GREEN HYDROGEN AND POWER-TO-X – USING DIGITAL TECHNOLOGIES TO OPTIMIZE OPERATIONS

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Abstract - In this paper, we investigate the potential of digital technologies to optimize operations of producing green hydrogen and green ammonia, especially in the context of given different sources of electricity and different demands in the downstream process. We show that the combined approach of energy management and optimization together with advanced process control, can lead to life cycle cost reduction of up to 20% and efficiency increase of up to 5% for the electrolyzers.

Index Terms — Green Hydrogen, Green Ammonia, Power-to-X, energy optimization.

I. INTRODUCTION

The use of hydrogen (H2) as an energy carrier and feedstock has been well known for centuries, but in recent years its ability to reduce carbon emissions has made it a popular topic in energy and industrial circles. There have been some exciting projects, from production facilities that operate on renewable energy to novel applications of hydrogen fuel cells, but much remains to be done for H2 to scale up and become a key component of a more sustainable economy and energy system. Alongside using especially excess renewable energy for producing green Hydrogen, the same process can be used to produce green ammonia. Putting all processes together that convert excess renewable generation to another form of energy, may it be producing hydrogen or ammonia is generally called Power-to-X (P2X).

In this paper, we investigate the potential of digital technologies to optimize operations of producing green hydrogen and green ammonia, especially in the context of given different sources of electricity and different demands in the downstream process. Optimizing the production, when facing volatile and multiple sources of energy, while keeping the process of converting the molecules stable and economically viable and at the same time fulfilling the required downstream demand is a very challenging task. With digital technologies, especially using mathematical optimization and advanced process control, we can not only make this process stable, but also bring down the cost for producing green hydrogen and ammonia to a sustainable level.

II. TRENDS AND COST REDUCTION POTENTIAL WITH DIGITAL SOLUTIONS

Global hydrogen demand reached 97m tons in 2023 and could reach up to 100m tons in 2024, with most production coming from unabated fossil fuels (grey hydrogen) which primarily served as feedstock for the refining and chemical sectors. While low-emission hydrogen played a minimal role at less than 1m tons in 2023, it could reach 49m tons a year by 2030 through projects that have already been announced [2].

Hydrogen as an energy source contributes to enhancing grid flexibility, complementing solutions such as batteries and acting as an energy storage medium. This makes hydrogen essential for balancing supply and demand, particularly as more renewable energy sources like wind and solar are integrated.

Currently, Green Hydrogen is seen as too cost expensive to compete with traditional hydrogen generation methods like grey or blue (see Figure 1: The cost of grey, blue, green hydrogen). However, digital solutions as described in this paper, are a key ingredient to lower the cost of hydrogen to become economically viable, together with the advances in abundant renewable energy. Especially, since the production cost within energy industries are currently high, particularly for green hydrogen where electricity represents over 70 percent of operating costs, as described by Boretti and Pollet in [2]. This requires optimized energy management systems and more efficient electrolysis processes sums up to over.

We show in this paper, that with energy management and optimization combined with advanced process control, we expect the life cycle cost of Hydrogen and Ammonia to can be reduced up to 20% and electrolyzer efficiency can be reduced up to 5%, while stabilizing the process operations and reduce process variability through repositioning of key process variables and reduce energy consumption through better rejection of disturbances and events like equipment trips.

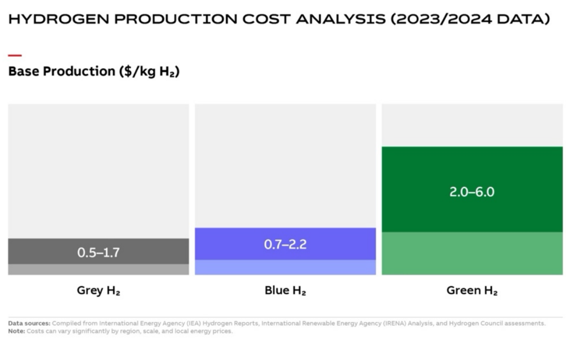

Figure 1: The cost of grey, blue, green hydrogen

III. DIGITAL TECHNOLOGIES FOR GREEN HYDROGEN AND AMMONIA

A. *Green Hydrogen and Ammonia enable sustainable circular processes – a real-world example*

In order to access the full potential of Power-2-X solutions, Power-2-X sites are located near easily available electricity, namely large off-shore/on-shore wind parks or large solar fields, and near a consumer oft he produced hydrogen or ammonia, typically energy intensive industries like steel, cement but also bus and truck operators building up a fleet of H2 fueled vehicles.

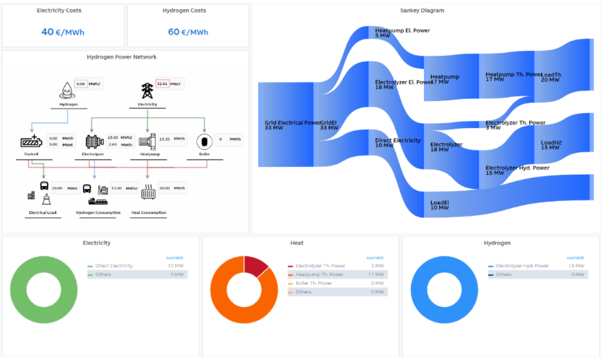

Figure 1: Example of an integrated energy system with a fuel cell, electrolyzer, heat pump and an auxiliary boiler. The right part of the picture shows the power flows resulting from operation.

In this example, sufficient renewable electricity is reflected in the relatively low electricity price of €40/MWh compared to €60/MWh for hydrogen. In this case, the electrolyzer is used to produce green hydrogen. The heat supply is provided by the heat pump, combined with waste heat from electrolysis. The current electricity demand is covered directly from the grid. If this setting is changing, for example the renewable energy is decreasing, the same facility can use other sources of electricity (within the framework of accounting for green H2 or Ammonia) to produce in order to avoid too big step changes or shutting down the production facility.

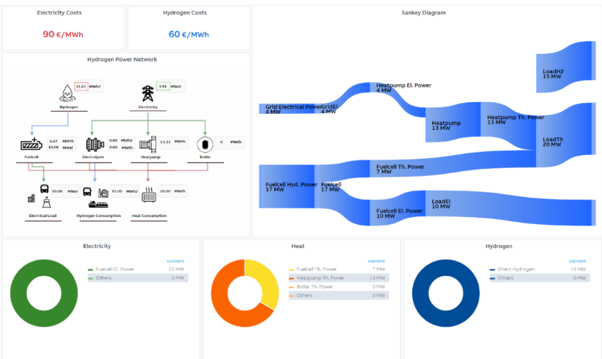

Figure 2: Exemplary integrated energy system – high-price scenario.

Figure 2 shows the lack of renewable electricity as an example with a high electricity price of €90/MWh. In this case, the hydrogen demand is met from the storage system. In addition, the fuel cell is used for reconversion into electricity. The heat pump is also needed in this scenario. The example shows how an energy site covers the demand for electricity, heat and hydrogen by adapting its operating methods.

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B. *Digital technologies enable reduction of CAPEX and OPEX*

CAPEX and OPEX are reduced via optimal asset orchestration. For this optimal orchestration, we need a sophisticated optimization system, based on mathematical optimization to compute the optimal operating points for the controllable assets, like the electrolyzers, fuel cells, storage devices – to optimize the total value of the energy in the integrated circular process (H2, ammonia, electricity, thermal, etc). Additionally, accurate forecasting of the energy demand and supply as input for the optimization is crucial. This all can be balanced out with the prices on the energy market and – here a very powerful handle of making even more value – taking advantage of opportunities in the balancing power market, capacity market or ancillary services.

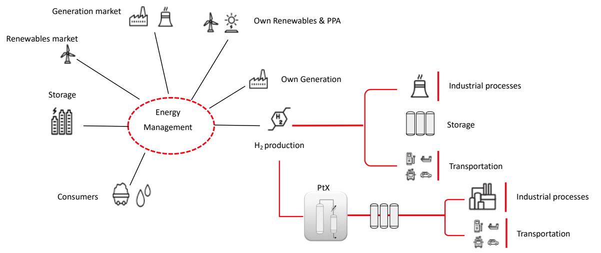

Figure 3: This figure visualizes the complexity that an optimization systems needs to account for and balance the different players out, so that the value of the produced hydrogen / ammonia is maximized and the cost for providing exactly the needed downstream demand at the industrial process or the transportation need is minimized.

C. *Typical Use Cases*

We encounter such scenarios typically in a combination of the two use cases:

a) A utility is looking to make better use of excess renewable power instead of selling it at lower prices. With an optimization system, the utility can optimally orchestrate energy flows based on renewable generation and downstream demand. The utility can also use a hydrogen plant to convert the excess wind power or solar power into hydrogen. Downstream consumers, such as industrial plants, heavy industry, and hydrogen fuel stations, can consume the produced hydrogen. As a result, the utility can leverage excess renewable power, selling it for the optimal price and optimal time.

b) An industrial plant is looking to decarbonize its industrial processes, replace grey hydrogen with green hydrogen, and exploit and avoid peak times and prices. The facility implements an energy management and optimization system to monitor, control and optimize multiple individual electrolyzer modules at the plant. In this way, the facility can balance available energy sources to ensure availability, while leveraging optimal market pricing. As a result, reducing the plant's OPEX lifecycle cost by up to 20%.

IV. TECHNICAL SOLUTION

A. Set-up of energy optimization and advanced control

The technical solution normally comprises multiple digital solutions that interact in high frequency with each other. We describe a case, where we use an energy management and optimization system together with an advanced process control solution.

The energy management and optimization solution interacts with the energy market, the forecast results, as well as the demand requirements and efficiency curves of the electrolyzers, so that it can compute an optimal schedule in a multi-step approach with predictive and real-time optimization. The advanced process module natively integrates with the energy optimization system and allows configuration of flexible strategies for Energy Optimization and Process Optimization, where APC acts as an enabler for site optimization strategies and energy market real-time interaction. Ist sophisticated Model Predictive Control technology manages and optimizes the process units, increase throughput, increase energy efficiency and reduce production costs by operating safely at close to process constraints and limits.

Figure 4 shows the ideal setup for the interaction of the energy management and optimization system (often called "energy real time optimizer") and the advanced process control.

The Challenging part of this setup is, that Electrolysis production plants are often coupled directly with renewable energy production units (e.g. onshore and offshore wind parks), need to fulfil a specific hydrogen demand schedule and/or are additionally operated based on specific market conditions (as described in the use cases). The specific operation requirements of each individual production plant is considered and forms a predictive operation based on the forecasts with information above and security constraints like max. and min. power, ramping or degradation.

B. Predictive optimization and real-time control

The **predictive intraday optimization** of such plants empowers the operator to identify potential flexibilities which can be positioned more efficiently within the spot market.

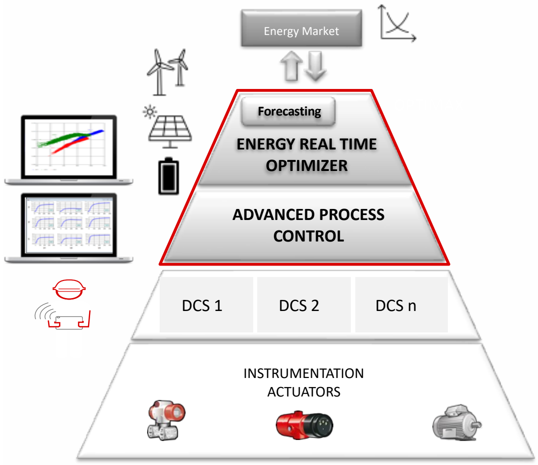

Figure 4: Ideal set-up for the interaction of energy real time optimizer and advanced process control

During the conceptual design phase and feasibility study, the predictive optimization can also advise with simulations in order to check profitability when adding flexibility options like hydrogen storages or enabling sector coupling reusing waste heat.

To achieve the required operation, a **realtime control** needs to be applied. Based on the current overall setpoint (see upper left corner in Figure 5), the power must be distributed in an optimal way to the single electrolyzer modules. The control functionality consists of:

- Safety constraints for each individual electrolyzer module. Operation only within predefined bounds.
- Simple color code for each operation point of individual modules, e.g. blue for the operation at the minimum, green between the borders and red for the operation at the maximum (see upper area in Figure 5).
- Monitoring for historical operation points, historical heat and mass flows and efficiencies for individual modules (see mid and lower area in Figure 5).
- Optimal operation based on physical safety constraints and efficiency curves for individual modules.

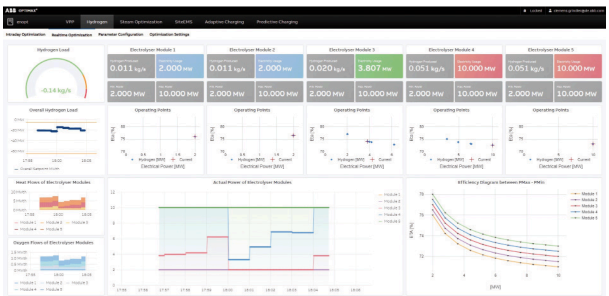

Figure 5: Realtime control of green hydrogen or ammonia production

The realtime control may consider ancillary service calls based on individual reserve market participation. Especially primary and secondary ancillary services are of interest in order to increase the profitability of the plants. Additional monitoring of subcomponents, specific KPI's and overall plant performance can help to ensure a safe operation and to find efficiency bottlenecks.

C. *Market Integration*

The **market integration** is visualized in Figure 6. Based on forecasts for electricity prices and energy demand, operation is planned by means of day-ahead optimization. Deviations from the forecasts are cyclically corrected via intraday optimization, which leads to the adjustment of the planning of the operation.

During the planning phase, belts are kept free for grid services. In addition, tertiary control (mFRR), secondary control (aFRR) and primary control (FCR) are provided. Since the primary control has to be carried out very quickly, the energy management system passes on the power bands planned for this purpose to the subordinate control system, where specific target values are determined directly from the grid frequency within the specified bands.

If there are fewer and fewer rotating masses in the energy system in the future, virtual flywheels will represent another important grid service.

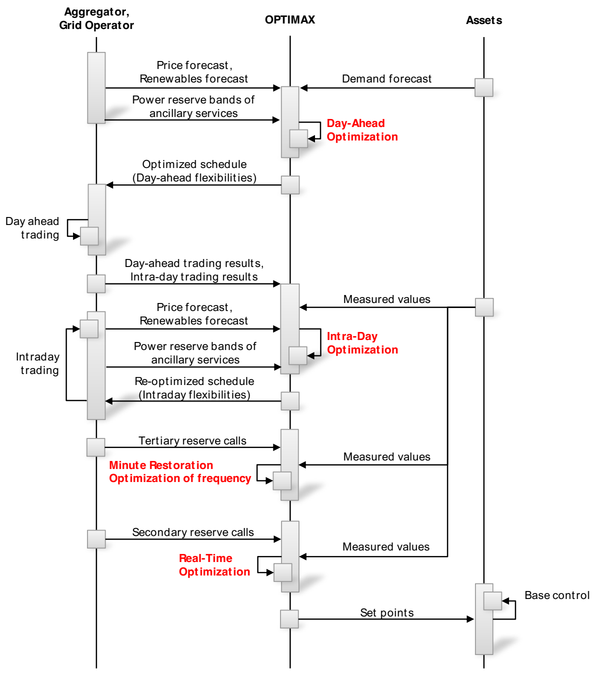

Figure 6: Communication flows for market integration and the operation of an energy site

V. REFERENCE CASE – HYNAMICS AUXERRE

Such a described energy and optimization system is deployed by **Hynamics, the hydrogen subsidiary of EDF group,** at Auxerre, Hynamics' first production and distribution site in Northern Burgundy, approximately 170 km southeast of Paris. The 1 MW hydrogen station for the urban community will supply five buses of the Leo network (Transdev), as well as light commercial vehicles and trucks, removing 2,200 tons of CO_2 emissions from the road each year.

In order to achieve theses optimization results, production costs for low carbon and renewable hydrogen, the performance of the electrolyzer process – which uses electricity from renewable sources to split water molecules into hydrogen and oxygen – is improved by the energy management and optimization system. The system provides data which can help determine optimal energy consumption levels required to produce hydrogen and minimize waste. The tool considers, among other things, the variability of electricity prices, asset availability and other associated factors.

The first studies show, that electrical costs of hydrogen production can be reduced by up to 16 percent. The 16% saving has been calculated by ABB Corporate Research Center in 2022 and is based upon an optimized versus an unoptimized operation of a hydrogen plant. The results showed an estimated reduction of >14% in electricity costs and >2% in electrical consumption. Thus, the lower bound of electrical cost reduction is up to 16% (see [1]).

Figure 7: AuxHYGen 1 MW hydrogen station for the urban community supporting local bus network

VI. CONCLUSION

With a combined approach of energy management and optimization together with advanced process control, we showed that we can

- Stabilize H2 Networks, minimize let down to Fuel Gas, avoid losses of valuable Hydrogen
- Optimal planning of the integrated circular energy system based on forecasts (renewable generation, demand and electricity price)
- Enabling efficient production balancing – favor Green, Blue, Turquoise or Grey/Black considering renewables availability & forecasting and electricity prices
- Interact with Energy Markets – automatic preparation of proposed energy purchase/sale to market or Energy Trader to capture opportunities to minimize H2 costs
- Manage process dynamics – handle delays, long settling times and impact of forecasting on Hydrogen balance
- Integrate grid services and flexibility options - demand response, FCR, aFRR, Intraday-Markets
- Optimize ancillary revenues while preserving equipment limits and constraints, considering Maximum ramp rates, Dynamics and Harmonics/Reactive Power constraints / requirements with integrated electrical digital twin.

This can lead to the reduction of life cycle cost of up to 20%, efficiency increase of up to 5% for the electrolyzers.

VII. REFERENCES

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VIII. VITA

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