Flexible Offshore Wind Hydrogen Power Plant Module (FlexH2)

a GROW Initiative

Public Annual Report FlexH2

1 April 2024 – 31 March 2025

Non-CONFIDENTIAL

Author/organisation: Yin Sun
Organization: Shell Global Solution International B.V.
Project: Flexible Offshore Wind Hydrogen Power Plant Module
RVO project number: MOOI52103
Reporting period: April 1st 2024– 31st March 2025
Date: April 28nd 2025
Version: 00

Contact:

- Yin Sun (project coordinator), Shell, yin.sun@shell.com
- David de Jager, GROW Programme Office, dejager@grow-offshorewind.nl

The FlexH2 project is part of the GROW programme on offshore wind energy. The GROW programme aims to reduce levelised costs of offshore wind electricity, to create added value for the Dutch economy and to strengthen the Dutch offshore wind industry. (www.grow-offshorewind.nl)

FlexH2 is supported with a Topsector Energy subsidy from the Dutch Ministry of Economic Affairs and Climate Policy, administered by Netherlands Enterprise Agency (RVO). The specific subsidy concerns the 2021 MOOI-subsidy round.

Het project is uitgevoerd met Topsector Energie subsidie van het Ministerie van Economische Zaken en Klimaat, uitgevoerd door Rijksdienst voor Ondernemend Nederland. De specifieke subsidie voor dit project betreft MOOI-subsidie ronde 2021: Missiegedreven Onderzoek, Ontwikkeling en Innovatie - Systeemoplossingen Inpassing Grootschalige Opwekking Hernieuwbare Elektriciteit

Table of contents

1 FlexH2 Project Outline

Motivation

The EU Green Deal sets out an ambitious plan for Europe to become the first continent to achieve carbon neutrality by 2050. The Commission's proposal to cut greenhouse gas (GHG) emissions by at least 55% by 2030 sets Europe on a responsible path to reach the carbon-neutral goal by 2050. Contributing to the EU-wide GHG emission reduction target, the Netherlands is committed to significantly increase the renewable electricity production from wind and solar to account for 70% of electricity supply by 2030. Due to the great potential of offshore wind (~70 GW offshore wind by 2050), a holistic energy system design and technological innovations are crucial to limit expensive grid expansion cost because of offshore wind power infeed, and to avoid excessive volatility in the energy balancing mechanisms, caused by intermittency and possible forecast errors of offshore wind power output.

Objective of the project

By the end of the FlexH2 project:

1. a lightweight and compact HVDC transmission system utilizing the line-commutated converter and grid-forming offshore wind turbines have been developed, which reduces the offshore wind transmission infrastructure LCOE by 30% in comparison to typical MMC-VSC HVDC power infrastructure;
2. a MW-level AC/DC solid state transformer has been developed, which reduces the weight and volume by 20% and 30%, respectively, compared with the conventional line frequency transformer;
3. a flexible grid interface has been created, which not only offers the flexibility to regulate the power export/import but also respects the technical constraints imposed on the production (i.e. offshore wind production) and demand-side (i.e. hydrogen electrolysis); and
4. a modular energy and risk management system has been developed, which is able to optimize its integration with the existing electric infrastructure and hydrogen infrastructure.

Leveraging these technological innovations, the FlexH2 project can reduce the overall Levelized Cost of Hydrogen (LCOH) for green hydrogen by 0.35 €/kg, therefore provide a cost-competitive solution for the CO_2 emission reduction.

Result

Three categories of results can be described:

1. **Technology research and development**
   - Increase of the TRL of grid-forming wind turbine technology for the offshore wind deployment.
   - Increase of the TRL of AC/DC solid-state transformer for the MW-level hydrogen electrolysis application.
   - Increase of the TRL of power plant controllers for offshore wind hydrogen production assets as described in this proposal.
2. **Functional specification that defines the minimum interface requirements for the three technological innovation pillars:**
   - Grid-forming wind turbine functional specifications that enable the electrical coupling with the line-commutated power converter.
   - AC/DC solid-state transformer functional specification that enables direct electrical coupling with onshore converter station DC link.

- Onshore converter station specification that enables flexible connection to the onshore power grid.

3. **Performance specification that defines the optimal operational philosophy of the flexible offshore wind hydrogen power plant module.**

Short description of the activities

In this project, we will develop a scalable solution for the wind-hydrogen power plant module. Specifically, the activities on three key aspects will be carried out:

- Three key technological innovation pillars: (1) Grid-forming offshore wind farms, and (2) high-performance solid-state transformer for large-scale electrolysers and (3) multi-terminal hybrid HVDC transmission systems and its system integration.
- System-level optimization and operation: Flexible design and operation of offshore wind hydrogen power plant module.
- Technology Demonstration: MV-kW level demonstrator to advance the TRL (technology readiness level) of the innovation in this research proposal.

Project consortium

The FlexH2 project consortium is depicted in the graph below. FlexH2 brings together stakeholders ranging from technology providers to end-users of various kinds: an offshore wind energy project developer (Shell), technology providers of wind turbines and electrical infrastructure components (General Electric, ABB, VONK), an offshore contractor (Van Oord), and knowledge institutes and consultancies (Technical University Eindhoven, Technical University Delft, TNO and DNV).

Project progress in the reporting period

	Milestone	End	Status
1	Electrical design of Diode Rectifier (DR)-HVDC converter station unit. Interface specifications between DR-HVDC and grid-forming offshore wind farm.	31/03/2023	Y1 - Completed
2	Offshore wind farm with advanced fault handling capability and delivery of OEM EMT model for additional system study to guide the practical implementation of the MV kW demonstration of the FlexH2 project. Achievement of project result 1.	31/03/2025	Y3 – draft delivered, 3 month delay
3	Base design of key components of medium voltage AC/DC solid-state transformer (SST).	31/03/2023	Y1 - Completed
4	Detailed design of SST power converter and system integration complete. Achievement of project result 2.	31/10/2024	Y3 – significant delay
5	Control and protection development for the onshore multi-terminal VSC-HVDC. Enables direct coupling of VSC-HVDC with diode-rectifier interfaced hydrogen electrolysis without/reduced harmonic filter requirements.	31/03/2024	Y2- Complete
6	Development completion of fully functional power plant controller for flexible offshore wind hydrogen power plant module. Achieve project result 3.	31/12/2024	Y3 – draft delivered, 4 month delay
7	Optimized design of offshore wind hydrogen power plant module. Optimized operational strategy for efficient system flexibility service delivery. Delivery of Energy Management System (EMS) for the FlexH2 concept. Achieve project result 4.	31/08/2025	Y3 - Ongoing
8	Implementation of milestone results from activity 3 into the MV kW FlexH2 system demonstrator. Achieve project result 5.	31/10/2025	Y3 – ongoing
9	MV kW solid-state transformer Demonstrator complete. Achieve project result 5.	31/12/2025	Y3-Significant Delay
10	FlexH2 project knowledge platform/website, where all project information is kept under one roof, which can be served as the digital centrum for knowledge sharing with a broader public.	31/03/2023	Completed
11	Final Dissemination Workshop, where all project results are delivered by project partners with participation from academic, industries government agencies/bodies as well as other relevant stakeholders.	31/03/2026	Pending

Societal impact

To fully decarbonize the energy system a cross-sectoral approach is inevitable. This is acknowledged in the mission stated by the MOOI-SIGOHE theme. The project FlexH2 aims to contribute to this by reducing the technological and economical barriers between large offshore wind energy, the power system and industry. The LCOE of Offshore wind energy is already lower than those of most traditional electricity generation technologies. A major drawback is its variable and synchronized behaviour, that will cause periods variating in length with shortage of electricity from renewables and periods with oversupply.

Infrastructure and flexible demand to accommodate this variable resource will be relatively under-utilized, and the contribution of the capital expenditure (CAPEX) for this infrastructure on the LCOE will be comparatively high. Furthermore, the value of the produced energy during times of oversupply will decrease, because of lack of electric demand that can put this energy to good use.

To integrate large amounts of variable energy sources (battery-)storage and demand response are essential but are limited to bridge relatively short periods of time by its economics (several days to a week by 2050). Utilizing the oversupply of wind energy by converting it into hydrogen is seen as an attractive way to create value for this energy, provided this value is greater than its cost.

The project FlexH2, therefore, aims to reduce the overall cost of using offshore wind electricity for hydrogen production by developing technology with this value chain and its economics in mind to achieve the following impacts:

1. Develop and mature key electrical energy infrastructures with a low CAPEX when scaled to industrial level (such as the diode rectifier based offshore HVDC station with grid forming wind farm)
2. Optimize the value of the system by creating synergy to its surroundings (such as flexibility to the power system and continuity to the industrial hydrogen off-take)

The FlexH2 project will provide solutions to several problems for the electricity with the variability of the production by stabilising the system with a flexible demand from the electrolysers and at the same time providing ancillary services stabilising the grid and providing electric power via reverse electrolysis (fuel cells) during times of low wind speed.

The outcome of the project should provide the basis for the accelerated development of Power-to-H2 projects in the Netherlands, such as NortH2, before 2030.

Knowledge dissemination and spin-offs

The knowledge and results produced within the project will have value for a broad group of stakeholders. The active sharing of this knowledge, both within the consortium and with the outside world, will be essential for the success of the developed technologies in the market.

Within FlexH2, knowledge integration and dissemination will not only concern technical-economic knowledge, but also acquired knowledge and experience with the legal aspects concerning offshore wind/ hydrogen grid integration. In this way, future legislation and regulations may serve the required products and services.

Within FlexH2 the key actors in the global offshore wind energy and grid technology are represented. Through their direct participation in the project, the uptake of the FlexH2 outcomes is ensured.

The main messages to our audience will be:

- In the FlexH2 project the relevant stakeholders are working together.
- We are improving the integration of offshore wind in the energy system.
- The FlexH2 system will increase the stability of the grid connected to offshore wind and improve the flexibility of the (renewable) energy system.
- The system will lead to hydrogen production via a cost competitive solution by effectively integrating offshore wind, electrolyser, and the grid.
- The innovation will lower the production costs of hydrogen and will contribute to decarbonising industrial sectors.
- The innovation will be applicable commercially before 2030 and can be applied modular.

Communication in FlexH2 will run via two tracks: Education and Dissemination.

For the time being, the following knowledge dissemination activities are planned:

- Project website (www.grow-flexh2.nl)
- Use of national media
- Learning Community
- Scientific publications

The following dissemination activities and public publications are available:

Project / Work Package		Year	Title/venue/authors/etc.
1	**Offshore wind farm**		
	Publications	..	..
		..	..
	Workshops/conferences	Year 1	"Voltage-power Relationship for DRU-HVDC connected OWF System" USA (IEEE COMPEL 2023) Chengqi Zhang Approved dissemination by consortium partners and presented.
		Year 3	"Robust black start of an offshore wind farm with DRU based HVDC link using power synchronisation control" UK (ECCE Europe 2025) Orcun Karaca – ABB Approved dissemination by consortium
2	**Solid-state transformer**		
	Publications	Year 3	"Medium Voltage Solid State Transformer Design for Large Scale H2 Electrolysis" IEEE Open Journal Power Electronics Zhengzhao Li Approved dissemination by consortium partners
		Year 3	"Partial discharge Mitigation of Medium Voltage Medium Frequency Dry-type Transformers using Semi-conductive screen" IEEE Open Journal Power Electronics Reza Mirzadarani Approved dissemination by consortium partners.
		Year 3	"Current balancing technique for the high-current winding of medium frequency transformer" IEEE Industrial Electronics Reza Mirzadarani Approved dissemination by consortium partners
		Year 3	"A control approach for performance improvement of MMR-based SST in H2 Electrolyzer Application" IEEE Power Electronics Zhengzhao Li Approved dissemination by consortium partners.
	Workshops/conferences	Year 1	"Three-Phase Medium-Voltage Medium-Frequency Transformer for SST in Green Hydrogen Production" Singapore (IECON 2023) Reza Mirzadarani

			Approved dissemination by consortium partners and presented.
		Year 1	“Comparison of Modular Multilevel Converter based Solid State Transformer for AC/DC Application” Singapore (IECON 2023) Zhengzhao Li Approved dissemination by consortium partners and presented.
		Year 2	“Symmetrical Transformer for Medium-Voltage Medium-Frequency ISOP Three-Phase LLC SST” Chengdu, China (IPEMC-ECCE Asia 2024) Reza Mirzadarani Approved dissemination by consortium partners but not yet presented.
3	**Hybrid HVDC system**		
	Publications	Year 3	“A direct current synchronisation control for voltage source converter with enhanced fault ride through capability” IEEE Open Journal Power Electronics Zheran Zeng Approved dissemination by consortium partners
		..	..
	Workshops/conferences	Year 2	“Impacts of Digital Control Delay on Power Tracking in Unified Virtual Oscillator Controller” Guangzhou (IEEE PEAS 2023) Zheran Zeng Approved dissemination by consortium partners and presented.
		..	..
4	**System integration optimization**		
	Publications	..	..
		..	..
	Workshops/conferences	..	..
		..	..
5	**Demonstration**		
	Publications	..	..
		..	..
	Workshops/conferences	..	..
		..	..
6	**Project dissemination (generic)**		
	Publications	..	..
		..	..
	Workshops/conferences	Year 3	“Hybrid solutions offshore: offshore wind to hydrogen” Rotterdam (Offshore Day 2024) Iratxe Gonzalez Aparicio and Lucia Beloqui Larumbe

			Dissemination approved by consortium partners.
		Year 3	"FlexH2 project presentation" in Arnhem By Songda Wang and Lucia Beloqui Larumbe Dissemination is approved by project partners.
	Internet		www.grow-offshorewind.nl www.grow-flexh2.nl

References to FlexH2 in the media in the reporting period:

Year 1 2022

The FlexH2 project has received a lot of publicity:

- GROW Project page: https://grow-offshorewind.nl/project/flexh2
- Topsector Energy project page: Flexible Offshore Wind Hydrogen Power Plant Module - Topsector Energie
- TNO: Maximising the value of wind energy in the energy mix (tno.nl)

December 2022

- GROW News, https://grow-offshorewind.nl/newsitem/flexh2
- Alles over waterstof: € 13 miljoen RVO subsidie voor innovaties hernieuwbare elektriciteit - Alles over WaterstofDepartment of Energy: Offshore Wind Market Report: 2022 Edition (energy.gov)
- Energeia: In 2022 €66 mln beschikbaar voor innovatie via regeling Mooi (energeia.nl)
- Energie-nieuws.nl: GROW-consortium ontvangt €4M subsidie voor project met flexibele waterstofproductie uit offshore wind | Windenergie Nieuws (windenergie-nieuws.nl)
- Energy Central: Dutch Offshore Wind-to-Hydrogen Project Ready to Take Off | Energy Central
- Energynews.biz: GROW consortium starts FlexH2 project - Green Hydrogen News (energynews.biz)
- Hydrogen Tech World: FlexH2 project to develop cost-saving wind-to-H2 solution | Hydrogen Tech World.com
- iiVonk.nl: Vonk invited in the GROW offshore wind consortium – Vonk (iivonk.com)
- Industry & Energy: GROW consortium begins FlexH2 project in The Netherlands - (industryandenergy.eu)
- Maritime Economy: GROW consortium | The Global Maritime Business News Portal - The Maritime Economy Publications
- Netherlands Enterprise Agency (RVO): Dutch-offshore-Wind-Innovation-Guide-Edition-2023.pdf (rvo.nl)
- Ocean energy resources: GROW consortium to start innovation project FlexH2 (ocean-energyresources.com)
- Recharge: Dutch back Shell-led offshore wind-to-hydrogen bid to 'slash transmission costs by more than $100m' | Recharge (rechargenews.com)
- WindTECH International: FlexH2 project awarded funding to develop hydrogen production technology from offshore wind - Windtech International (windtech-international.com)

February 2022

- TU Eindhoven: Major boost for innovation in off-shore wind and green hydrogen production. (tue.nl)

April 2022

- GROW News: https://grow-offshorewind.nl/newsitem/flexh2-starts-today
- ScolarshipDb: PhD on Multi-terminal Hybrid HVDC system, Eindhoven University of Technology (TU/e), Netherlands | scholarshipdb.net
- TU Delft: Flexible Offshore Wind Hydrogen Power Plant Module — TU Delft Research Portal
- Windpowernl: FlexH2 project kicks off | Windpowernl

August 2022

- GROW News: https://grow-offshorewind.nl/newsitem/flexh2-in-the-news
- Change inc: Het Nederlandse FlexH2 kijkt hoe windenergie een constante bijdrage kan leveren aan de energiemix | Change Inc.
- Innovation Origins: FlexH2 wants a cost-effective solution to produce green hydrogen - Innovation Origins

Year 2 2023

- TNO website: Flexible Offshore Wind Hydrogen Power Plant Module
- TNO website: Maximising the value of wind energy in the future energy mix

April 2023

- Vonk website: Dutch company crucial link in major Hydrogen project

Mei 2023

- windpowernl: The Netherlands takes lead in offshore wind and hydrogen production

July 2023

- Publication website https://grow-flexh2.nl/
- ReFlexion of Zian Qin: Solid State Transformers
- Innovation Origins: FlexH2: van offshore windenergie tot groene waterstofproductie

November 2023

- Reflexion of Iratxe Gonzalez-Aparicio: Offshore wind to hydrogen: flexibility provider in a Dutch electrified market

December 2023

- Wind Energie nieuws: Slimme schakeling tussen offshore windenergie en waterstofopslag

Year 3 2024

September 2024

- ReFlexion on Long distance transmission with HVDC technology of Carl Barker: https://grow-flexh2.nl/reflexion/long-distance-transmission-with-hvdc-technology

June 2024

- Presentation at the Offshore Day https://grow-flexh2.nl/newsitem/flexh2-at-the-offshore-day

May 2024

- ReFlexion on Grid-Forming Control Technology of Dongsheng Yang: https://grow-flexh2.nl/reflexion/grid-forming-control-technology

April 2024

- Mentioning of FlexH2 in LinkedIn post by Hydrogen Intelligence: Link

February 2024

- FlexH2 project in Live webinar of TKI Offshore Energy: https://grow-flexh2.nl/newsitem/flexh2-in-live-webinar-tki-offshore-energy