ArchitectECA2030

SC 2 Demo 2.1 Key Card

Condition Monitoring and Predictive Maintenance of Inverter Power Components

Main aim

- *Implementation of predictive maintenance capability to propulsion system's power electronics components.*
- *Finding robust methods for typical faults progress monitoring of IGBT modules.*
- *Definition of requirements for the implementation of these methods.*

State-of-the-art	Beyond SotA / Innovation	Targeted TRL
• *The predictive maintenance is not a standard feature in the power inverters of electric vehicles.* • *The topic is a subject of academic and industrial research for more than 10 years.*	• *Detailed measurement of electrical quantities on the power components including dynamic behaviour during transient states.* • *Finding robust methods for health status monitoring and fault prediction utilizing electrical measurements.*	• *TRL3 - Methods developed and principles derived for power components health status monitoring. Implementation issues discussed.*

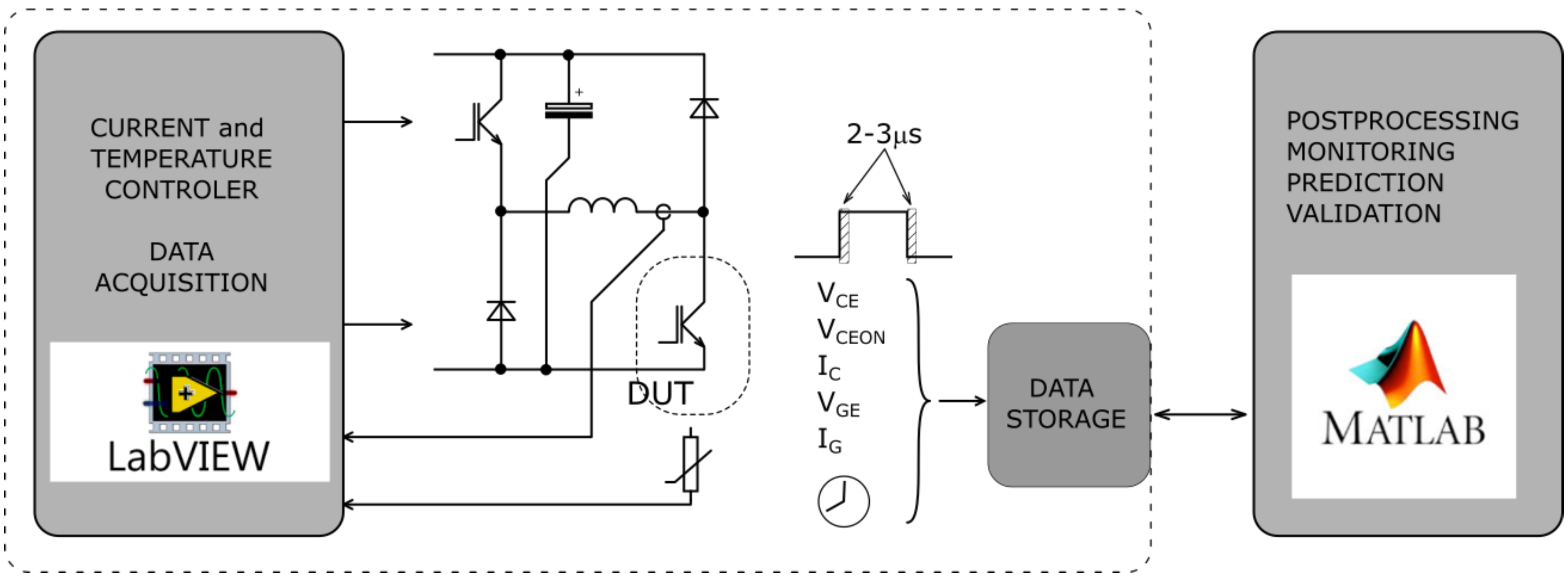
Link to project objectives

Objective	*Addressed (Y/N)*	*How*
O1 – Continuous robust design optimization for each part in the ECS value chain	Y	Monitoring of power module subcomponents from the measurement of electrical quantities inside of the inverter, connection with car decision making.
O2 – Framework for safety validation of ECS value chain	N	
O3 – Identification & management of residual risks over the entire ECS value chain	N	
O4 – End-user acceptance by trustworthy ECS value chain	N	
O5 – Zero emissions, zero crashes, zero congestions by ECA2030-car	Y	Reduction of power module fault probability by fault prediction with the possibility of derating from the upper layer.

Joint demonstrator			Linked supply chains (Y/N)		Considered MonDev layers	
DEM 2.1	**DEM 2.1**	**DEM 2.3**	SC1	N	System (S)	N
			SC2	Y	*Subsystem (SS)*	N
			SC3	N	*Component (C)*	N
			SC4	N	*Subcomponent (SC)*	Y

Setup

A laboratory testbench for accelerated ageing of IGBTs was built like a demonstrator. The key functionalities of the stand are the ability to control the IGBT load/stress and the ability to acquire and store records of external quantities during switching processes. LabVIEW development environment and NI Compact RIO platform were used to realize these real-time functionalities.



Offline tasks related to data analysis, condition indicator development, prognosis methods development and their validation have been realized on the powerful computer in MATLAB environment.

Benchmark scenario/mission/etc.
Trustworthy predictive maintenance methods in power inverters helps prevent propulsion system failures and contributes to lowering residual risks of the powertrain and thus of a whole car.

KPIs (related to requirements)	Baseline
• *Implementation costs*	• *Reasonable complexity and costs of IGBT condition monitoring for final applications.*
• *Scalability to various inverter sizes*	• *Condition indicators should be scalable for various inverter sizes, voltages, and current levels. Model based methods will be considered as an ideal approach. Finding appropriate models for degradation processes is challenging.*
• *Availability of measured data*	• *Signals on the IGBT (V_{CE}, V_{CEON}, V_{GE}, I_G, I_C) during switching-on and switching-off states are considered as the most critical data for further analysis and condition indicators extraction.*
• *Availability of high-level data processing system*	• *The data collected using prepared demonstrator testbench must be comprehensively analysed to select suitable condition indicators.*
• *Trustworthy Remaining Useful Life (RUL) prognosis*	• *Ability to prognose monitored faults with reasonable prediction horizon. Reasonable prediction horizon means sufficient time range to make acceptable preventive actions leading to avoiding or postponing of the fault.*

Evaluation

Independent lifelong test runs on a testbench, and verification of RUL prediction based on realized experiments and developed methods.

Current status/demonstration

Testbench for IGBT modules accelerated ageing has been designed and built/assembled and equipped with control and data acquisition system already in 1st monitoring period of the project.

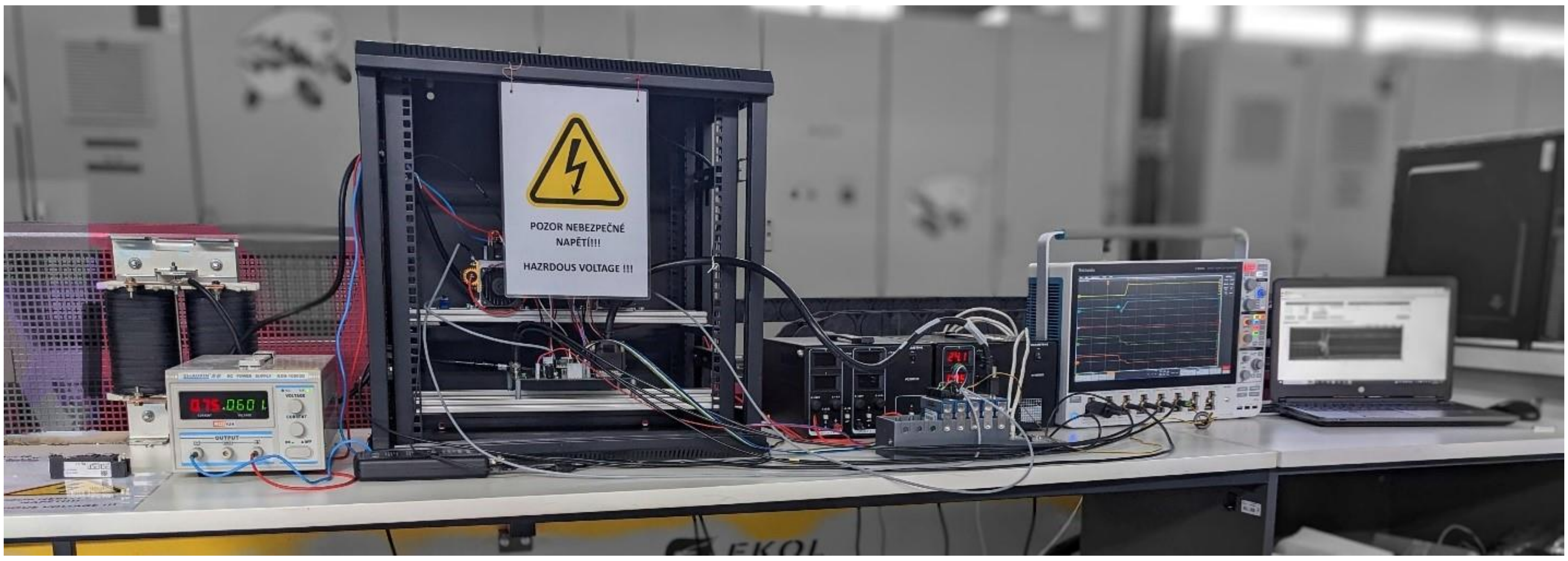


Fig. 1. The testbench setup for accelerated ageing tests of IGBT modules

The complete control and data acquisition software has been developed in the 2nd monitoring period. The key modules of the software are following:

- *Feedback controller*
- *Load generator*
- *Acquisition control and synchronization module*
- *Data management*
- *Oscilloscope control library for LabVIEW*

Fig. 2. Example of the testbed control application screen

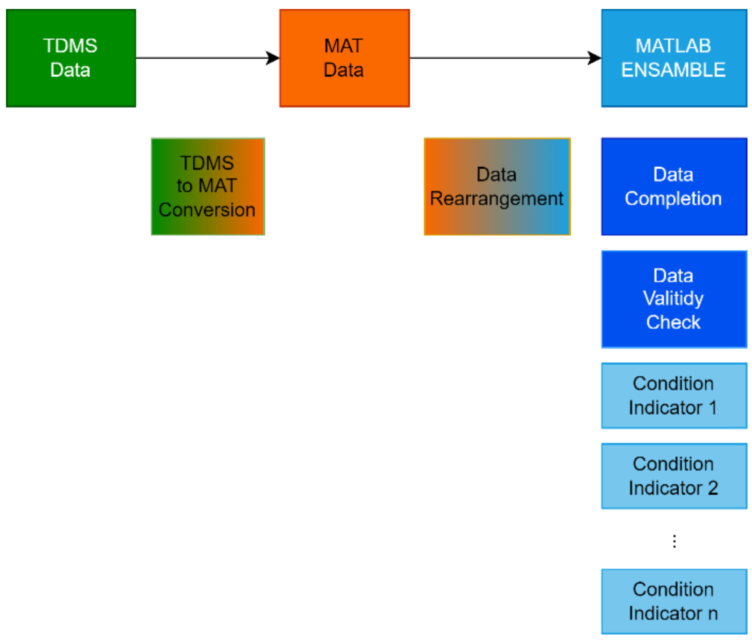


Fig. 3. Flowchart of data processing and analysys

- *Multiple tests were performed with successful data acquisition in 3rd monitoring period. There were multiple types of performed tests: constant load test (propagating die solder joint corruption fault), power cycling test (bond-wire lift-off fault propagation) and thermal sensitive parameters measurement.*
- *The acquired data were processed in the MATLAB environment (converting, timestamping, sorting, pre-processing). Some features have been extracted; others can be easily added in the developed framework.*
- *V_{CEON} condition indicator has significantly changing trend at the end of the accelerated lifetime test under constant load condition. The trend approximation of the V_{CEON} can be seen in the figures bellow for 800, 300 and 0 minutes before the transistor damage.*

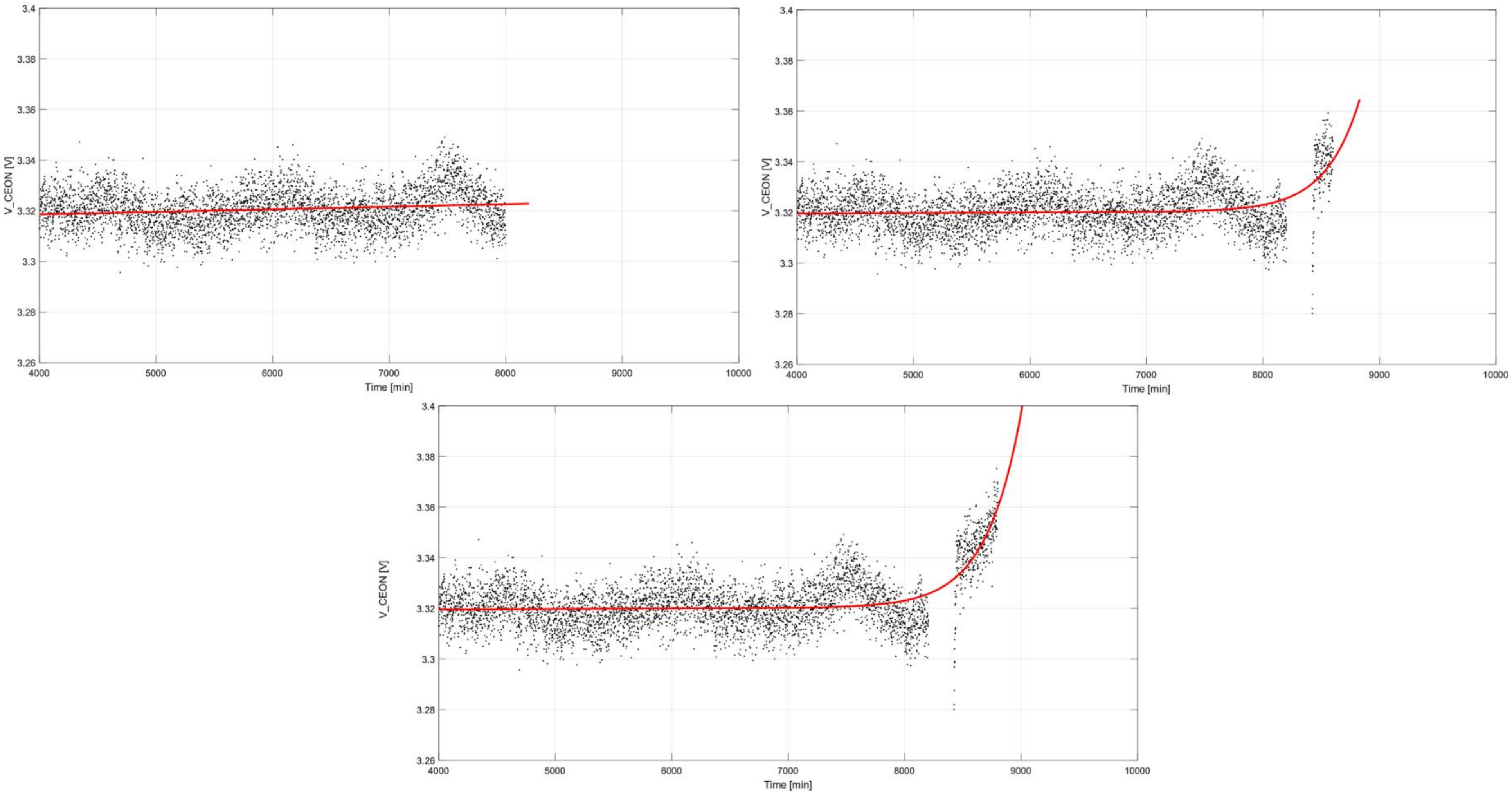


Fig. 4 V_{CEON} condition indicator data during accelerated tests and its approximation 800 and 300 minutes before transistor damage and at the end of the transistor life.

Highlights and conclusions

- *The ability of several condition indicators based on measurement of electrical quantities to assess the health of an IGBT module and for RUL estimation was explored.*
- *Collector-emitter on state voltage V_{CEON} and switching off time t_{OFF} were selected as good candidates for in depth analysis. Both condition indicators were able to detect the failure of the tested IGBT module. However, their performance varied quite significantly. V_{CEON} changed its value significantly, while t_{OFF} changed only marginally (in tenths of nanoseconds).*
- *V_{CEON} reacted to the degradation in health of the transistor roughly 200 minutes before the transistor failure. Longer prediction horizons were tested as well; however, the ability of the method to precisely predict RUL degraded significantly.*

Impact

Ability of early faults prediction in power inverter allows efficient maintenance actions planning and lowering risk of failures of the propulsion system.

Used standards	Future standardization potentials
• *ISO 26262 - Road vehicles - Functional safety* • *IEEE Std 1856TM-2017 - IEEE Standard Framework for Prognostics and Health Management of Electronic Systems* • *ANSI/UL 4600 (2020) - Standard for Evaluation of Autonomous Products*	• *Not perceived yet.*

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