Test Infrastructure for the Investigation and Standardisation of the Fault Ride Through Behavior of Electrolysers

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***Abstract*: Grid compliance tests for electrolysers need to be performed beyond the current standards. More comprehensive tests are needed to ensure a high level of frequency stability despite the ambitious installation targets of 10 GW electrolysis capacity in Germany and 40 GW in the EU until 2030. Especially the Fault Ride Through (FRT) behavior of electrolysers is insufficiently studied yet. To perform Fault Ride Through tests with hydrogen-based units the Fraunhofer IWES in Germany developed an extensive test infrastructure, which is presented in this paper.**

Keywords - hydrogen, electrolyser, grid simulator, test infrastructure, fault ride through

I. INTRODUCTION

Hydrogen units such as electrolysers, fuel cells, and combined heat and power (CHP) stations will play a decisive role in the energy transition towards climate neutrality. They are indispensable for both the production of hydrogen and its reconversion into electricity. The importance of hydrogen is shown by the current plans of various governments. The EU Hydrogen Strategy targets 6 GW of installed electrolysis capacity until 2024 and 40 GW until 2030 [1]. Moreover, many EU member states have included ambitious plans for hydrogen production in their national energy and climate plans. Thus, the new German government recently increased the previous plans of 5 GW [2] installed electrolysis capacity to 10 GW until 2030 [3].

The capacity of electrolyser units currently installed is in the low MW range up to 10 MW per system [4]. Thus, thousands of units must be installed and integrated into the electrical grid. The unit size will grow in the coming years, so that plants with capacities of 100 MW are possible [5]. The main issues related to grid compliance will be the same, regardless of the size of the electrolyser.

Since electrolysers are nonlinear, dynamic loads connected to the grid via power electronics, it can be assumed that they will cause extensive grid perturbations, e. g. harmonics [6] and thus, require an in-depth analysis and controller design [7]. The effect will be exacerbated as an increasing number of units is installed in a small grid area [6]. One example is the case of an offshore wind farm, where the wind turbines are directly coupled to electrolysis units. This grid condition promises a vast potential in production capacity and reduction of the levelized costs of hydrogen [8], but also creates an electrical grid full of converter-based power consuming units (PCU) and power generating units (PGU) which can have a major impact on voltage and frequency stability [9]. To ensure a reliable grid operation for these future scenarios early efforts in energy system research are necessary.

Besides the current challenges regarding power quality [9] and black start capability [10] further and more specific tests are in need. Fault Ride Through (FRT) tests should be considered to prevent large amounts of consumption power being switched off simultaneously due to a grid failure. The FRT capability ensures a safe grid operation and reduces the risk of grid failures even in the event of a short circuit. The rising amount of installed wind turbines in the last decade has shown that short voltage dips cannot be neglected and consequently, corresponding grid codes were defined [11, 12]. In addition to grid codes, standards such as the IEC 61400-21-1 have been established to define the measurement and assessment of electrical characteristics [13]. To transfer the experiences gained from the wind industry and include them into the scenarios of future grids at an early stage, it is of great importance to investigate the FRT capability of hydrogen equipment. If this ability is not present, there may be issues in maintaining frequency stability [14].

To perform FRT tests, typically an FRT container, or a converter-based test bench is needed. This paper exemplarily describes such a test bench, namely the electrical test infrastructure of the Fraunhofer-Institute for Wind Energy Systems (IWES) in Bremerhaven, Germany. The test infrastructure offers the possibility to perform different dynamic tests in the context of grid compliance. In order to prove the FRT capability of hydrogen-based units such as electrolysers, fuel cells and CHPs the Fraunhofer IWES grid simulator can be used to test different units individually or collectively under various grid conditions.

II. TEST FACILITIES AT FRAUNHOFER IWES

To investigate the behavior of hydrogen units the Fraunhofer IWES offers a total of three hydrogen labs in Germany – in Bremerhaven, Leuna and Görlitz. This paper focuses on the test benches in Bremerhaven. The Hydrogen Lab Bremerhaven (HLB) covers all aspects of the integration of wind and hydrogen energy systems combining the lab with the electrical test capabilities of the Dynamic Nacelle Testing Laboratory (DyNaLab) and the Power Electronics Grid Simulator (PEGS).

The mentioned systems are described in more detail in the following subsections. Figure 1 shows an overview of Bremerhaven with focus on the test facilities.

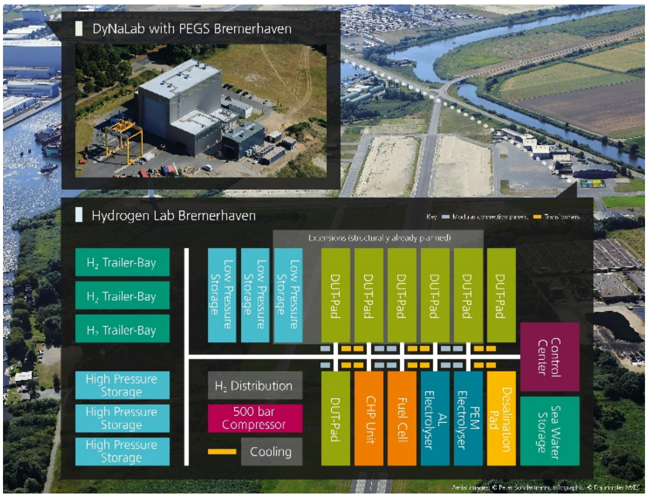

Figure 1: Overview of the test facilities in Bremerhaven with the HLB layout

A. Hydrogen Lab Bremerhaven (HLB)

The lab consists of hydrogen fueled PGUs and PCUs. Systems for gas treatment, compression and storage are provided. The focus lies on the test, validation, and standardisation of electrical aspects of both hydrogen-based energy systems and single hydrogen units. A list of the key units is shown in table 1.

Table 1 - List of key units at the HLB.

Unit	***Nominal Power***	***Block colour in fig. 1***	***Description***
PEM elektrolyser	1.4 MW	Dark Blue	PEM electrolyser with nine stacks and nominal H_2 production rate of 210 m_N^3/h.
Alkaline electrolyser	1.3 MW	Dark Blue	Alkaline electrolyser with three stacks and nominal H_2 production rate of 270 m_N^3/h.
Fuel cell	270 kW	Orange	The fuel cell converts hydrogen back into electrical energy.
Combined heat and power unit (CHP)	170 kW_{el} 183 kW_{th}	Orange	CHP with hydrogen powered combustion engine to supply electrical energy and heat.
Device under test (DUT) pads	5.0 MW per pad	Green	The DUT pads can flexibly be used for connecting all kinds of PGUs and PCUs.

Table 1 shows the nominal power, the block colour depicted in Figure 1 and a short description for each unit. The device under test (DUT) pads are designed as an open platform for electrolysers, fuel cells, CHP units as well as other electrical components. Several DUTs can be tested simultaneously on the test field. The nominal power of a single DUT pad is up to 5 MW. The installation can easily be done via an ISO container base, which allows a quick assembly and disassembly. Every DUT pad can be directly connected to the electrical power system. The pads are available for manufacturers and operators to validate and assess their equipment. The following Figure 2 depicts the concept of a DUT pad.

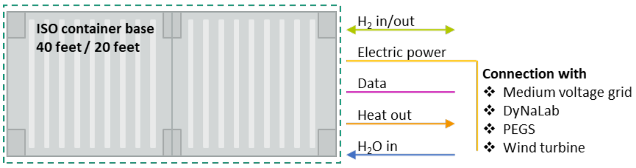

Figure 2: Design and concept of the DUT pad

B. Power Electronics Grid Simulator

The PEGS is a voltage controlled high performance converter system which can be connected to the different units of the HLB. PEGS is used to emulate an artificial medium voltage grid to enable the possibility to perform static and dynamic tests. Within the static tests, the determination of the injected active and reactive power can be examined for various grid conditions. Furthermore, performing dynamic tests, transient grid events like voltage dips, frequency changes and phase angle jumps can be examined.

One of the PEGS capabilities is to simulate an artificial series impedance to change the virtual short circuit power at the point of common coupling (PCC). Therefore, depending on the test specification, a high or low short-circuit ratio can be realized to emulate a weak or stiff grid. This impedance emulation can be used to reproduce the behavior of an FRT container during a field measurement. The phase current of the DUT will be measured in order to calculate and emulate the expected voltage at the PCC [15].

Summary of characteristic values of the PEGS:

- 10/20/36 kV nominal voltage levels
- Frequency range from 45 to 65 Hz
- 44 MVA installed converter power
- < 3 % Total Harmonic Distortion (THD) at 50 Hz

Possible grid event simulations by PEGS:

- Frequency changes from 45 to 65 Hz with a ramp up to 20 Hz/s
- Phase angle changes from 0 to 180 ° with a ramp up to 90 °/ms
- Under voltage ride through from 1 p.u. to 0 p.u.
- Over voltage ride through from 1 p.u. to 1.5 p.u.
- Symmetrical and asymmetrical faults
- Emulation of virtual impedances

C. Test setup

Different hydrogen-based units can be connected to PEGS via the medium voltage system. An equivalent circuit diagram is shown in Figure 3.

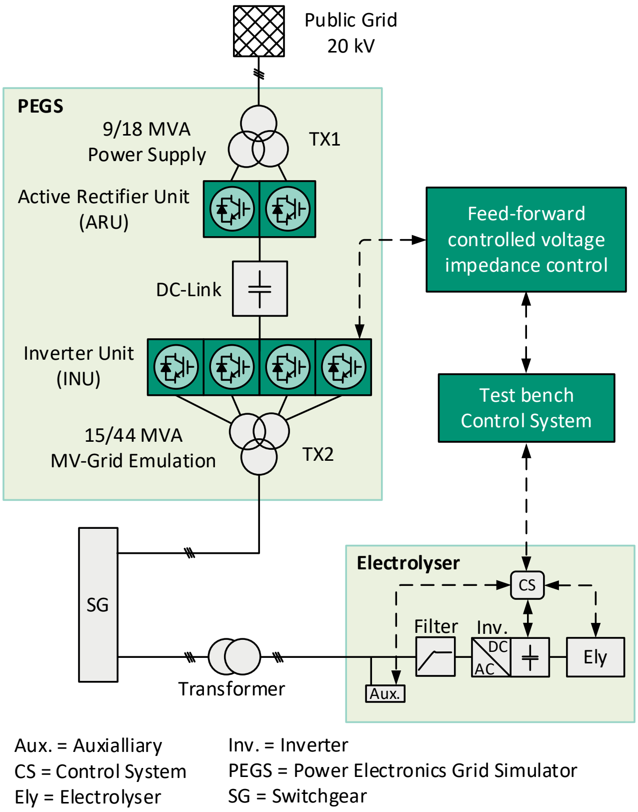

Figure 3: Exemplary test setup at the HLB

The PEGS consists of two three-winding transformers, an Active Rectifier Unit (ARU), a DC link and an Inverter Unit (INU). The INU is designed as a multi-level-inverter and consists of four 3-phase 3-level-inverters, whereby each phase of the simulator is emulated independently. The connection with the DUT is realized by a medium voltage switchgear, which provides the possibility to connect and disconnect DUTs depending on the desired test setup. In Figure 3 the example of an electrolyser connected to the PEGS is shown. Instead of the electrolyser any other electrical unit can be connected. In the case depicted above the electrolyser consists of a filter, an inverter, and an electrolysis cell. Next to the medium voltage connection there is a data connection between the control systems of the DUT and the test bench to create realistic conditions.

It is possible to connect every DUT individually or collectively to the PEGS. Thus, all electrical tests can be performed with each unit and in different test scenarios. To emphasize the range of feasibility regarding testing, three different exemplary scenarios are briefly described in the following. The first scenario consists of a single DUT that is connected to the PEGS. This is the current standard in validation and certification processes. The second scenario can be an island grid consisting of a single wind turbine and a single electrolyser. This configuration represents future offshore wind power plants with direct electrolysis coupling [16]. The third scenario can be a network with seven or more DUTs consisting of different types of PGUs and PCUs. This configuration represents a future microgrid.

III. Conclusion

To prevent large amounts of consumption power from being switched off at the same time, FRT capabilities must be implemented and therefore tests must be accounted for. If this ability is not present, there may be difficulties in maintaining transient and frequency stability.

To perform FRT tests under realistic grid conditions, this paper described the electrical test infrastructure of the Fraunhofer IWES in Bremerhaven, Germany. The test infrastructure offers the possibility to perform different dynamic tests in the context of grid compliance. To verify the FRT capability of hydrogen-based units such as electrolysers, fuel cells and CHPs, the Fraunhofer IWES developed a comprehensive medium voltage system where different units can be connected individually or collectively to a virtual power grid. This offers the possibility to investigate different test scenarios under various grid conditions. To replicate the future grid configurations within the test infrastructure, different test scenarios are feasible to investigate either the FRT test capability of a single DUT or the controller interactions between different DUTs.

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