E-VOLVE Cluster: Increasing Innovation Efficiency to Support the Transition Toward Sustainable e-mobility

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Abstract. The transition to e-mobility is disrupting the automotive market. To facilitate this transition, the European Commission with the support of the 2ZERO partnership is calling for experts to engage in collaborative R&D programs, and develop pre-competitive solutions and methodologies supporting the uptake of e-mobility. The target of this paper is to provide an overview of the granted European projects running under the umbrella of the E-VOLVE cluster, illustrating the complementarity of the different initiatives as well as their coverage of the main priorities as defined by ERTRAC. The focus is set on the targets and outcomes of the projects HiPE, HighScape, RHODaS, SCAPE, EM-TECH and Multi-Moby, addressing innovative components (power electronics, e-motors), advanced control strategies, and circularity for safe, efficient, affordable and sustainable e-mobility.

Keywords: e-mobility · power electronics · e-machine · sustainability

1 Introduction

Undoubtedly, the transition to e-mobility is one of the most important trends in the automotive domain to address the societal challenge to drastically reduce emissions (Paris Agreement [1], European Green Deal [2]). All European carmakers are strongly committed to the uptake of e-mobility – the number of electric vehicle models launched

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and planned is rising from 50 models in 2018 to >250 in 2025 [3]. This trend is further confirmed by the market share of battery electric cars that almost doubled to ~10% in 2021 [4]. The automotive sector is looking for: (a) technology solutions able to address the changing users and market needs; (b) increased user acceptance for e-mobility through affordable, energy efficient systems implementing innovative and holistic user-centric solutions providing high comfort and safety; (c) agility and first mover advantage through accelerated design and testing methodologies; and (d) sustainable technologies to minimize the environmental footprint throughout the entire lifecycle of the vehicle (production, operation including charging, end-of-life). In this context, the E-VOLVE (Electric Vehicle Optimized for Life, Value and Efficiency) cluster [5] explores and exploits synergies between European projects launched within the 2ZERO program. This paper presents the ongoing projects and discusses the complementarity of these approaches to support the uptake of affordable, sustainable and user-centric e-mobility, while strengthening European competitiveness.

2 The Collaborative Projects

2.1 HiPE

The HiPE project aims to develop a new family of highly energy efficient, cost-effective, modular, compact and integrated wide bandgap (WBG) power electronics solutions for the next generation of battery electric vehicles (BEVs). The projects outputs will include (a) a scalable and modular family of WBG-based traction inverters with significantly improved specific cooling performance, suitable for 400 V, 800 V and 1200 V applications, with power ratings from 50 to 250 kW, integrated into electric drives including the high-to-low voltage (HV/LV) DC/DC converters, thus enabling drastic size and weight reductions; (b) a family of integrated WBG-based bidirectional on-board chargers (OBCs) and HV/LV DC/DC converters, with optimized innovative topologies, including use of Gallium Nitride (GaN); and (c) integrated, fault-tolerant and cost-effective GaN-based power electronics for high-voltage ancillaries and chassis actuators. The HiPE smart power electronics solutions will include intelligent and predictive controllers to optimize performance, innovative and computationally efficient data-driven approaches to monitor the state-of-health of the relevant hardware, as well as novel self-adaptive digital-twin-based methodologies to tailor the component- and vehicle-level algorithms to the specific condition of the hardware installed on each individual BEV, and actively improve reliability and availability of the electronic parts during field use. For this, four experimental Use Cases (UCs) were developed covering the HiPE outputs: UC1: Integrated WBG-based traction inverters, HV/LV DC/DC converters and electric motors for high volume passenger vehicle up to 150 kW; UC2: Integrated WBG-based traction inverters, HV/LV DC/DC converters and electric motors for light commercial vehicles; UC3: Integrated WBG-based on-board chargers and HV/LV DC/DC converters; UC4: Integrated and fault-tolerant power electronics for ancillaries and chassis components.

2.2 HighScape

HighScape envisions a series of research and innovation activities to develop, test, and validate innovative solutions for next-generation BEVs that can only be achieved through the latest wide bandgap (WBG) technologies. HighScape will focus on BEV architectures with distributed multiple wheel drives and, in particular, in-wheel direct drive powertrains, and will explore the feasibility of a family of highly efficient, integrated, compact, low-cost, scalable, and modular power electronics components and systems, including integrated traction inverters, on-board chargers, DC/DC converters, and electric drives for auxiliaries and actuators. The proposed solutions will achieve automotive quality levels with robust and reliable functionalities that will be evaluated and validated on test benches and on two differently sized BEV prototypes. The project will lead to the following results: (a) component integration at a level not achieved before, e.g., with the installation of the WBG traction inverters in the in-wheel machines; the functional integration of the traction inverter with the on-board charger, and the integration of the latter and the DC/DC converters in the battery system; and the implementation of multi-motor and fault-tolerant inverter solutions for the auxiliaries and chassis actuators; (b) implementation of reconfigurable winding traction drive topologies, and integrated and predictive thermal management at the vehicle level using phase changing materials in the power electronics components; (c) achievement and demonstration of significantly higher power densities, specific powers, and energy efficiency for the resulting power electronics systems and associated drives; (d) significant cost reductions over the current state of the art due to dual use of parts, modularity of subsystems, and model-based design to avoid over-engineering; and (e) increased reliability of power electronics systems, enabled by design and intelligent algorithms for predictive condition monitoring.

2.3 RHODaS

The objective of the RHODaS project is to develop disruptive high-power modular power inverter topologies for e-axle Integrated Motor Drive (eIMD) to be used in all-electric heavy-duty long-haul vehicles over 12 tonnes. RHODaS uses new WBG semiconductor materials as well as cutting-edge digital technologies to improve architectural efficiency, power density, reliability, cost, and sustainability, to develop a high power SiC – GaN hybrid power inverter up to 250 kW/1000 V. RHODaS's main contributions are: (a) development of hybrid high-power T-Type multilevel inverter topologies, up to 150 kW/250 kW rated/peak power. The volumetric and gravimetric densities of the power converter are expected to be 100 kW/l and 50 kW/kg respectively; (b) study of components and advanced thermal management strategies. The advanced thermal management system can extend working temperature ranges up to 150 ºC using combined air-liquid solutions; (c) assembly of the converter coupled to the motor casing. This assembly will increase the power density of the traction drive up to 33 kW/L; (d) ensure the sustainability of the designed converter and its components throughout its life cycle; (e) integration of analogue and digital drivers with the high voltage WBG materials, including protections and fault detection circuits; (f) development of new control and modulation techniques to reduce switching losses and total EMIs, while improving reliability and control; (g) integration of new sensor networks at the material, component and system level to provide real-time data for remaining useful life (RUL) prediction's accuracy of 75%; and (h) development of integrated and modular IMD designs to be applied in "multi-axle traction" concepts for heavy-duty long-haul trucks.

2.4 SCAPE

The SCAPE project proposes a standardisable, modular, and scalable approach for the design of the BEV power conversion system, based on multilevel neutral-point-clamped power converters. This approach has a great potential to reduce the cost of BEV power electronics thanks to scale economies, suitable for a wide range of BEV applications (from two-wheelers to heavy-duty vehicles), to allow to take full advantage of chip-embedding (CE) board integration technology, and to enable advanced functionalities such as online diagnosis, digital twin, and predictive maintenance. The SCAPE expected outcomes are: (a) EV power electronics cost decrease by 30–40%, achieved through the combination of economies of scale, CE, reduced weight, less design expenses, and better reliability of the system; (b) powertrain losses reduction by at least a 35%, and specific-power figures beyond 30 kW/kg and power-density beyond 100 kW/litre, thanks to the higher efficiency of the multilevel converter topology, the higher performance and compactness offered by CE technology, the reduced need of heat dissipation, higher switching frequency (reduced size of passive power filters), and the advanced control strategies; (c) advanced converter designs featuring an integration of the traction inverter and the on-board charger, allowing to further reduce the power electronics volume and cost; (d) modular and flexible design provided by the use of interconnected building blocks, and CE technology that can be adapted to any available space and shape within batteries, or coupled to electric motors yielding a highly compact system; and (e) monitoring system integrated within the building block, which provides information to an advanced control system linked to a digital twin to enable optimal operation with increased lifetime and early detection of failures. In addition, the SCAPE powertrain inverter topology is inherently fault-tolerant and can remain in operation after the failure of one or more building blocks. The SCAPE outcomes will be validated with a prototype of the integrated inverter/OBC and the auxiliary DC/DC converter in a relevant environment. The prototype is based on the use case of a medium-size battery electric car, with 100 kW of power and 800 V traction battery.

2.5 EM-TECH

EM-TECH brings together 10 participants from industry and academia to develop novel solutions that push the boundaries of electric machine technology for automotive propulsion through: (a) innovative direct and active cooling concepts; (b) virtual sensing for the high-fidelity real-time estimation of the machine's operating conditions; (c) improved machine control that brings the design and operating cost savings enabled by (b); (d) electric gearing to improve operational flexibility and energy efficiency; (e) digital twin-based optimization that incorporates the systematic consideration of life cycle analysis and life cycle cost aspects from the early design stages; and (f) use of recycled permanent magnets and circularity solutions. The proposed innovations will be implemented in a new series of radial flux direct drive in-wheel motors, featuring unprecedented torque density and specific power (>150 Nm/litre, >50 Nm/kg), as well as in ironless axial flux machines with one stator and two rotors, offering power density and specific power above 30 kW/litre and 10 kW/kg. The solutions will be suitable for both car and van applications (continuous powers of 50 kW–120 kW), will offer competitive costs (<6 Euros/kW for a production of 100000 units/year), and will lead to a significant reduction of the energy losses of the motor during real vehicle operation (>25%), as well as to >60% reduction of rare earths, including magnet recycling solutions. EM-TECH will also support the development of European leadership in key digital technologies and the development of the corresponding value chains.

2.6 Multi-Moby

Multi-Moby is an elaborate project, using recent developments and results from a series of ongoing and past EU Horizon projects, to generate new technologies for safe, efficient and affordable urban BEVs. The Multi-Moby BEVs consist of vans, pick-ups, and passenger vehicles, which share the same Super High Strength Steel body frame, manufactured in a microfactory based on low-investment and lean processes. Despite their low cost, the Multi-Moby BEVs have excellent passive safety characteristics, verified with crash test experiments. The vehicles are further enhanced with vehicle-to-everything (V2X) based active safety controllers, e.g., pre-emptive braking, pre-emptive traction control, and pre-emptive antilock braking system (ABS) functionalities. In addition, Multi-Moby has assessed newly developed gimbal-based camera systems for environmental detection, as a low-cost alternative to lidars and radars for automated driving solutions. The Multi-Moby BEVs are 4-wheel-drive, consisting of two on-board centralised powertrains with 100 V and 48 V powertrain options (with corresponding battery pack voltages). This includes newly developed 15 kW (per axle) 100 V permanent magnet assisted synchronous reluctance motors (PMaSRM), or 9.5 kW (per axle) 48 V powertrains with belt transmissions. Besides the 100 V and 48 V battery pack options, a novel 48 V hybrid supercapacitor-battery pack with cylindrical cells has been developed. The hybrid supercapacitor-battery cells combine the high-power density of supercapacitors with the high energy density of batteries. Fast charging is provided by a novel 7 kW DC wall box charger, based on the latest generation of SiC-based MOSFETs which can reduce charging losses.

3 Addressing the ERTRAC Research Needs

Figure 1 provides a mapping between the "research needs for powertrain" according to the European Road Transport Research Advisory Council (ERTRAC) [6] and the initiatives introduced in this paper. Clearly, all projects address "modelling and simulation" as well as "advanced components, materials and processes" – which are the core of the calls addressed by the projects in the E-VOLVE cluster. Furthermore, environmental sustainability is a key research topic for most of the projects. Still, each project has its own specificity by addressing different BEV systems and different application domains. Summarizing, the projects represented in the E-VOLVE cluster are highly complementary to cover the European vision toward zero emission road transport.

	Research Need for Powertrains	HiPE	HighScape	RHODaS	SCAPE	EM-TECH	Multi-Moby
Method.	Modelling and simulation	X	X	X	X	X	X
	Connectivity and data management						X
	Recycling, Materials for New Powertrains			X		X	
	Availability / Sustainability of resources	x	x	x	X	X	
BEV	Advanced Components, Materials and Processes	X	X	X	X	X	X
	Connected and AI-based systems		X			X	X
	System approach, vehicle integration	X	X				X
	Safety test procedures and technologies						X
	Charging technologies (bidirectional, comfort-charging, robotic)		X				X
	Battery Swapping technologies						
	Data acquisition and AI supported development						
	Implementation of eco-design principles			X	X	X	
Appl. domain	Light electric vehicle				x		X
	Passenger cars	X	X		X	X	X
	Light commercial vehicles				x	x	X
	Heavy-duty			X	x		

Fig. 1. E-VOLVE projects coverage regarding the ERTRAC roadmap [6] - Image courtesy of E-VOLVE cluster, reproduced with permission.

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