ENERGY CONTROL OF A SELF-SUFFICIENT MICROGRID BASED ON A COMBINED ELECTRICAL AND HYDROGEN DISTRIBUTION GRID

M.Sc. David Stephan, Prof. Dr.-Ing. Uwe Werner, Prof. Dr.-Ing. Carsten Fichter

University of Applied Science Bremerhaven, Institute for Automation- and Electrical Engineering (IAE), An der Karlstadt 8, 27568 Bremerhaven, Germany, +49 (0)471/4823308, dstephan@hs-bremerhaven.de, https://www.hs-bremerhaven.de

Abstract: This article presents the operating and control structure of the microgrid at Bremerhaven University of Applied Sciences. The microgrid is used for self-sufficient energy supply and consists of a combination of a power distribution network and a hydrogen network. These distribution grids provide the basis for sector coupling within the microgrid. Capable of generating, storing, and converting green hydrogen back into electricity, the microgrid will be powered primarily by renewable energy. The microgrid connects electricity with gas sector and heating sector. The fitted electrolyser and the fuel cell bridge the gap between the electricity and gas sectors. In contrast to an island grid, the microgrid can be operated parallel to the grid. Electrical energy can also feed in higher-level power grid. The correlating challenges of different energy flows and the overall view of a regulated microgrid based on a power grid and an H_2 gas pipeline system are the content of this publication.

Keywords: hydrogen, microgrid, green energy, renewable energy, rotating converter, DC, AC, energy management,

1 Introduction

The distribution and storage of electrical energy as part of a combined microgrid will play an increasingly important role in the future energy supply for the reduction of CO_2 greenhouse gas emissions. A purely capacitive grid expansion in Germany is just one piece of the puzzle for the energy transition. One way to move away from the central control of the power grid towards a decentralized topology of the power grid with intelligent control units. With an increasing share of renewable, decentralized electrical generator units, such as photovoltaic or wind power plants, site-specific stand-alone grids that act as microgrids can make an important contribution to grid-friendly supply stability in the energy mix. Excess electricity can also be more variable and better regulated at the smallest site-related level. The grid fluctuations from the microgrid decrease steadily via the distribution grid to the transmission grid. The microgrid can also be used as a self-sufficient system for regional district supply. Microgrids are self-sufficient supply areas that have special operational requirements and a connection to the public power grid. In the context of this article, the microgrid forms the interface between the power grid and the grid with a gaseous energy carrier, which is mainly based on hydrogen (Figure 1). Due to the strongly fluctuating energy production from renewable energies and the fact that these cannot be stored in the electrical grid, a storage media is required that is easy to handle. The basis for this paper is the ERDF project "Wasserstoff – grünes Gas für Bremerhaven".

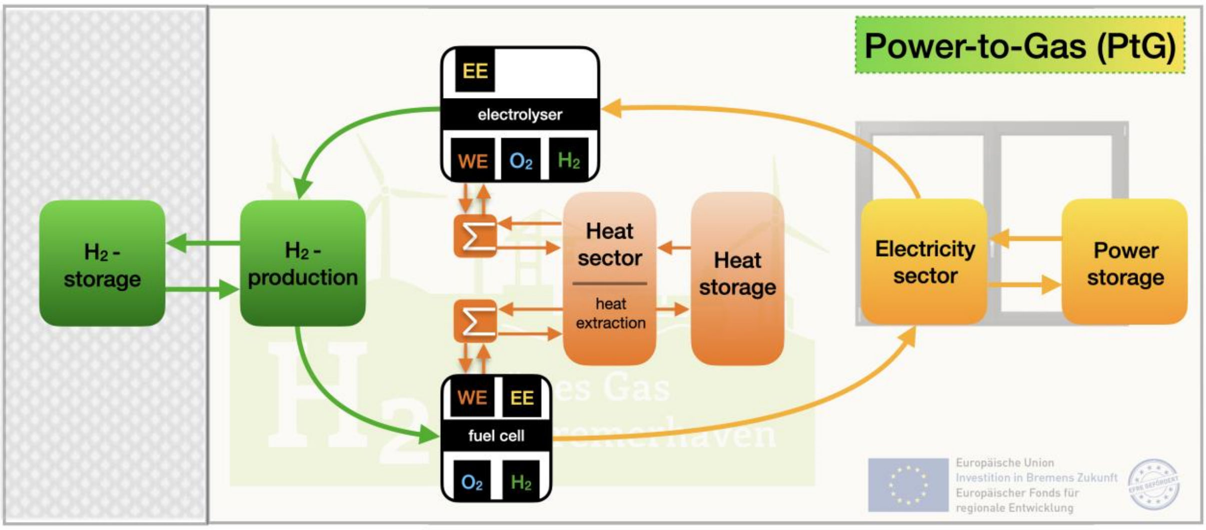

Figure 1: Sector coupling of the microgrid supply container at the Bremerhaven University of Applied Sciences

2 System structure of the microgrid

The microgrid described in Figure 2 is fed exclusively from renewable energies such as wind turbines and photovoltaic systems and, as a "topological power plant", is also able to provide services for system stability to the higher-level power grid. Active and reactive power control is also considered and then mapped. Such ancillary services could help to partially replace conventional power plants in the energy transition. In addition, the available power of renewable energies can be reliably forecast, intelligently planned, and controlled via the control technology of the microgrid. The overall efficiency of the system can be improved by the microgrid's forward thinking using weather forecasts. Based on the consumer and producer profiles, the control unit decides, whether the excess energy is stored in batteries or used to generate hydrogen. This results in two core points of the system, on the one hand the generation and storage of hydrogen as a green energy carrier based on renewable energy and on the other hand reconversion of hydrogen into electrical energy using a fuel cell. In the first step the project focus on a small-scale unit. Based on the results, in the next step it will be scaled up to Lune Delta green industrial area. The power grid of the microgrid consists of three voltage levels. Starting with the 24 V DC level for the sensors, the 48 V DC level at the output of the fuel cell for the battery storage and the 400 V three-phase level for feeding in renewable energies. The grid connection point is a switchable connection between the microgrid and the higher-level power grid. The 48 V DC is converted using a DC-AC inverter or a rotating converter. The hydrogen is generated by a PEM electrolyser. It can be fed via a 400 V AC or 48 V DC busbar. The hydrogen produced leaves the electrolyser at 16 bar and is initially stored in a low-pressure storage tank. The hydrogen from the low-pressure tank is compressed to 200 bar with a hydrogen compressor and then fed into the high-pressure storage tank. Intermediate storage of the H_2 is created because the amount of hydrogen is not sufficient to achieve the same electrical output by reconverting the H_2 at the outlet of the fuel cell if the electrical performance data required for the electrolyser and the fuel cell are the same.

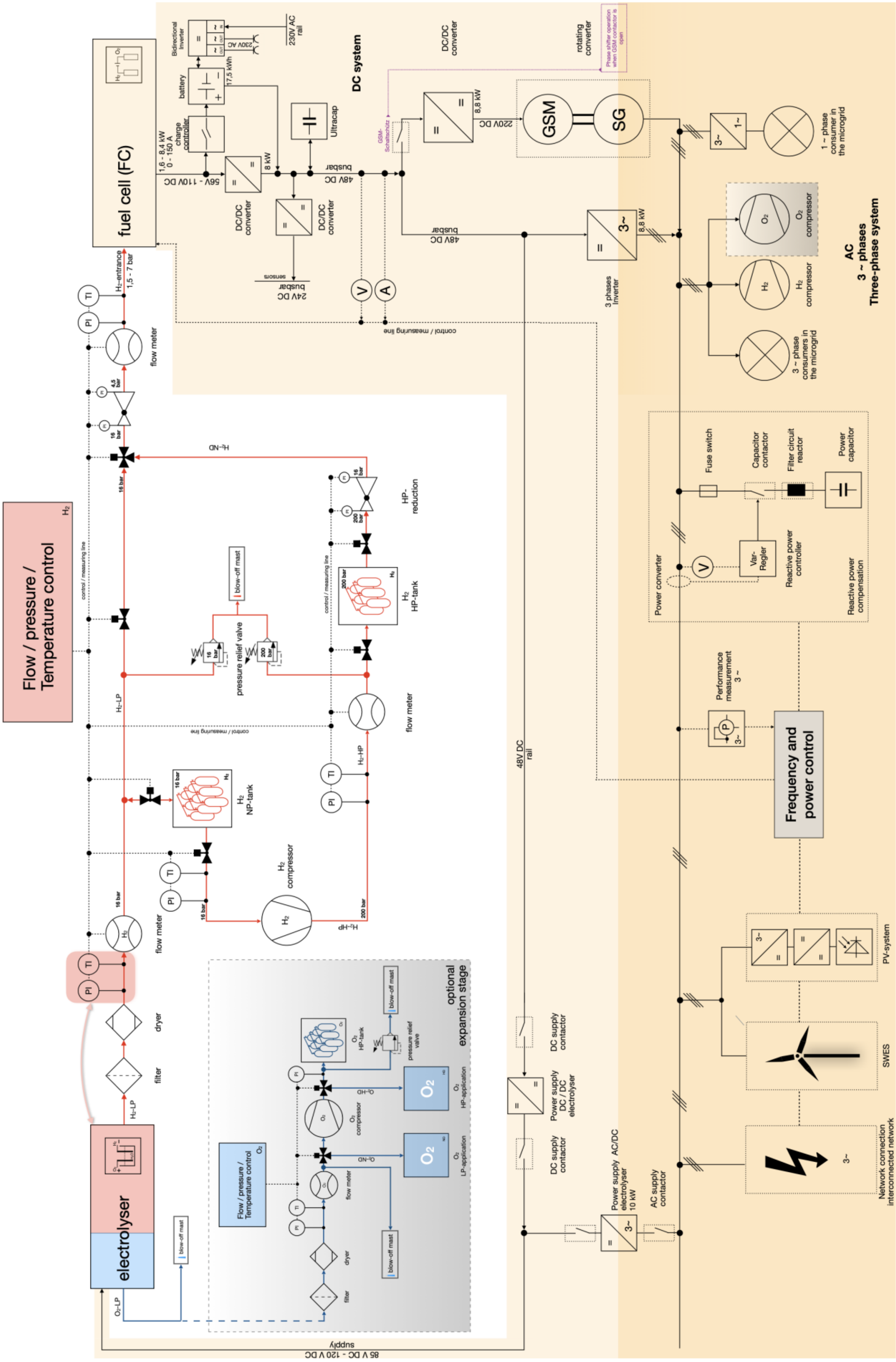

Figure 2: schematics of the whole system structure

2.1 Hydrogen distribution grid

The hydrogen distribution grid (Figure 3) consists of three pressure levels. The hydrogen leaves the electrolyser at a pressure of 16 bar and is fed directly into the central pressure range piping system H_2-LP (16 bar). The hydrogen can be stored in a low-pressure system and, if necessary, brought to a higher-pressure level H_2-HP (200 bar) using a pneumatically driven hydrogen compressor. The hydrogen is stored in a bundle of 6 gas bottles at 200 bar and, if necessary, can be feed in to the 16 bar gas system via the HP reducing valve and fed into the central pressure line system H_2-LP (16 bar).

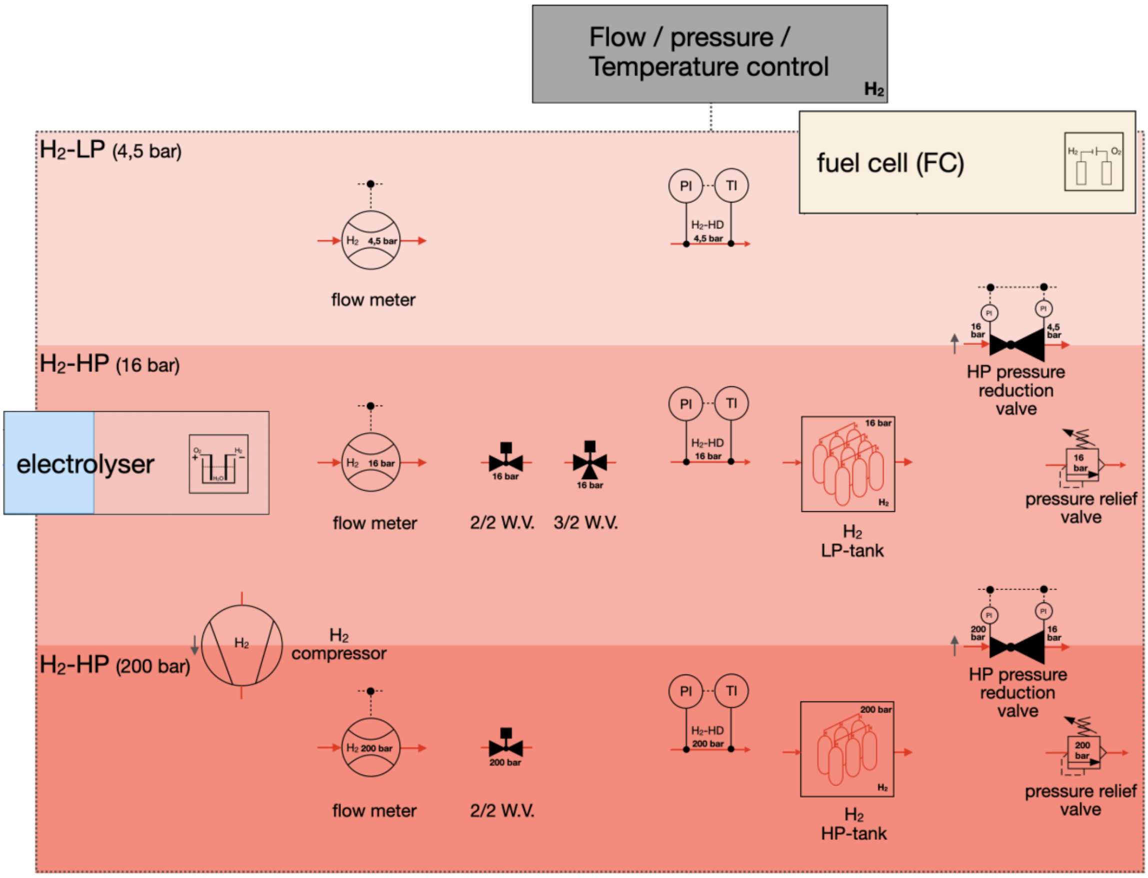

Figure 3: pressure stages of hydrogen distribution grid

The third pressure level of the hydrogen grid H2-LP (4.5 bar) is determined by the inlet pressure of the fuel cell. Because of the variable inlet pressure of the fuel cell (1.5 bar to 7 bar), an average inlet pressure of 4.5 bar was specified. If the inlet pressure is lower than 1.5 bar, the fuel cell would switch off; exceeding the 7 bar limit instead would damage the fuel cell. Pressure relief valves were installed within the 20 bar and 200 bar pressure piping systems to protect the pipes and components from overpressure. In the lowest pressure stage H_2-LP (4.5 bar) no pressure relief valve is provided due to the regulated pressure reducing valve. Temperature, pressure, and flow measurements are integrated in all three pressure levels, so that the measured values can be used to control the microgrid. Solenoid valves are used to regulate the flow of hydrogen.

2.2 Power distribution grid

The grid of the microgrid consists of several voltage levels and has two options for converting the 48 V direct voltage occurring at the output of the DC-DC converter into 400 V AC (Figure 4 - right side). Since a voltage drop at the output of the fuel cell is to be expected, an output voltage range was specified. When idling, the fuel cell has a DC voltage of 110 V, which drops to 56 V under full load. The DC-DC converter connected to the fuel cell ensures that the fuel cell can feed the 48 V busbar with a constant voltage. The 24 V busbar is exclusively reserved for the voltage supply of sensors, actuators, and programmable logic controllers.

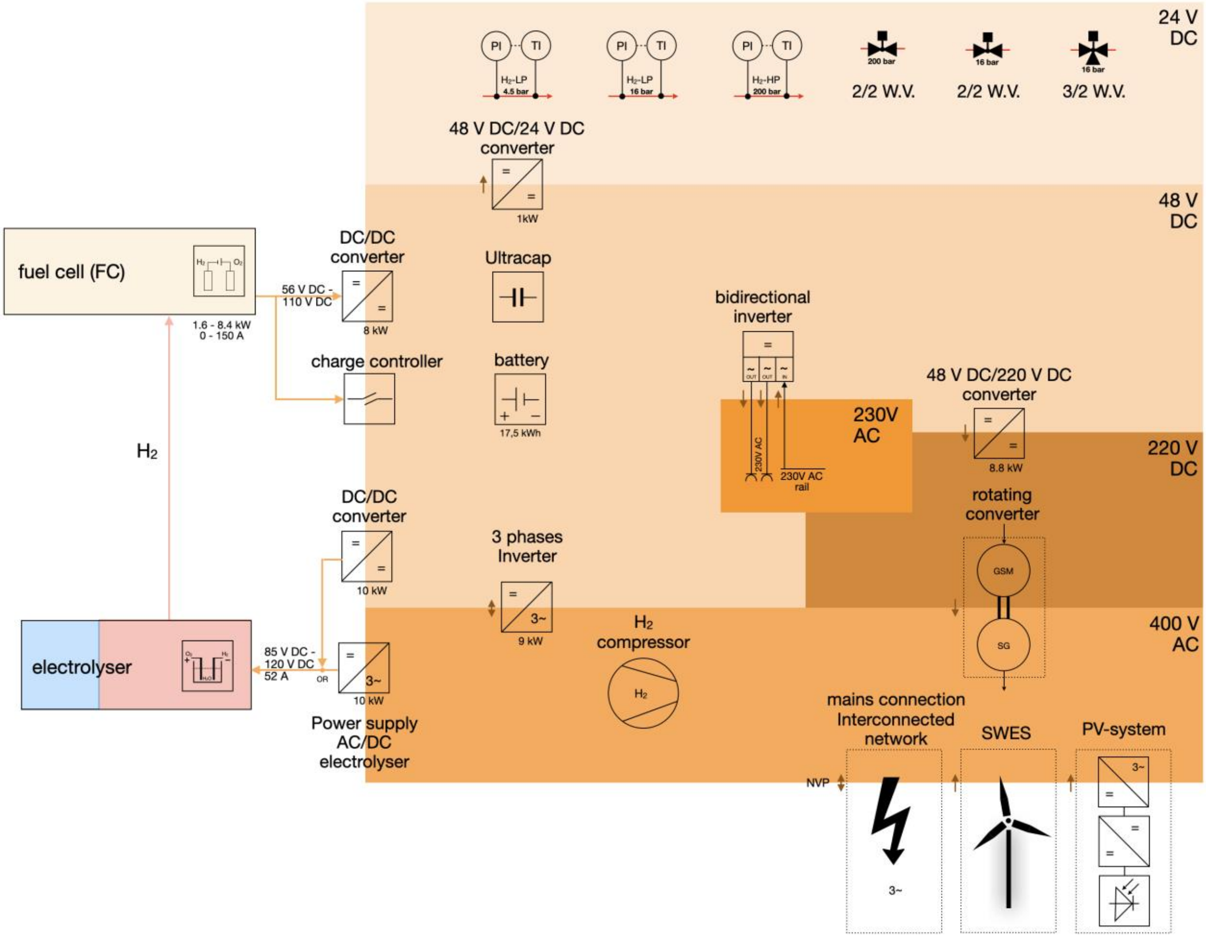

Figure 4: power stages of electrical distribution grid

The 24 V busbar is supplied via a DC-DC converter from the 48 V busbar. The 48 V power grid is one of two main distribution busbars and offers the possibility to connect a battery, supercapacitor, and a bidirectional inverter. With the help of the bidirectional inverter, it is possible to generate two 230 V AC connections on one side via the 48 V power busbar or the battery. On the other hand, it is also possible to charge the battery via a 230 V power grid.

This can be an advantage during commissioning the microgrids. The microgrid has two variants for generating three-phase alternating current. The consideration of the feed-in behavior of inverters and rotating converters should provide results regarding reactive power compensation, control behavior, network quality and system stability. You can choose between a converter-fed three-phase system and the generation of the three-phase system via the rotating GSM-SM machine set. A 220 V DC intermediate voltage is required for the DC machine (GSM) of the rotating converter. This is the only way to ensure that sufficient power is available for the transmission. Other DC consumers can also be connected to this 220 V DC system. The 400 V three-phase busbar connects the feeding renewable energies, such as the photovoltaic system and small wind turbine system, with the electrolyser. The pneumatically operated hydrogen compressor is also supplied indirectly via the 400 V AC busbar. To ensure variable and trouble-free operation of the electrolyser, it can be supplied via the 48 V and 400 V busbar. Among other things, this offers the possibility of conducting studies in the direction of electrolysis power supply and showing their advantages and disadvantages.

3 Control microgrid

The control challenge is to connect the different components of a microgrid in such a way that they can communicate with each other (Figure 5).

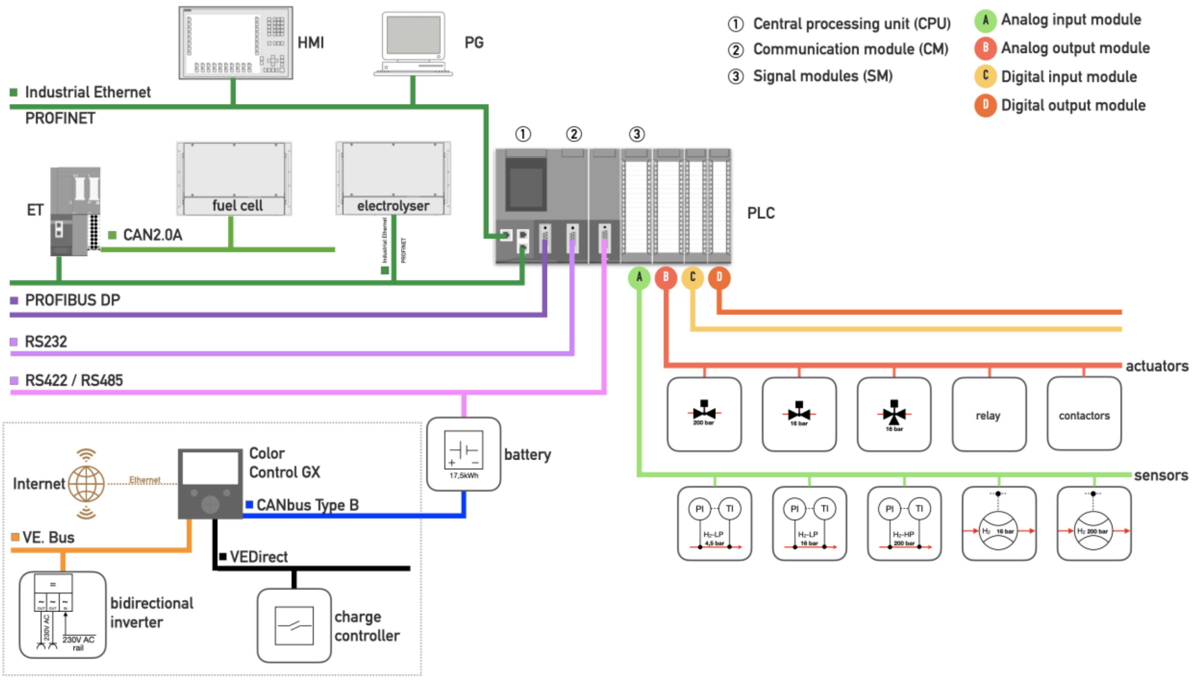

Figure 5: Operation draft of communication structure and HMI

Complete control of the microgrid is only possible if all components are connected to one another via a central regulation/control unit. The basic control of the microgrid consists of a centrally located programmable logic controller (PLC) and a decentralized ET. Communication between sensors, actuators and PLC can take place via analog input/output modules. The state of charge of the 48 Volt battery can be queried via an RS485 module. The entire control system is configured and programmed using the Siemens TIA Portal. During operation mode, an HMI (Human Machine Interface) not only serves to visualize the process data, but also to control the energy management. Data and measurement values are obtained from the electrolyser via a PROFINET connection. The ET used has the task of converting the data sets obtained from the fuel cell from the CAN2.0A BUS to the existing PROFINET network. This leads to simplified cabling and decentralized data processing within the microgrid. The data can be read out locally and transferred to the PLC via PROFINET.

The use of PROFINET also simplifies the parameterization work compared to PROFIBUS. Despite the disadvantages of PROFIBUS, an interface was provided on the PLC to ensure downward compatibility with older drives and components. The microgrid of the university is variable for follow-up projects and can adapt to changes. The digital input modules are used for various manual buttons and switches relevant to the operation of the plant. The PLC's digital output modules are used to control warning/signal lights inside and outside the container. The battery management components are located at the bottom left of the screen within the dotted line (Figure 5 - left side). This controller runs in parallel to the PLC but has a common interface to the battery. In addition, the bi-directional inverter within this system allows the battery storage to be pre-charged to facilitate microgrid start-up after an extended shutdown or during initial start-up.

4 Operation draft HMI

The operational draft of the system communication describes the interfaces of the microgrid control. The operating structure was implemented in the HMI according to figure 6.

Focused on the clear structuring of the microgrid and its main components. The HMI should display and control the microgrid in a clear manner and is able to display the faults to the user as quickly as possible in case of malfunctions. The color representation is intended to underline the structure and configuration of the operating concept. The color of the hydrogen grid was derived from green hydrogen and therefore colored green. The energy grid was colored yellow / orange according to the microgrid overview to find one's way around the system (microgrid environment) more quickly. The color gradient of the fuel cell from green to orange represents the conversion of green hydrogen into electrical energy. The color gradient of the electrolyser from white to green symbolizes the production of green hydrogen by renewable energies. If you follow the operating concept in Figure 6, you can click in the user interface of the HMI control panel of the microgrid container to access the corresponding submenu marked in the same color that was previously clicked. For example, if you click on the purple-colored control panel Construction Container, you get to this submenu. The submenu has the same background color as the parent element. This simplifies the clarity significantly and leads to intuitive operation of the HMI. As a result, little training effort can be expected. The home screen takes you to three main submenus of the initialized control. The Construction Container menu covers the entire control and monitoring of the microgrid container. All HMI system-relevant displays and menus are located under the button System images. All-important alarm messages and status displays, such as the hydrogen detector, are located under the safety system tab. This means that the user can access the three most important submenus directly from the start screen. This helps the users to quickly find his/her way around the operation of the microgrid and faults can be rectified quickly. The construction container area is structured according to its energy sectors. The microgrid consists of an energy sector (electricity area) and of a gas sector, which is realized by the hydrogen.

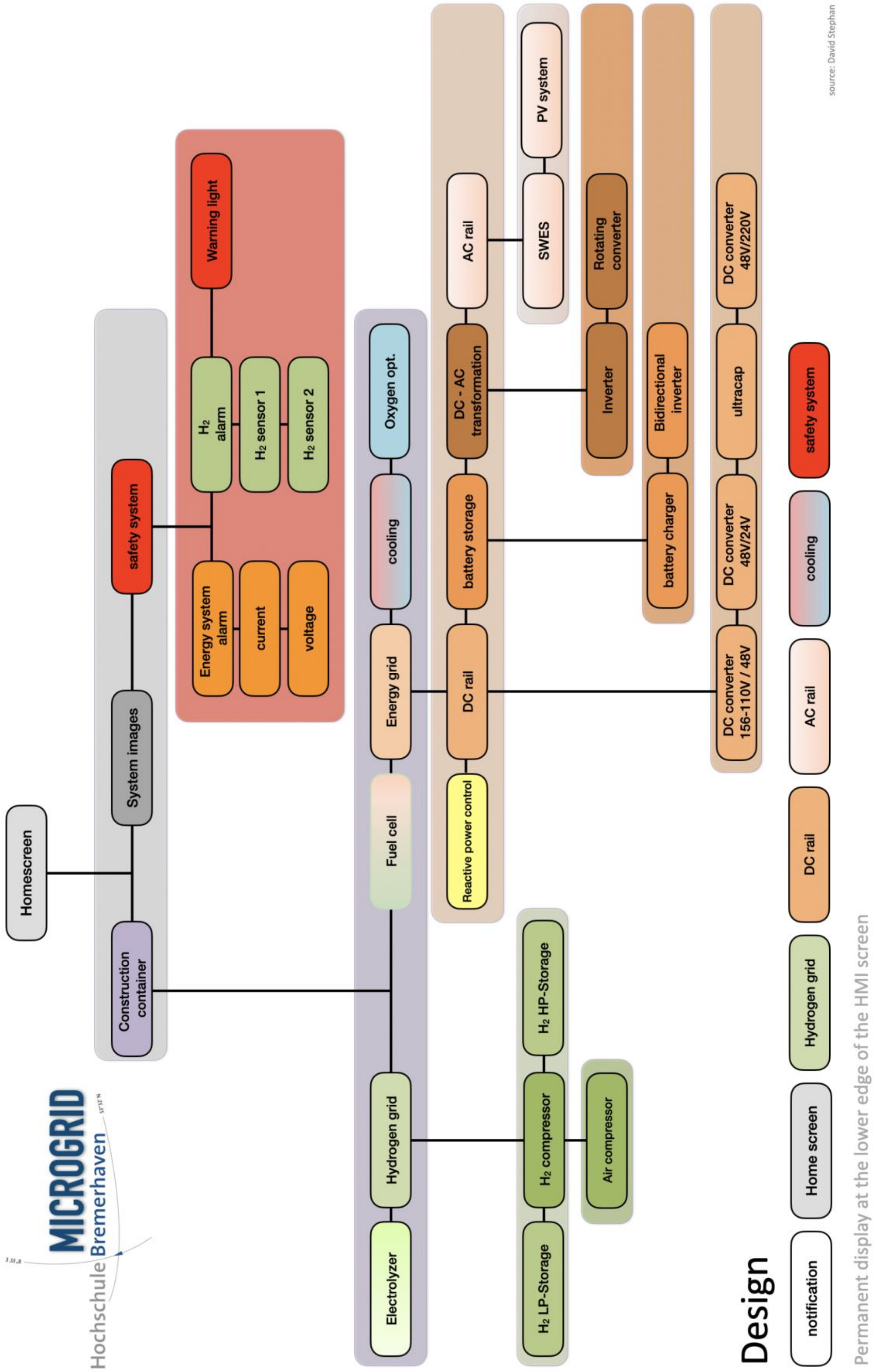

Figure 6: Operation draft of Human Machine Interface (HMI)

5 Energy management

As already mentioned, the microgrid is powered by renewable energy, which are the prerequisite to produce green hydrogen. The renewable energy is fed into the microgrid's 400 V busbar. There, the electrical energy obtained from the wind and the sun is combined and fed to the electrolyser. Depending on available electrical energy, hydrogen is produced. The hydrogen can be stored in a low-pressure or high-pressure storage system. In the gas sector, the two hydrogen storage systems represent a variant of energy storage. In the electricity sector, battery storage systems are used for long-term storage and supercapacitors for short-term storage of electrical energy (Figure 2). The electrolyser is the link between the electricity and gas sectors. The fuel cell converts the energy contained in the gas back into electricity. This leads to a coupling of the energy sectors in the energy management area with their advantages and disadvantages (Figure 1). The supercapacitor compensates for the high starting currents of the rotating converter and thus keeps the voltage stable. The battery storage buffers the electrical energy required when hydrogen production fluctuates or when the hydrogen storage is empty. The heat sector describes the third energy sector. The waste heat from the electrolyser and fuel cell is decoupled by the cooling circuit. The balance efficiency of the electrolyser and fuel cell can be increased through the further use of the waste heat.

5.1 Active power control

The microgrid at the Bremerhaven University of Applied Sciences provides reactive power for mains voltage stabilization in isolated operation. There is also an option to perform a black start in island mode. The microgrid has two different types of active power control and compensation (Figure 7). The harmonic type of active power control takes place via the rotating converter. The clocked type of active power control takes place via the power electronics on the 400 V busbar. The primary control (also called reserve second) is used for frequency and active power control. As well as the secondary control to regulate the voltage and to compensate for the reactive power.

5.2 Reactive power control - rotating converter

An advantage of the rotating converter is the possibility of reactive power compensation in the phase shifter mode of the synchronous machine. As already described, the microgrid has two options for feeding the power from the fuel cell into the 400 V AC busbar. This can be done with the 3-phase inverter or the rotating converter. If the power is fed in via the first option, the contactor to the DC machine can be opened (Figure 7 – marked purple). As a result, the DC motor is no longer supplied with voltage. The connection to the 400V AC busbar remains on the other side of the rotating converter. The generator is operated as a phase shifter and rotates with the 400 V busbar at the mains frequency of 50 Hz. The reactive power can be controlled via the excitation of the synchronous generator. However, it must be taken into account that the DC motor is also driven and the synchronous generator in phase shifter operation cannot supply or absorb pure reactive power but must also generate active power.

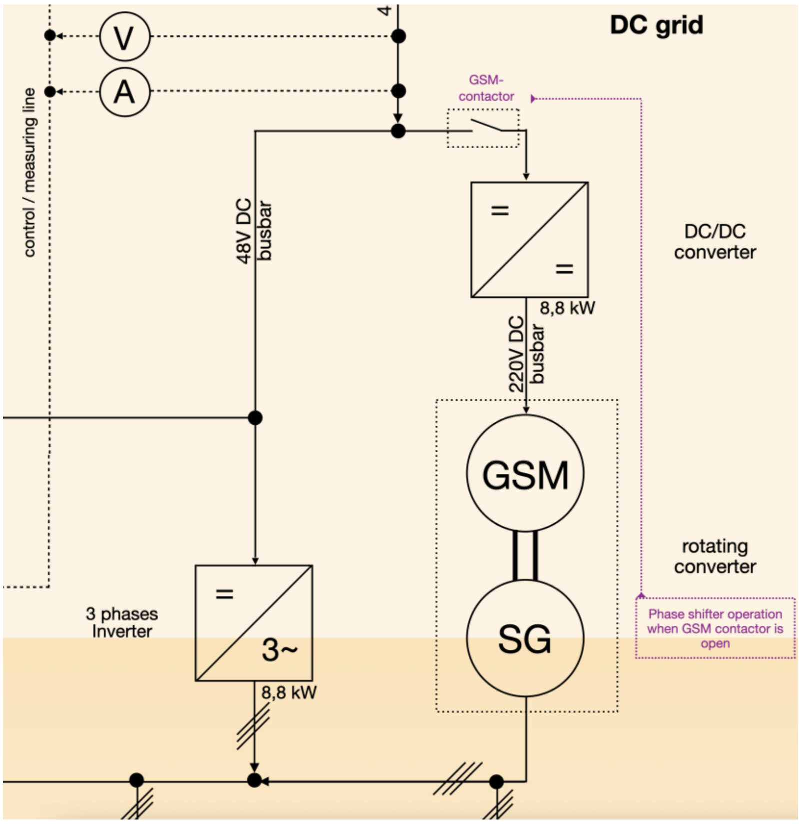

Figure 7: Options for the 400 volt supply of the AC voltage busbar

This leads to a reduction in the energy generated from the reconversion of the fuel cell. The advantage, however, is that no additional components for reactive power compensation need to be added to the microgrid. With the second option of feeding the 400 VAC busbar via the rotating power converter (contactor left path open, right path now closed), there is the possibility of reactive power compensation via excitation of the synchronous generator.

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7 References

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