrical drives and the power semiconductors used to drive them, intelligent controllers require the capability to monitor and interpret the state of the system components in real time. In the internal, strategic research project "PowerCare", Fraunhofer will combine new, highly efficient GaN devices and a multi-channel pulse width modulator (PWM) controller with embedded AI to develop and demonstrate an inverter and motor controller with integrated failure prediction. The failure prediction will cover both the inverter electronics and the motor itself - where feasible, without additional sensors.

The overall solution concept (as depicted in Figure 1) is based on the Institutes' respective background and pre-developments. In the following sections, an insight will be given into the concept development and initial results in the three main target areas of the project:

1. Novel, vertical GaN trench MOSFETs and their behavioral models
2. Embedded AI models for failure prediction of electric motors and GaN power semiconductors
3. Demonstration of GaN MOSFETs and intelligent motor control

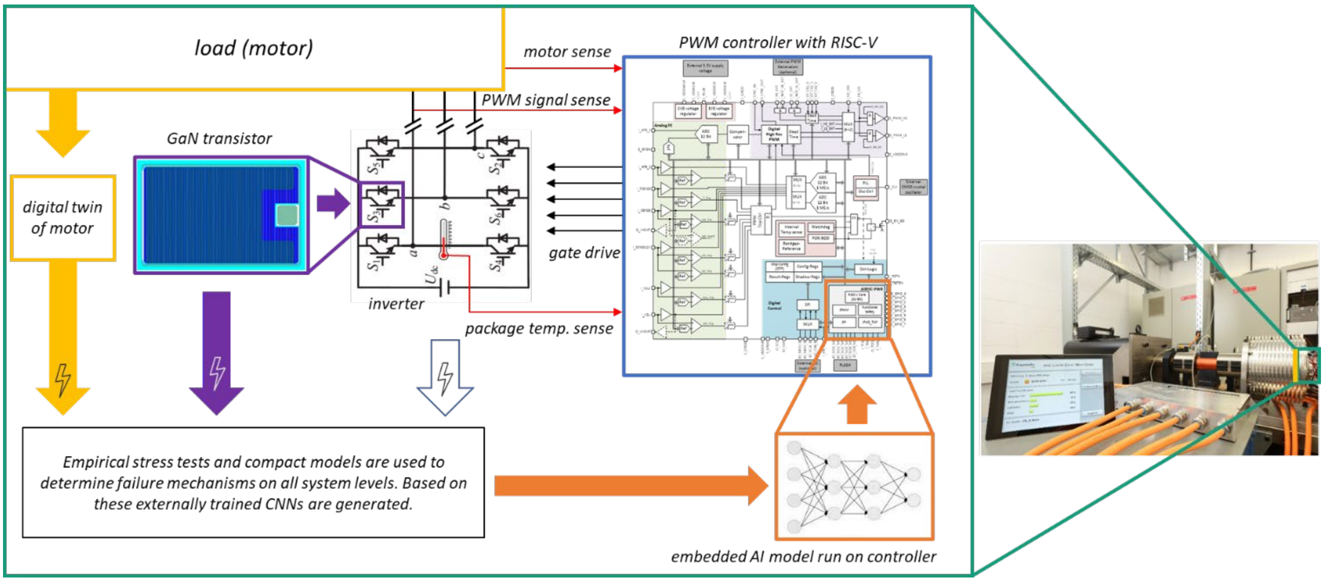

Fig. 1: Solution concept of the “PowerCare” project.

2. Vertical GaN Trench MOSFETs

Besides commercial GaN HEMTs, vertical GaN trench MOSFETs based on ceramic 8” GaN-on-QST substrates will be developed and utilized. While lateral GaN HEMTs are rapidly being adopted in many application areas, vertical GaN is still being scaled to commercial viability, currently focusing on high voltage applications, and its envisaged benefits are still to be verified. Here, a voltage-scalable power device platform is being established, that offers significant area current density, cost and in mid-term inverter efficiency advantages vs. currently employed lateral GaN devices. Discrete components are subjected to reliability and stress tests, assembled into power modules, which are in turn modelled and characterized.

3. Embedded AI Models for Failure Prediction

Failure models for inverters as well as for the connected electric motors are developed and ported to a RISC-V based power module for *in situ* execution.

The basis for the failure models for electric motors is a hybrid motor model consisting of an application-specific pre-processing of the sensor data (e.g., FFT, filtering), a compact model component and a ML-based model, based on the “Cognitive Power Electronics” approach [1]. The model will consider changes in load current and other sensor data (vibration, acoustics, instantaneous rotation rate) that can be observed due to impending failures. Starting with the detection of bearing damage, the development will cover further faults, such as demagnetization or winding faults.

The failure models of the transistors and inverters are developed based on data from life tests and parameter measurements and enable the training of the failure prediction. The failure prediction of the GaN-based semiconductors and inverters will be trained using SPICE-based analogue circuit simulations to keep the generation of larger training sets practical. The calibrated model is then used to predict usage and failure modes in the inverter, which are in turn empirically validated and readjusted.

4. Demonstration of GaN MOSFETs and Intelligent Motor Control

A GaN-based intelligent power module consisting of a power section and an AI section will be built, into which the trained failure models are integrated and executed locally, with the current and sensor data from the inverter and motor serving as input parameters.
A RISC-V based PWM controller [2] will be extended with hardware accelerators for the functions important for the models (e.g., FFT, filtering). The model size and execution speed will be optimized for real-time requirements (e.g., quantization or pruning). For this purpose, a subset of the RISC-V SIMD extension ("P"), a reconfigurable logic part and additional PWM channels will be added to the device to form a three-phase system. In addition, the AI library “AIfES” will be ported to the PWM controller for the inference and on-device training for the execution of hybrid models (e.g., physics guided neuronal networks).

5. Summary and Outlook

It is expected that the research on the three levels described results in a technological leap in the intelligence of power modules, which equally includes the connected electric drive. The actual paper will include initial results from all three research domains.
A first obvious field of application is the monitoring of its own operating status, which is used here for anomaly detection for imminent component failures. A lean, empirically trained AI takes over the interweaving of the complex appearances, which up to now have been realized predominantly by pure threshold value observations of sensors or operating parameters. In the continuation of the approach, it could also be possible to increase the efficiency of the system by dynamically adapting the control of the power module based on the load data recorded in real time.
Regarding potential application scenarios, permanently operated conveyor systems with high demands on system availability and reliability are considered as a first step. Other worthwhile use cases for intelligent drive systems with monitored safety are drones and electric aircrafts, cobots in production and logistics environments, as well as medical robots. In these applications, the new compound semiconductors enable drives with great precision and at the same time compact and low-maintenance designs due to their high maximum switching frequency.

References

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