Bridging Ecosystems for

European Technological Advancement

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1 Executive summary

The purpose of this deliverable, D3.9, is to describe the components that have been selected for the heat pump and converter electronics and circuits. The requirements for each demonstrator are shortly summarized, then the selection of the components is described in detail.

2 Introduction & Scope

2.1 Purpose and target group

The purpose of this deliverable, D3.9, is to describe the components selected for the heat pump system and the power converter electronics and circuits. The requirements of each demonstrator are first briefly summarised, followed by a detailed presentation of the component selection and the rationale behind the design choices.

This deliverable is primarily addressed to Technology, Hardware (HW) and Software (SW) providers, including semiconductor and power electronics vendors, industrial energy and infrastructure HW/SW suppliers, IoT hardware providers, and system integrators. In addition, Energy and Infrastructure service providers and Cynergy4MIE project reviewers are targeted, as the document supports the assessment of component selection, system integration, and alignment with the project objectives.

2.2 Contributions of partners

Chapter	Partner	Contribution
3.1	PRODRIVE & TU/e	Input from WP1, WP2 and WP3 and component description for D6.1
3.2	ITRI & RECHI	Input from WP1, WP2 and WP3 and component description for D6.2
Rest	TU/e	Document setup

2.3 Relation to other activities in the project

The content of this deliverable is closely related to the work done by members of SC6 in other work packages, like WP1, WP2 and WP4.

3 Description of the technical work

In this section the requirements of the two demonstrators are shortly summarized. Afterwards the architecture is detailed. Lastly, the most important components are highlighted and why they were chosen.

3.1 Demonstrator 6.1 - Power converter for green hydrogen

3.1.1 Summary of requirements

In demonstrator 6.1, the partners will apply SiC technology and a modular design approach in the development of a new rectifier system. The high switching frequency of the more efficient SiC MOSFETs, combined with a multi-step converter layout, will allow for a flexible voltage output range suitable for all electrolyser types and all project scales. Additionally, the higher frequency will decrease the grid disturbance, allowing for unlimited system scalability and no external filtering. To maximize the system performance, commonality and ease-of-maintenance, a modular system is chosen of 200 kW rectifier modules. All modules will have integrated control in such a way that they can operate in any given configuration while maximizing overall system performance. At the same time TU/e will investigate the reliability of GaN HEMTs. This information is required to assess whether GaN is a suitable successor of SiC MOSFETs for hydrogen rectifier systems.

Requirement ID and main category	Requirement type	Use case	Priority	Description	Rationale
F1.6.1	Functional suitability	Bulk hydrogen production	High	Modular system with optimized control methods for maximum system performance	Scalable rectifier suiting all potential hydrogen production system configurations
NF1.6.2	Performance	Bulk hydrogen production	High	Overall system efficiency > 97%	Decrease losses in power conversion
NF1.6.3	Performance	Bulk hydrogen production	High	High grid quality and grid stability	Large systems must not disturb local power grids, even on GW-scale
F1.6.4	Functional	GaN degradation testing	High	Simulate realistic inductive hard switching conditions at least 3x rated DUT peak current and at full DUT voltage rating (600 V)	Accelerated degradation only makes sense if the degradation is relatable to realistic conditions
F1.6.5	Functional	GaN degradation testing	Medium	Test at least 10 switches at the same time	A large sample size is required for statistical significance
F1.6.6	Interface	GaN degradation testing	Medium	Modular device interface such that multiple device types and footprints can be tested	Testing various devices is valuable and requires a modular interface.
F1.6.7	Interface	GaN degradation testing	High	Interface support for static device analyser like the Keysight B1500A	A device analyser allows for accurate analysis of static parameters during

					and after the degradation cycle
F1.6.8	Functional	GaN degradation testing	High	Automated device parameter analysis	To allow for analysis of parameters during degradation testing
NF1.6.9	Reliability	GaN degradation testing	Medium	Allow for continuous unsupervised testing during at least three days	Better test accuracy and lower labour intensity

- The rectifier demonstrator is to be realized and validated in a lab environment
- Based on 1200 V SiC MOSFETs with high switching frequency, increased efficiency and integrated filtering
- 200kW rectifier module with flexible Vout (0-1500 V)
- Decentralized integrated control based on I/O connection to overall system
- Integrated water cooling
- Test venue – lab environment of TU/e has many facilities

3.1.2 Architecture

The architecture can be summarized as follows:

Figure 1 presents the high-level system architecture for a single rectifier module. The module is a two-step SiC-based converter for optimized efficiency, with an AC/DC rectifier step and a DC/DC conversion step to allow for a flexible output voltage. Additionally, the module will feature integrated filtering, control, and cooling, to allow for a low THD and low output ripple.

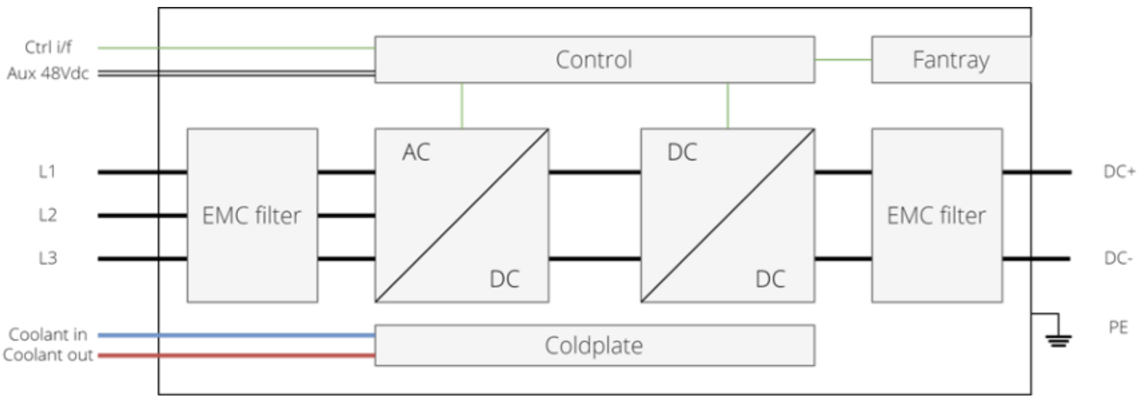

FIGURE 1: ARCHITECTURE OF A SINGLE RECTIFIER MODULE

3.1.3 Components of the demonstrator

In the current design, some of the chosen components include the following:

3.1.3.1 Component 1 – 1200V SiC MOSFETs

For the rectifier, the core of the design revolves around 1200V SiC MOSFETs. The reason for this is the fact that they are widely available, as they are also used in the automotive industry, therefore securing a steady supply chain. Furthermore, the high switching frequency allows for very accurate control over the output of the system, as well as the effect on the grid connection for bulk rectification. SiC also offers higher efficiency and allows for the use of smaller passives in the system.

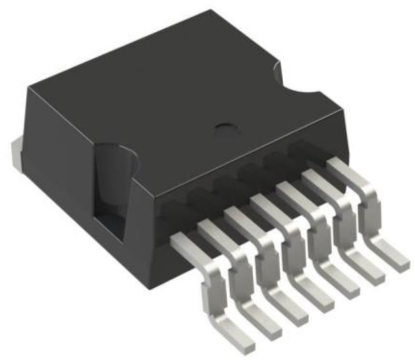

FIGURE 2: SELECTED SIC MOSFET

3.1.3.2 Component 2 - Inductors

The widebandgap switched waveforms of the rectifier are required to be filtered by high current inductors. These inductors have specific requirements to be soft-saturating and remain inductive at high biasing currents. For this, a custom edge-wound concept is chosen which uses powder cores to optimize the power density.

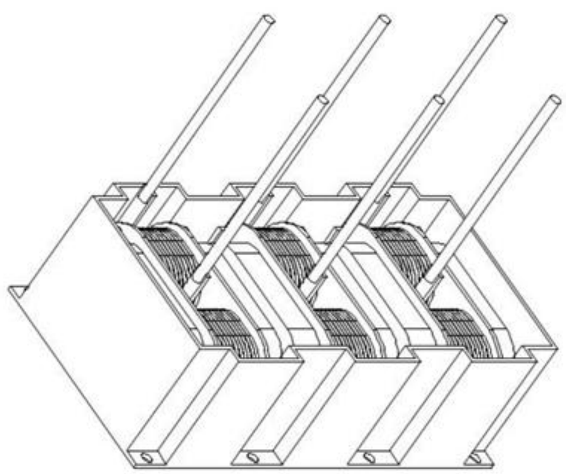

FIGURE 3: DRAWINGS OF THE DESIGNED INDUCTORS

3.1.3.3 Component 3 - GaN Device Under Test (DUT)

The selection of the DUT is crucial for the design of the degradation setup. One of the requirements specifies the test current as 3x the peak current rating of the DUT. If a DUT is chosen with a high peak current rating, then the setup needs to have a three times higher current rating. Therefore, the device with the lowest peak current rating is selected. Furthermore, to be able to relate the results to the hydrogen rectifier application high voltage devices must be chosen.

FIGURE 4: GAN SYSTEMS GS-065-004-1-L HEMT THAT IS SELECTED AS THE DUT

3.1.3.4 Component 4 – Degradation setup current biasing switch

In the GaN HEMT degradation setup, a circuit is required to bias the GaN DUT at a set current. This circuit needs to be much more reliable than the GaN DUT. Therefore, a SiC MOSFET and Schottky diode have been selected with current ratings that are much higher than those of the DUT. SiC has been chosen as it is a more mature technology that is known for its higher robustness. The selected components are the Infineon IMTA65R060M2H and the Infineon IDL10G65C5.

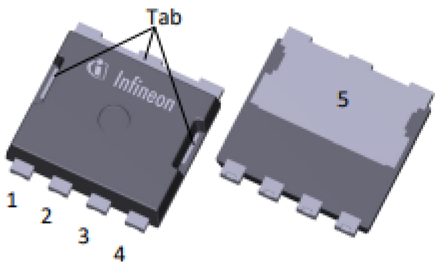

FIGURE 5: RENDER OF THE SIC BIASSING MOSFET

3.2 Demonstrator 6.2 - Heat pump water heater and air conditioner

3.2.1 Summary of requirements

Monitoring international market trends and developments in the application of various refrigerants reveals a growing interest in R-290 due to its favourable thermodynamic properties. The primary advantage of R-290 lies in its exceptionally low Global Warming Potential (GWP = 3). This characteristic aligns with low-carbon and sustainability goals, positioning R-290 as a highly promising energy-efficient alternative refrigerant. In addition, to ensure that the heat pump system developed in this demonstrator meets the operational conditions of the European Union, the project references the testing conditions for air-to-water heat pumps established by the European Heat Pump Association (EHPA) to define its working conditions.

Based on the above, demonstrator 6.2 aims to develop a mobile intelligent high-efficiency heat pump system with a rated power of 10 kW, utilizing the environmentally friendly refrigerant R-290 (GWP =

3). The system integrates cooling, heating, and hot water functionalities, achieving a coefficient of performance (COP) greater than 2.0.

The target operating conditions for this demonstration are as follows:

(1) Develop an R-290 heat pump system using low-GWP eco-friendly refrigerant (GWP = 3) to replace high-carbon-emission oil and coal-fired heating equipment.

(2) Features portability, modular design, and the ability to simultaneously provide cooling, heating, and hot water.

(3) Under an outdoor dry-bulb temperature of -15 °C, with an inlet water temperature of 2 °C, the outlet water temperature shall reach 55 °C while maintaining a coefficient of performance (COP) ≥ 2.

(4) Under an outdoor dry-bulb temperature of 7 °C, with an inlet water temperature of 9 °C, the outlet water temperature shall be 55 °C with a heating capacity exceeding 10 kW, coefficient of performance (COP) ≥ 3.4

Requirement ID and main category	Requirement type	Use case	Priority	Description	Rationale
F1.6.10	Function	Heat Pump Systems	High	Successful system component integration and modular design. The system could provide cooling, heating, and hot water.	Provide versatile heating and cooling solutions for different operating environments.
F1.6.11	Function	Heat Pump Systems	High	Achievement of system portability, modular design.	Efficient and affordable heat pump system suitable for extreme weather conditions.
F1.6.12	Function	Heat Pump Systems	High	Low-GWP (GWP = 3) R-290 refrigerant-based heat pump system to replace high-carbon-emission oil and coal-fired heating equipment.	Reduced emissions from heating systems.

3.2.2 Architecture

The heat pump system will comprise a refrigerant loop and a cold/hot water loop, with both loops interconnected to facilitate energy transfer, thereby ensuring the system's cooling and heating capacities under varying environmental conditions.

The system will adopt R-290 as the refrigerant, with the R-290 compressor serving as a key component for refrigerant circulation. Simultaneously, multiple components, including heat exchangers, expansion valves, and gas-liquid separator, will be implemented. The high-temperature, high-pressure refrigerant gas discharged from the compressor will provide heating energy by flowing through the hot water double-pipe heat exchanger. Likewise, the refrigerant liquid exiting the expansion valve will provide cooling energy by flowing through the cooling water double-pipe heat exchanger.

As for the water circulation, the water loop will be designed to incorporate water pumps, double-pipe heat exchangers, and a system control mechanism to regulate water circulation in response to diverse operational demands. Additionally, water storage units corresponding to cold and hot water will be established, while an indoor unit will be integrated into the water loop to supply heating and cooling. To prevent the risk of freezing in sub-zero conditions, ethylene glycol will be employed as the cooling water medium.

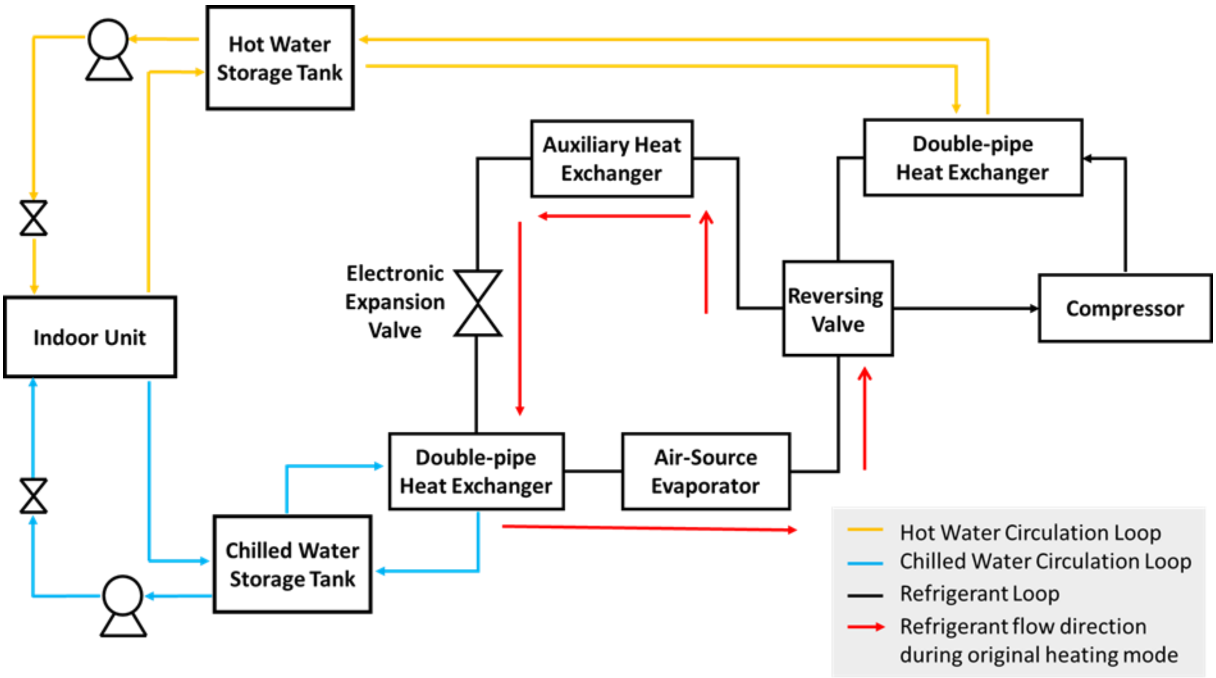

FIGURE 6: THE ARCHITECTURE OF THE HEAT PUMP SYSTEM

3.2.3 Components of the demonstrator

The overall heat pump system comprises several key components, which are detailed as follows.

3.2.3.1 High-efficiency R-290 Compressor

The compressor serves as the core technical component of the heat pump system loop. To accommodate the application of low-GWP refrigerants, such as R-290, the compressor design—including the compression mechanism and motor configuration—focuses on achieving high energy efficiency, low noise operation, and high reliability.

FIGURE 7: THE SCHEMATIC DIAGRAM OF THE COMPRESSOR

3.2.3.2 Drive and Control System Module

To meet the system's cooling and heating demands, the arrangement of key system components, combined with comprehensive system control, enables operation under various modes, including cooling cycle, heating cycle, defrost cycle, heat pump cycle, chilled water cycle, and combined operation modes. Additionally, the system modules are equipped with protective mechanisms that adjust operation in real time based on temperature and pressure conditions. On the other hand, the compressor control board is planned to incorporate detection functions, including speed control feedback, temperature feedback, and voltage/current feedback.

4 Conclusion

4.1 Contribution to overall picture

This document describes the architecture and the most important components of demonstrators D6.1 and D6.2. Furthermore, the rationale behind the component decisions is detailed.

4.2 Impacts to other WPs, Tasks and SCs

Partner/Topic	Description
WP4	PRODRIVE: the architecture described in this document is used as an input for the development of the firmware of the converter which is part of WP4. ITRI: The system control and operation logic will be developed based on the system architecture and component configuration.
WP5	PRODRIVE: the chosen components and architecture will be used during the system integration part of WP5. TU/e: the methods and models created in WP3 will be integrated into the demonstrator in WP5. ITRI: The architecture and control operation logic established in WP2 and WP4 will be combined and executed in WP5. RECHI: The key components developed in WP3 will be applied in system loop and integrated into the demonstrator.

4.3 Contribution to demonstration

Partner/Topic	Description
D6.1	The content of chapter 3.1 describes the used components for D6.1
D6.2	The content of chapter 3.2 describes the used components for D6.2

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