Holland Hydrogen 1 – renewable hydrogen powered from offshore wind

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Abstract – Hydrogen has a key role in the energy transition with the potential to decarbonize hard-to-electrify sectors such as refining and chemicals, steel and others.
Holland Hydrogen 1 is a grid-connected 200 MW hydrogen electrolyzer plant which will produce up to 60 tons of hydrogen per day. The plant will be powered by offshore wind from the North Sea and supply hydrogen via pipeline to the Pernis refinery.
This paper outlines the technical and other choices for the 380 kV grid connection and electrolyzer power supply configuration and the challenges of achieving grid compliance including control of harmonics, control of the rectifiers and the balance of plant including hydrogen compressors.
The paper will cover the impact of a 380 kV grid connection on the construction, commissioning and start-up activities.

Index Terms — Hydrogen, Offshore Wind, Electrolysis, Compression.

I. INTRODUCTION

A. *Hydrogen in the Energy Transition*

It is widely agreed that hydrogen will need to play an important role in achieving a net zero carbon energy transition. Hydrogen can act as an energy storage medium for renewable and other intermittent sources, helping balance supply and demand, as well as being a potential energy vector via pipelines (gaseous or liquid) or marine shipping (liquid). Furthermore, hydrogen can help fuel a range of end uses (industrial energy, heavy duty transport and heating), for which there are very few other viable zero carbon solutions.

This role of hydrogen has been recognized recently in Europe, with new strategies to promote hydrogen, backed by investment programs.

B. *Holland Hydrogen 1 project*

The Shell Holland Hydrogen 1 Project (HH1) is an ambitious project to install an electrolyser plant at a size helping to make a change in the use of electrolyser technology in Europe, thereby accelerating the path to industrialisation for this essential net-zero carbon technology. The project aims to deploy 200 MW of electrolysis capacity at the Port of Rotterdam to produce hydrogen. The produced hydrogen will be used for industries and transports.

The electrolyser plant will be supplied with electricity produced mainly by the Hollandse Kust Noord (HKN) offshore windfarm, of which Shell is an equity shareholder and developer. The electricity will be transported to the Port of Rotterdam via the extra high voltage of 380 kV through the TenneT grid.
At the Maasvlakte 2 area, for the purpose of Hydrogen production, a conversion park (HCP) with four plots is created for new factories. One of those plots is used for building the factory of HH1. Beside the four plots on the conversion park for the new factories, there is an area available to build a local 380 kV substation. This plot named Stroomplot (HCP380), will be used to supply power to all the new factories. The power to HCP380 has been fed from TenneT substation MVL380 at Maasvlakte.
In the final situation the Stroomplot will be fed from the new TenneT substation Amaliahaven (AMH380), which is planned to be operational in 2026. When AMH380 is in operation, the initial connection to MVL380 will be switched to AMH380.

The hydrogen produced by the Electrolyser plant will be transported to the Pernis Refinery via a hydrogen backbone pipeline and will displace grey hydrogen currently used in the refinery's hydro processing operations. As hydrogen offtake markets develop in the future, the hydrogen will likely be transported to other industrial players in the port area and more widely in the Netherlands for fuel in hydrogen mobility applications.

II. GRID CONNECTION

In order to develop a substation designed for multiple plants in all 4 plots mentioned above and HH1 factory, the total scope was split in two parts – 380 kV substation and HH1 plant. The 380 kV substation HCP380 is designed to be expandable to feed 4 plants equivalent to HH1. The substation gets it feed from a TenneT substation at Maasvlakte through a single feed. The substation presently has redundant outgoing feeders to HH1 and is designed for extension for future loads. As all the other 380 kV substations in Netherlands are managed by TenneT and they have quite established standards for the same, this project also adopted the same standard.

The benefit of adopting the transmission system operator (TSO) standard was that most of the vendors of 380 kV equipment already had equipment designed for the TSO, so the process of technical evaluation was quite straight forward. The disadvantage of the same was that it limited number of vendors, which is anyway limited because of the extra high voltage range.

The feed for HCP380 was originally to be from Amaliahaven substation AMH380 which is planned to be completed in the coming year. However, to expedite HH1 project delivery presently the feed to Stroomplot is taken from Maasvlakte substation, MVL380 which is in vicinity of

AMH380. The design of the cable system has been done in such a way that the feeder can be transferred to the new substation with minimal regret cost.

At HH1 the design of the Electrical system is quite standard to any other Oil & Gas facility, other than the specialized equipment required for electrolyzer application. Static VAr compensators (STATCOMs) are installed to manage the VAr requirements in different operating scenarios of electrolyzer operation. Harmonic filters are installed to manage the stringent THD requirements for the 380 kV system [1]. Multiple rectifiers and transformers are installed to provide DC power to electrolyzers. All the above-mentioned specialized equipment are connected to the 33 kV board in the plant's main intake substation. All the equipment is designed for constantly varying loading of the plant, depending on the power produced by the upstream wind farm.

The plant's main intake transformer is a standard utility interface transformer of YNyn0 +d11 configuration. However, the primary side neutral has been solidly earthed as required by the utility company. This leads to significantly high fault current at such a high voltage. The combination of such a high current and high voltage requires very low earthing grid resistance to bring the step and touch potential within the acceptable range, which is an additional requirement for the plant.

III. ELECTROLYSER POWER SUPPLY

The electrolyzers use low voltage DC (<1000 V). Thyristor-based rectifiers have been chosen for the project. The secondary of the transformer which feeds the rectifier is also in the range of low voltage, so a HV/LV transformer with on-load tap changer (OLTC) has been selected. The variable power to the electrolyzers is controlled through management of thyristor firing angle and transformer OLTC [2].

The electrical protection design for most of the plant is standard design used at other plants of this size. The only system which is non-standard is the secondary of the rectifier transformer and DC system of the rectifier, which has very high current. The rated current (30+ kA) is comparable to short circuit current in a standard system. The secondary current of the transformer is managed with the use of instantaneous element of the upstream relay. For low range arc flash currents, the methodology of comparison of AC and DC current is envisioned. The fault on DC side is managed with fast action of suppressing the pulse of thyristor.

In case of loss of main power supply, there are comparatively very small rectifiers called polarizers, which are needed to remain powered to avoid damage of cells [3]. The polarizers are powered by Emergency Diesel Generators for this purpose. A booster polarizer rectifier is also added in the circuit to attain the minimum voltage required to avoid the reverse current. The topology of the rectifiers can be seen from the figure below.

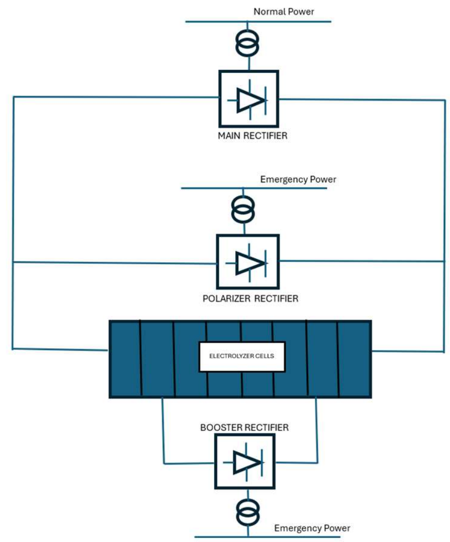

Figure 1 Electrolyzer rectifiers topology

IV. ELECTROLYSER CONTROL

As production of hydrogen is linked to production of power by the upstream windfarm, the design of the control system has been done in such a way that both systems are "synchronized", based on the windfarm power production forecast and power trading in real time.

The control of power to individual electrolyzers is achieved through control of DC voltage to the electrolyzers. The control is achieved with combination of rectifier-transformer OLTC and thyristor firing angle control. The OLTC is used for coarse control while fine control is achieved by controlling the firing angle of the rectifier thyristors [2].

In case of any process trip of the electrolyzer, the controller instantly suppresses the gate pulse of thyristors to shut down the rectifiers. The suppression of gate pulse is also done in case of any upstream electrical trip to avoid damage of thyristors due to transient recovery voltage.

There are insulation monitoring devices also installed on the electrolyzer modules to keep monitoring the leakage current as the DC system is floating. The modules are installed on insulated frames. In case of detection of leakage with insulation values going below the predefined values, the electrolyzer will be tripped. For human safety the electrolyzer modules have Plexiglas installed all around at ground level to avoid contact with floating frames.

On DC side of the system there is a DC isolator between the rectifier and the electrolyzer to isolate the cells from the power source during maintenance. However, there still will be residual voltages on cells which will be further brought down to safe to touch range by intermediate isolators.

As hydrogen production is directly linked to the electricity production of the windfarm the amount of hydrogen that needs to be compressed will vary between 0% and 100%. Compressor capacity control is achieved by various methods of compressor control.

V. PROJECT CHALLENGES

As majority of the loads in the plant are power electronic based, the biggest challenge has been managing the harmonic content. The utility company requirement on allowed emission is significantly lower than defined in IEC 61000-3-6 [1], recognizing that more predominantly power electronic based load was to be added to the grid [4][5].

This impact of this onerous requirement was that the system to be designed in such a way that most of the harmonics are cancelled within the plant by multi-pulse rectifiers fed by phase shifted transformers, for the 200 MW – 5x 40 MW in a 24 & 36 pulse design. The network configuration can be seen from the key single line diagram provided below.

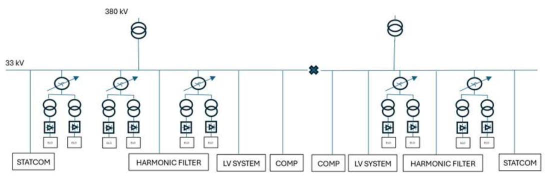

Figure 2 Key Single Line

The other challenge has been managing the power factor of the plant. As the plant loading is varying with power production of the wind farm, the power factor demand being linked to it keeps changing. This required dynamic power factor correction via STATCOM since there is no on-site power generation.

A. Harmonic Mitigation

Harmonics are managed with 24 and 36 pulse design of the system. The rectifier transformers are also chosen of multi-winding type, which also helps in cancelling some of the harmonics and electromagnetic field & forces around. A single multi-winding transformer feeds two of the rectifiers achieving 12 pulse configurations. Each transformer has a different phase shift which helps in achieving 24 and 36 pulse configurations of the system at upstream voltage level. In addition to managing the harmonics with multi-winding, phase shifted transformers there are harmonic filters of different harmonic orders to bring the harmonics within the utility acceptable range. The transformer and rectifier set up is as shown below.

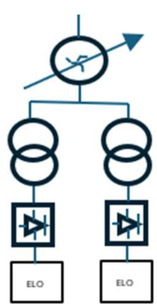

Figure 3 Transformer/Rectifier Electrolyzer set up [2]

To avoid overloading of harmonic filters it is recommended to operate most of the electrolyzers at the equal loading to keep the 24 and 36 pulse configurations of the system achievable. In case of unbalanced operation, the multi-pulse configuration will be lost which will lead to higher harmonic production.

B. Reactive Power Compensation

The reactive power compensation is dynamic in nature, to keep the power factor of the system within the grid compliance requirement. Reactive power produced or consumed in the system is measured, based on the operating scenario, and compensate accordingly.

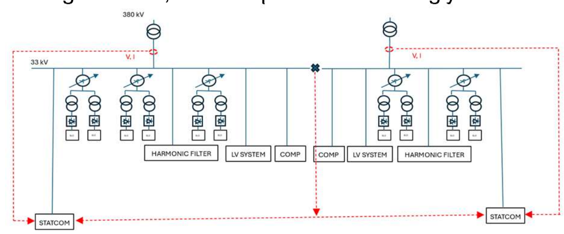

Figure 4 Control scheme reactive power control

All the equipment must work in a synchronized manner to achieve the production with a dynamic load. The production of hydrogen changes according to wind power produced; grid compliance on harmonics and power factor must be maintained. The production of hydrogen is controlled by changing the set points of rectifiers. On change of set points the reactive power demand of the plant also changes. With change of power factor demand the STATCOM takes control of the situation and changes its set point to produce or absorb reactive power as required to keep it within the limits of power factor agreed with the utility company.

C. Electrolyser Control

The production of hydrogen is linked to the power produced by HKN wind farm. The power produced is traded within the project entities per the Power Purchase Agreement (PPA), and is used to schedule production HH1 operations, who based on requirement from the customer end, set the hydrogen production target in the plant controller. This task can be done manually as well as automatically. Based on the set point for hydrogen production, the rectifier controller changes its voltage set point. The voltage on the rectifier terminals is achieved by combination of transformer OLTC position and thyristor firing angle, which is controlled by the rectifier controller. The voltage determines the current flow in the electrolyzer which eventually determines how much hydrogen is produced.

VI. BALANCE OF PLANT

In the total plant the balance of load is less than 10% of the total load. The biggest consumer of balance of the plant are the two reciprocating export gas compressors which compress the hydrogen to the gas grid pressure. The compressors and associated motors are in a hazardous area; Ex P motors have been selected.

All the equipment in the plant have been designed with an electrical fail-safe philosophy: on loss of power the plant can be safely shutdown supported with UPS power which makes operator visualize and control where needed for the safe shutdown. The biggest consumer on the EDGs are polarizers which are standard equipment for the electrolyzers. Polarizers are small rating rectifiers which are used after failure of power to the main rectifier of the electrolyzers to maintain a voltage on electrolyzer cells to avoid reverse flow of electrons leading to damage on electrodes. As this load is not a very large load a single standard plant EDG has been selected; other loads which do not require uninterrupted power are fed from the EDG to reduce UPS size.

VII. CONSTRUCTION

Like all facilities there is an earthing grid for electrical safety (e.g. to manage touch and step potentials). Since the main intake transformer from the 380 kV grid is Y-Y and is solidly earthed, the required values of earthing grid resistance are very stringent, < 0.1 Ohm to manage the touch potential [6]. Achieving this low earth resistance has been a challenging task and to prove it with a measurement value has been a challenge. To manage the situation, we are using the potential rise test on the grid to prove the adequacy of the grid.

200 MW is significant power for a plant in ~ 200 m x 200 m plot. 90% of this power is used by electrolyzers at low voltage with high current and large cross-sectional area. To manage this significant heat produced due to losses, openings are provided in the trench covers for heat dissipation. An option for inspection of cable trenches has been provided with hatches at some intervals to check the health of the cable periodically.

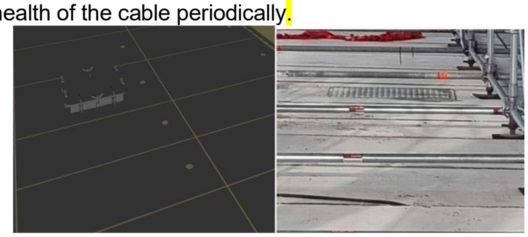

Figure 5 Cable Trench heat vent and inspection hatch

Significant progress has been made with construction of the plant which can be seen with some of the recent site pictures.

Figure 5 Overall Plant Overview

Figure 6 Electrolyzer Hall

VIII. TESTING, COMMISSIONING AND START-UP

The commissioning of the 380 kV switchgear was done by the main electrical contractor. Partial discharge (PD) testing was done on all the gas compartments of the switchgear with acceptance criteria of zero measured PD. Even minor installation defects such as the presence of small amounts of contamination resulted in failure of the test, requiring strip down and reassembly or replacement.

Resonant frequency high voltage testing of cable system was a major task; the capacitance of 6 km of 380 kV cable was so large that the testing team had to bring 2 HV tester units in series to attain the resonance frequency.

The most challenging protection relay testing was for the 380 kV cable differential protection, where the testing setup was GPS time synchronized [7]. The testing of faults within the zone of protection was possible, but to prove the stability of the relay during a through-fault was challenging as the requirement for testing was set that the testing current should be as close as the design of the system which was difficult to create through a single current injection device. Parallel devices were used to create enough current to complete this test.

Credit: Omicronenergy.com

The Stroomplot substation has been energized and is in operation.

Figure 7 Stroomplot 380 kV Substation

At HH1 testing of electrical distribution equipment is complete and the 380kV and 33 kV system have been energized. In the coming months the process loads will be commissioned and energized sequentially.

Figure 8 380kV GIS and the Main Intake substation

Figure 9 Main Intake transformer

The plan for the electrolyzer rectifier testing is to use a resistive load bank. The complexity is involved in managing the controller of rectifiers, transformer OLTC, and then manage the produced hydrogen. There is a lack of big size DC load bank in market, which is bringing challenge in executing this test, but the option is still explored to derisk the challenges of hot commissioning.

Testing activities continue towards ready for startup status of the plant.

IX. CONCLUSIONS

HCP380 is the first 380 kV substation built and in operation by Shell. Following industrial standards – particularly the TSO standard helped significantly.

The electolyzer plant testing, commissioning and start-up activities are ongoing in 2025. The flexible operation of the plant, following the renewable power generation profile will be needed to demonstrate grid compliance over the wide operating range of the plant.

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XI. VITA

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