

Optimization of Operating Sequence of Electrolyzer Units for Hydrogen Production

Copyright Material PCIC Europe
Paper N° PCIC energy EUR26_08

Joseph Mathew
Shell India Markets Pvt. Ltd
Shell Technology Centre
Bangalore 562149
India

Dhaval Patel
Shell India Markets Pvt. Ltd
Shell Technology Centre
Bangalore 562149
India

Amulya K Sahoo
Shell Research Limited
Shell Centre London
SE1 7NA
United Kingdom

Abstract – The electrolysis process has emerged as a cornerstone technology for sustainable industrial applications, particularly in the production of green hydrogen, driving the development of gigawatt-scale plants. Among the various electrolyzer technologies, Alkaline Water Electrolysis (AWE) continues to dominate due to its technological maturity and operational reliability. AWE systems are characterized by low-voltage, high-current requirements, making thyristor-based controlled rectifiers the most practical solution. However, when integrated with the electrical grid, these systems generate substantial harmonic currents, necessitating large harmonic filters that significantly increase both spatial footprint and Capital Expenditure (CAPEX). This study introduces a novel sequencing methodology designed to enable partial-load operation while reducing source harmonic currents. The proposed approach effectively reduces harmonic filter size requirements, thereby optimizing plant layout and lowering overall system costs.

Index Terms — Green Hydrogen, Electrolyzer, Power system, Thyristor, Harmonics

I. INTRODUCTION

The global energy system is rapidly evolving to reduce greenhouse gas emissions, and hydrogen is increasingly viewed as a critical option for decarbonizing hard-to-abate sectors such as heavy industry, chemicals, and long-distance transport. While progress is uneven, recent global assessments underscore hydrogen's potential to complement electrification where direct use of renewable power is challenging. Today, most hydrogen is produced from fossil fuels, predominantly via steam methane reforming (SMR), with low-emissions hydrogen accounting for less than 1% of global production in 2023. U.S. data show a similar pattern, with ~95% produced via SMR [1]. This legacy pathway carries substantial lifecycle CO₂ emissions absent carbon capture. To align hydrogen supply with decarbonization targets, industries are adopting water electrolysis powered by renewable electricity ("green hydrogen"), which splits water into hydrogen and oxygen with very low operational emissions when renewable power is used. Commercial electrolyzer technologies include Alkaline, Proton Exchange Membrane (PEM), Solid Oxide Electrolyzer Cell (SOEC), and Anion Exchange Membrane (AEM) systems, each with distinct operating conditions and maturity levels; AEM is emerging compared to mature alkaline and PEM systems, and SOEC is advancing toward larger-scale deployment. Regardless of type, hydrogen output is proportional to the DC current delivered to the stack. At

multi-megawatt scales, electrolyzers are frequently supplied by thyristor line-commutated rectifiers due to their robustness at high currents. However, these rectifiers introduce significant input current harmonics and reactive power demand, especially under partial loading [2], which can degrade power quality and complicate grid code compliance. Plants typically deploy passive and/or active harmonic filters and compensation equipment, adding capital cost and footprint. This paper addresses these challenges by proposing an operating sequence/control methodology that enables partial-load operation while reducing source harmonic currents, thereby lowering filter ratings and associated CAPEX and space requirements for large-scale green hydrogen production facilities. Section II gives a summary of existing electrolyzer technologies and the need to decarbonise the hydrogen production. Section III describes a review of power supply topologies normally used for large scale electrolysis. Section IV gives a brief technical review of multi-pulse rectifiers and the topology for multi-pulse rectifiers. Section V gives the innovative operating sequence for optimal use of the multi-pulse rectifier for reducing operating cost and filter size requirements.

II. REVIEW OF EXISTING ELECTROLYZER TECHNOLOGIES

A. History of electrolysis technology

Electrolysis is the process of splitting water molecules into hydrogen and oxygen using DC current. Electrolysis has been used commercially for over a century, with the major application being ammonia production for the fertilizer industry. Other chemical manufacturing also thrived with the invention of the electrolysis process as well as the metallurgy industry.

Throughout the 20th century, advancements in electrode and cell design paved the way for Alkaline Water Electrolysis (AWE), which is still considered the workhorse of electrolysis. AWE technology helped in the advancement of new technologies like PEM, SOEC etc. PEM technology allowed the physical size reduction of the electrolyzer while SOEC allowed for high temperature efficiency. All these new technologies are aimed at making energy with reduced greenhouse gas emissions at an industrial scale. It represents a change in production from fossil fuel based to renewable based energy production.

B. Electrolyzer technologies

1. PEM Electrolyzer

They were introduced in the 1960s by General Electric. The electrode materials used are mainly

platinum, iridium, ruthenium, and platinum on carbon, while solid polymer material is used as the electrolyte. PEM electrolyzers operate at a temperature of 50 to 90 degree Celsius, under an operating pressure of 15 – 30 Bar.

2. Alkaline water electrolyzer

AWE is the most widely used in industrial applications as it is the most mature electrolyzer technology. 20 – 40% NaOH is used as the electrolyte and while several electrode materials have been tested, Cu/Ni/Mo cathode material is found to have the highest hydrogen production by volume. The performance of AWE technology heavily depends on the geometry of the electrode materials. Compared to PEM, AWEs use a corrosive liquid electrolyte.

3. Solid Oxide Electrolyzer Cell (SOEC)

SOEC is the new and emerging technology in the electrolysis space. SOECs have a higher overall efficiency, compared to PEM and AWE even though they operate at higher temperatures. The electricity required to drive the SOEC is lower, as it used the waste heat from other processes to increase the temperature. The cathode material used is a mixture of lanthanum strontium manganite and yttrium-stabilized zirconia, and the anode materials are mostly ceramic based.

III. POWER SUPPLY TOPOLOGIES FOR ELECTROLYZER

Electrolyzers require a stable and regulated DC supply for their operation, while the utility grid typically provides a three-phase AC supply. This creates the fundamental need for an AC-to-DC conversion stage, accomplished through rectifiers [4]. In most large-scale projects, a combination of thyristor rectifier and tap-changing auto-transformers are used. This allows finer control of voltage in the system, and having a smaller range in the firing angle, reducing the reactive power consumption of the system. Diode rectifiers are also used for projects, along with AC voltage regulators or tap changing transformers. In these systems, the diodes operate as line-commutated devices with no active switching control.

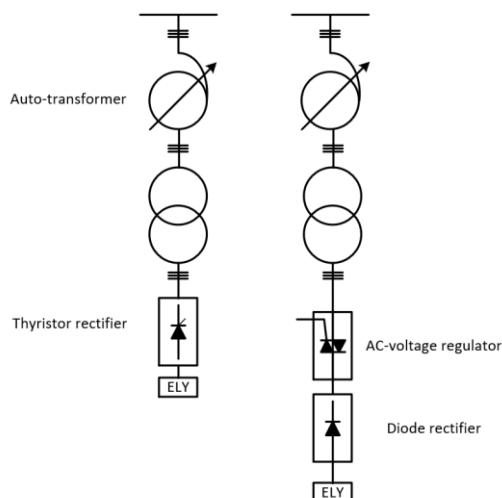


Fig. 1. Some commonly used topologies for electrolyzer projects

When multiple rectifiers are combined with appropriately phase-shifted transformer secondary windings, the harmonic content of the line currents can be significantly reduced. This results in improved power factor and lower Total Harmonic Distortion (THD), contributing to better power quality when supplying large DC loads such as electrolyzers. (Fig. 2)

When electrolyzers are powered using directly connected renewable energy sources like solar or wind, additional design challenges arise. Renewable energy is inherently intermittent, with fluctuations resulting from environmental variations and changing operating conditions. The power supplied to the electrolyzer therefore becomes non-constant, and in the absence of a controllable rectification stage, these variations directly translate to fluctuations in DC output. Direct coupling of a renewable source such as solar PV to the electrolyzer, while simple, results in uncontrolled hydrogen production and rapid current oscillations. These uncontrolled operating conditions can lead to detrimental effects on the electrolyzer stack, including cathodic degeneration, membrane stress, catalyst layer damage, and long-term deterioration of the cell structure. Such degradation reduces system efficiency, shortens stack lifetime, and increases operation and maintenance costs.

Most of the large-scale projects for hydrogen generation use thyristor rectifiers, along with tap changer transformers for a wider range of voltage control. The firing angle for the thyristors are maintained at a very narrow range, typically from 15 to 35 degrees. Although a higher firing angle range will allow for a wider range of voltage control, there are drawbacks to this method. Firstly, a low firing angle, although it allows for higher voltage, the commutation between the devices will be the bottleneck. Overlap between the conducting devices will cause a momentary short circuit in the DC side, reducing the output voltage, essentially, nullifying the benefit of having a lower firing angle. Higher values of firing angle will reduce the output voltage, also increasing the reactive power requirement of the rectifier.

Advancements in power electronics have enabled the use of fully controlled rectifiers based on IGBTs and silicon carbide (SiC) MOSFETs. These devices offer complete control over both turn-on and turn-off events via gate signals, allowing high-frequency switching in the tens of kilohertz range. High-frequency switching significantly improves the quality of AC current drawn from the grid, reducing THD and allowing operation at near-unity power factor. Moreover, the higher switching frequency leads to much smaller filter components, reducing both capital expenditure and physical footprint. Fully controlled PWM rectifiers provide precise and instantaneous regulation of DC output, ensuring that the electrolyzer stack receives smooth and controllable power even during rapid changes in renewable generation. This capability prevents stress on the stack, enhances efficiency, extends component lifetime, and allows the electrolyzer to operate safely under highly variable conditions.

While modern controlled rectifiers offer superior dynamic performance and power-quality characteristics, practical deployment considerations remain significant. High-power electrolyzer installations typically operate at multi-megawatt scales where cost, current-handling capability, and reliability are critical. Diode and thyristor-based rectifiers still dominate in this space. Although additional stages—such as DC–DC converters or tap-changing transformers—may be required to achieve

precise voltage control, the robustness and commercial maturity of diode and thyristor-based solutions make them the most widely adopted choice in large-scale hydrogen production facilities.

IV. MULTIPULSE RECTIFIERS

Diode/Thyristor rectifiers are widely used in industrial applications where scale is of importance. As mentioned in the previous section, the next generation of semiconductor devices provide much more freedom of operation and high degree of controllability and performance. For large-scale production facilities, what is required is to be able to scale production to large-scale, while being commercially viable.

A. Theory of zig-zag winding

This type of winding is also called interconnected star winding, normally used in neutral formation, harmonic suppression, grounding transformers etc. While conventional star-delta transformers can produce only conventional set amounts of phase angles, Zig zag windings are an inexpensive way to obtain small, precise phase shift angle. Phase shifts are essential in removing 5th and 7th harmonic currents, reducing the incoming current THD, and thereby improving power quality. This is the reason why they are most used in multi-pulse systems.

In zig-zag windings, each phase is composed of two (equal/unequal) halves, located on two different core legs. Each phase has 120 electrical degrees of separation between the induced voltages, and because of this separation, the resulting phasor becomes a synthetic phasor, shifted slightly from the original system phase. To calculate the exact phase angle and voltage of the zig-zag winding, the following formula can be used.

$$V_{\text{zig-zag}} = V_1 + x \cdot V_2$$

Where V_1 and V_2 are the voltage vectors related to core limb A and core limb B respectively. V_2 leads V_1 by 120 degrees and by selecting a suitable value of x , it is possible to obtain non-conventional phase angles used in industrial applications. For example, to get a phase shift of 15 degrees, the value of x is 0.267. This means that to get the primary MMF phase angle of 15 degrees, if there are 1000 turns in core limb A, then there should be 267 turns in core limb B.

The major drawback of zig-zag winding is the complexity required to manufacture the transformer, and the required copper per unit of power delivered is high, driving up the cost.

B. Topology configuration

In large multi-megawatt industrial installations, it is standard practice to distribute the total load across multiple transformers rather than rely on a single unit. This approach improves system reliability and helps limit the harmonic currents drawn from the utility supply, which are regulated under the IEC 61000-3 series. IEC 61000-3-2 specifies allowable harmonic current emissions for equipment drawing up to 16 A per phase, while IEC 61000-3-12 applies to equipment with input currents between 16 A and 75 A per phase, both defining limits for individual harmonic orders to maintain power quality. However, even when harmonic emissions comply with these standards, the inherent impedances of transformers, cables, and network

components cause harmonic voltage drops whenever nonlinear loads operate. These drops distort the supply voltage seen by rectifiers, a phenomenon well documented in power-quality studies identifying voltage waveform distortion as a key consequence of harmonic currents interacting with system impedances. Once the distorted AC supply reaches the rectifier, the resulting DC output exhibits increased ripple and voltage instability, which directly affects electrolyzer stacks. Because electrolyzers are highly sensitive to fluctuations in DC voltage, such instability accelerates component degradation, reduces operational efficiency, and ultimately shortens the usable lifespan of the electrolyzer system, thereby increasing maintenance and operating costs.

For a 96-pulse rectifier, the angle of the primary MMF is decided by the following formula:

$$\theta_{\text{phase shift}} = 360/\text{pulse number}$$

Here, the angle displacement to be provided to each of the zig-zag winding is $360/96 = 3.75$ degrees.

Each transformer feeding the system is configured with a zig-zag primary winding and a dual secondary arrangement consisting of star (Y) and delta (Δ) outputs. This transformer configuration supplies power to a 12-pulse rectifier system.

A 12-pulse rectifier is formed by connecting two separate three-phase bridge rectifiers to the transformer's secondary windings:

1. One rectifier is fed from the star-connected (Y) secondary winding.
2. The other rectifier is fed from the delta-connected (Δ) secondary winding.

Because of the inherent phase shift between star and delta connections, the input phase voltages feeding the two rectifiers are naturally displaced by 30 electrical degrees. This phase displacement is essential for reducing harmonic distortion in the rectifier output by enabling 12-pulse operation. [5]

The transformer's star and delta windings are designed with an appropriate turns ratio so that the line-to-line voltage magnitudes supplied to both rectifiers are equal, even though their phase angles differ. Equal voltage magnitudes ensure balanced operation of both bridges and proper sharing of load current.

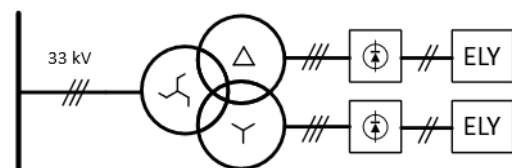


Fig. 2. 12-Pulse converter

The DC output terminals of the two three-phase rectifier bridges are then connected to each electrolyzer. This connection combines their individual outputs to form a higher DC current, while the 30-degree phase displacement between the AC inputs ensures that the 12-pulse waveform characteristics—such as reduced harmonics and smoother DC output—are achieved.

V. OPERATING SEQUENCE OF RECTIFIERS

As discussed, large-scale hydrogen production plants must continuously adapt to fluctuations in renewable

energy availability as well as variations in hydrogen demand. These fluctuations often prevent the plant from operating all installed electrolyzer units at their rated capacity. In practical operation, this means that even when all eight rectifier–electrolyzer units are energized, many periods arise where the system must run at a reduced load. Under such partial-load operating conditions, it becomes essential to regulate the DC power delivered to each electrolyzer stack to maintain stable hydrogen output, protect stack health, and ensure compatibility with upstream electrical constraints.

For thyristor-based rectifiers, this power regulation is achieved through adjustment of the firing angle. By shifting the firing instant of the thyristors relative to the AC waveform, the effective output voltage of the rectifier can be smoothly modulated, enabling the electrolyzer to operate at any desired power setpoint within its allowable range. This inherent controllability makes thyristor rectifiers suitable for applications requiring flexible power regulation, although this comes at the cost of increased harmonic distortion, especially at lighter loads.

Diode rectifiers, in contrast, do not possess any inherent means of regulating their output voltage, as their operation is dictated solely by the applied AC voltage and transformer configuration. To enable partial-load operation in diode-based systems, it is therefore necessary to introduce a downstream DC–DC buck converter. By adjusting the duty ratio of this converter, the output voltage supplied to the electrolyzer can be precisely controlled, allowing smooth power modulation even when the rectifier itself operates at a fixed voltage. This arrangement not only enables controlled hydrogen production under variable renewable input conditions but also mitigates rapid current fluctuations that could otherwise accelerate stack degradation.

In the analysed plant configuration, the total installed capacity is denoted as X MW. When the electrical system can supply the full X MW, the plant operates at its maximum capacity with all units running at rated power. During partial-load scenarios, operational constraints require that each electrolyzer unit be maintained at no less than 50% (turn down) of its rated power. Operating below this threshold is avoided because such conditions, when combined with the voltage and power ripple inherently produced by rectifier systems, can significantly accelerate degradation of the electrolyzer stacks and reduce their operational lifetime. To manage power quality and distribution within the system, the plant employs a series of zig-zag transformers whose primary windings are deliberately phase-shifted. Each transformer is offset by 3.75° relative to the preceding unit, resulting in a cumulative phase shift of 26.25° between the first and last transformers in the series. This staggered phase-shift arrangement supports harmonic mitigation and ensures smoother power delivery to the electrolyzer units, thereby enhancing overall system reliability and performance.

The sequencing strategy for operating the rectifier units is designed with two primary objectives: minimizing the overall filter size requirement of the plant and reducing the frequency of shutdown and startup cycles of the electrolyzer units. Frequent cycling of electrolyzer units is undesirable because each startup and shutdown event necessitates the activation of auxiliary Balance of Plant (BOP) systems, which provide the necessary pressure and temperature conditioning required for safe and stable operation. These auxiliary processes contribute to additional energy consumption, mechanical wear, and

operational delays. Consequently, maintaining an electrolyzer unit in continuous operation is generally more advantageous than subjecting it to repetitive startup–shutdown cycles. By carefully sequencing the loading and unloading of rectifiers, the system can maintain smoother power delivery, optimize the utilization of filtering equipment, and enhance the overall reliability and operational efficiency of the plant.

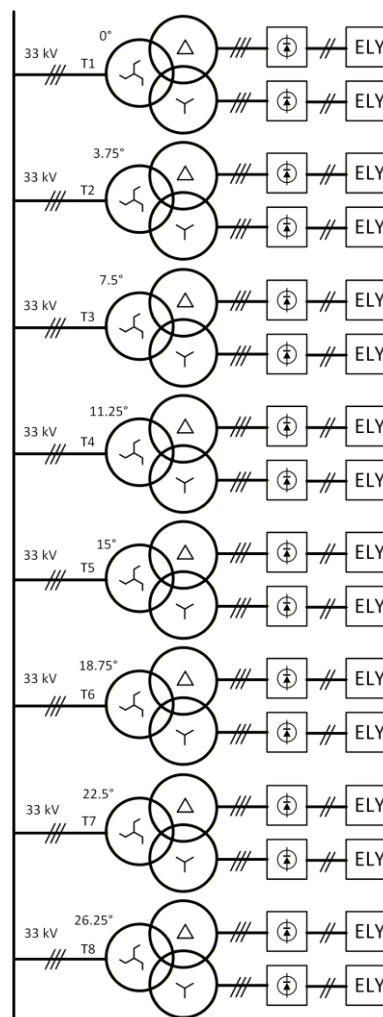


Fig. 3. Architecture of the system (ELY - electrolyzer)

The sequence of operation is explained as follows:

1. If the power requirement is from $X/2$ to X , then all the rectifier and electrolyzer units are in operation. This ensures that all the electrolyzer units are operated above the half power point. This mode is the complete 96 pulse operation, with the highest harmonic order.
2. For the power ranges from $X/4$ to $X/2$, transformers T1, T3, T5, T7 are in operation. The phase of the primary MMF of these transformers are 0 , 7.5 , 15 and 22.5 degrees respectively, such that the system operates in 48 pulse mode operation.
3. For power range in $X/8$ to $X/4$, transformers T1 and T5 are in operation, with the primary MMF being 0 and 15 degrees respectively, giving a 24-pulse operation.
4. For very low power, less than $X/8$, only T1 is in operation, giving a 12-pulse operation.

Load	Operating units	Type of operation
X/16* to X/8	T1	12 – pulse
X/8 to X/4	T1, T5	24 – pulse
X/4 to X/2	T1, T3, T5, T7	48 – pulse
X/2 to X	T1, T2, T3, T4, T5, T6, T7, T8	96 – pulse

*For 50% Turndown

Table 1. Operating sequence

An important question that may arise when examining the proposed operating sequence is why the plant does not simply use an alternative combination of transformers, given that the primary objective is to achieve a specific pulse number. For instance, a 48-pulse configuration could theoretically be obtained by operating transformers T2, T4, T6, and T8 instead of the standard sequence using T1, T3, T5, and T7. From a harmonic perspective, both transformer sets would yield identical input voltage and current profiles, thereby offering equivalent power quality performance. However, the rationale behind selecting the specific operational sequence extends beyond harmonic cancellation alone. The chosen strategy aims to minimize the number of electrolyzer units that must undergo startup and shutdown cycles. Since each transition requires engagement of auxiliary Balance of Plant (BOP) systems, frequent cycling results in additional energy consumption, increased wear on mechanical components, and overall inefficiency. Operationally, it is significantly more economical and practical to bring a single unit online than to shut down one unit and simultaneously initiate two others merely to achieve the same pulse operation. Thus, the selected transformer sequence not only preserves the desired harmonic performance but also enhances system reliability, optimizes operational effort, and reduces lifecycle costs for the electrolyzer system.

While selecting the system architecture, the strength of the grid plays an important role. Grid strength is defined as the ratio of short circuit MVA to the full load power, often called Short Circuit Ratio (SCR). This is an indication of the short circuit power that can be provided by a system, without the complete collapse of the network. A high SCR is indicative of a strong grid. Weak grids typically have an SCR less than 3, and strong grids have SCR greater than 5. A weak grid will have much more variations in the input sinusoidal voltage profile with respect to the load connected to it. If the load is highly non-linear with considerable current THD, then the voltage that is seen at the input of the load will also have significant deviations from sine wave.

Pulse Number	Dominant Harmonic Order	Typical Input Current THD	Typical Input Voltage THD	Approx. Harmonic Factor, k
6	5,7,11,13	30%	3 - 5%	0.27
12	11,13,23,25	8 - 12%	1 - 2%	0.114
24	23,25,47,49	2 - 3%	~ 0.5%	0.057
48	47,49,95,97	Around 1%	0.2 - 0.3%	0.028
96	95,97,191,193	< 0.5%	< 0.1%	0.014

Table 2. Harmonics of multi-pulse rectifiers for a typical strong grid (SCR ~ 7) [6]

For varying grid strength, voltage THD also varies. The variation of the voltage THD with grid strength is given below.

Grid strength (SCR)	6-pulse	12-pulse	24-pulse	48-pulse	96-pulse
30	0.90%	0.38%	0.19%	0.093%	0.047%
20	1.35%	0.57%	0.29%	0.14%	0.07%
10	2.70%	1.14%	0.57%	0.28%	0.14%
5	5.40%	2.28%	1.14%	0.56%	0.28%
3	9.00%	3.80%	1.90%	0.93%	0.47%
2	13.5%	5.70%	2.85%	1.40%	0.70%

Table 3. Input voltage THD variation with grid strength and pulse number

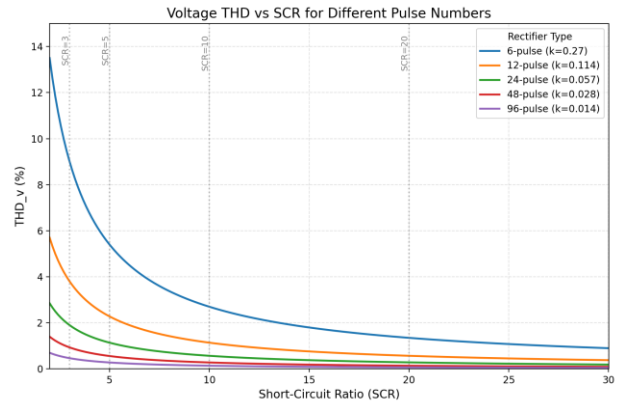


Fig. 4. Input voltage THD variation with grid strength and pulse number

For megawatt scale projects, 8 such transformers are used, where each of the primary MMF is phase shifted by 3.75 degrees, to push the input current harmonics to 95th and 97th order, beyond the minimum harmonic order of 50 as specified in IEC standards.

This sequencing strategy enables optimal rectifier mode selection across varying power levels. For lower power demands, 12- or 24-pulse rectifiers are employed, effectively minimizing harmonic current contributions. As load requirements increase, the system transitions to 96-pulse rectifiers, which offer improved harmonic performance and ensure compliance with IEC harmonic standards. Together, this staged approach delivers a scalable, standards-aligned solution for diverse operating conditions.

CONCLUSION

This work presented an innovative sequencing strategy for operating a multi-pulse rectifier system in large-scale electrolysis plants. The proposed methodology integrates power availability, hydrogen production demand, and system-level operational constraints into a unified sequencing framework. By explicitly accounting for input current and voltage harmonic limits, the approach achieves substantial reductions in filter sizing requirements, resulting in meaningful CAPEX savings without compromising grid compliance or system reliability. In addition to electrical performance optimization, the sequencing strategy places strong emphasis on plant-wide operational efficiency. By systematically selecting operating sequences that minimize the number of electrolyzer startups and shutdowns, the method reduces the burden on balance-of-plant (BOP) equipment and extends

component life. This coordinated consideration of electrical constraints, production targets, and mechanical stress factors ensures that the overall system operates with both high flexibility and high availability.

A version of this system is currently being implemented in multi-megawatt scale projects in the Netherlands and will soon prove to be a viable and cost-competitive technology for large electrolysis projects.

Taken together, the proposed sequencing operation forms a comprehensive pathway to minimizing both CAPEX and Operational Expenditure (OPEX) for large-scale hydrogen production facilities. It enables improved operability, optimized electrical performance, and reduced auxiliary system requirements, thereby supporting the deployment of economically viable and grid-friendly electrolysis installations. Future work can extend this framework to incorporate dynamic grid conditions, renewable generation variability, and predictive maintenance strategies to further enhance system robustness and lifecycle cost performance.

VI. REFERENCES

- [1] IRENA (2018), Hydrogen from renewable power: Technology outlook for the energy transition, International Renewable Energy Agency, Abu Dhabi.
- [2] B. Yodwong, D. Guilbert, M. Phattanasak, W. Kaewmanee, M. Hinaje, G. Vitale, "AC-DC Converters for Electrolyzer Applications: State of the Art and Future Challenges", in *Electronics* 2020, 2020, 9, 10.3390/electronics9060912, hal-02733976
- [3] M H Kebede, F Ustolin, S Völler, M Korpås, I Oleinikova, System integration of large-scale green hydrogen production: Conceptualization, challenges, and opportunities, *Energy Conversion and Management: X*, Volume 28, 2025
- [4] J. S. Dudor and L. K. Padden, "Protective Relaying on Medium and High Voltage Systems, Some Lessons To Be Learned," in *IEEE PCIC Conference Record*, 1994, pp 53-61.
- [5] Bin Wu, "High Power AC Drives", Wiley – IEEE Press
- [6] ABB Technical Guide No. 6 "Guide to harmonics with AC drives".

VITA

Joseph Mathew graduated from Indian Institute of Technology Madras in 2025 with an MTech degree in Electrical Engineering. He has been working as an electrical engineer in Shell India Markets Pvt. Ltd. (Shell Projects & Technology) since 2025. He is interested in the areas of power systems, power electronics and DC-DC converters and has authored two previous papers. Joseph.Mathew@shell.com

Dhaval Patel received his master's degree in Power Electronics from VIT University, Vellore, India, in 2015. He is currently an Electrical Engineer in the Green Hydrogen Technology team at Shell, where he has been working since 2023. He has a total of 10 years of professional experience in HVDC system design and power-electronics product development. D-P.Patel@shell.com

Amulya K. Sahoo graduated from Utkal University in 1995 with a B. E. degree in Electrical Engineering. He has been working in Oil and gas Industry in last 30 years (20 years in Shell). He is currently working as Principal Power-to-Hydrogen Integrator at Shell Research Limited, based in London, UK. His main interest is power system design, renewable coupled electrolysis, hydrogen production optimization etc. a.sahoo@shell.com