Thyristor Vs IGBT Rectifiers for Green Hydrogen Production – Which Reigns Supreme?

“One needs to examine the pros and cons of Thyristor Vs IGBT Rectifiers to determine the ideal choice for green hydrogen production.”

Amidst the surging demand and fascination surrounding Green Hydrogen production, a burning question lingers in the minds of every conscientious electrical engineer: Which technology should we embrace? Who reigns supreme in the Thyristor Vs IGBT Rectifiers game? This question haunts EPC companies, consultants, and advisors throughout the supply chain. The quest for the perfect solution has gripped the industry as everyone eagerly seeks the correct answers to pave the way for a sustainable future.

As individuals around the globe ponder questions of reliability, efficiency, quality, and operability, a unique set of region and country-specific inquiries arises. Factors such as overall costs, environmental considerations, technology accessibility, after-sales support, and dependency are pivotal in shaping our choices. Intertwined with the dynamics of our friendly and adversary nations, these questions propel us into a realm where decisions carry far-reaching consequences.

Being in the business of designing and manufacturing an entire range of Static Power Converters from a few hundred KW to a few thousand KWs of Rectifiers (of Statcon Energiaa make), an honest and fair attempt is made to touch upon different aspects and questions in this regard.

Before delving into the technicalities, there are essentially **three** types of **AC-DC Power Converter technologies** that exist, viz:

1. Thyristor (SCR) controlled rectifier – Being the oldest among all and still very much in use in high to very high current AC-DC Converters.
2. Diode Rectifier with IGBT chopper – Uses diode rectifier of high to very high current with large numbers of smaller rating non-isolated IGBT buck choppers being used in parallel.
3. IGBT-based Active Front End (IGBT-AFE) technology – Uses IGBT-based 3-phase converters of relatively smaller current, connect them in parallel and then large numbers of smaller rating non-isolated IGBT buck chopper being used in parallel.

As a convention, all of the three above will use galvanic isolation transformer in MW Range.

As comprehensive information about all three types can be found in various sources, I will not discuss them here.

Thyristor-based rectifiers are the oldest among all three technologies and are still popular in operation across the globe for high voltage-high current applications. There has been no competition despite the other two technologies in use but in a minimal manner. This is despite the fact that a Thyristor Converter has been criticised for being bulky, having a slow transient response and the one generating high input line current harmonics & a lower Power Factor. This was ignored till the Green Hydrogen rectifier requirements emerged, asking for strict compliance to these two apart from a few others, which are discussed below:

1. **The Technology**: While the Thyristor-based technology uses a simple Power Circuit and Control Circuit, the Diode+IGBT Chopper has a complex Buck Chopper, and the AFE-IGBT technology is

very complicated. Continuing in the same order, while the first one may not require air-conditioning or a dust-protected environment, the other two will. The first is readily available in India, while the other two are scarce.

It is worth mentioning that many Chinese companies are offering a combination of Diode and IGBT (though not at a very low cost) using a crude SMPS-type configuration and selling it. Generally, this is limited to voltages in the range of 20-110V and a few thousand Amps. Moreover, it does not provide any improvement in the incoming line power quality. In the same vein, there is a concern regarding the delivery of 100% DC output under the working environment in India or other Asian countries, where the temperature may reach up to 50 degrees Celsius, and the sites are often filled with dust. It is quite natural to expect no wastage of precious electricity for air-conditioning.

Most European products utilise air-conditioning (especially both IGBT types) and begin derating as the ambient temperature reaches 40 degrees Celsius. However, Chinese products do not pay attention to this concern, and an EPC (Engineering, Procurement, and Construction) company realises the issue only after the summer begins, which is very late, resulting in working at only 70% of the plant capacity.

2. Use of Bulky Transformer & Other **Magnetics**: Both the 1st and 2nd technologies require a full capacity transformer at their input for galvanic isolation (between input and output) and to match the voltage level of the DC output. On the other hand, the 3rd technology presently requires transformers at input but in the future, it may get rid of it. This (transformer) has the inherent advantage of providing human safety, immunity against AC line disturbances such as surges, ensuring the safety of power semiconductors and other electronic components. Furthermore, considering factors such as efficiency, harmonics, and no-load loss, modern practices involve the utilisation of Medium Voltage (MV) transformers and the elimination of double conversion. By avoiding the process of converting MV voltage into 415V and then converting it into AC-DC using this 415V as the input, significant cost reductions can be achieved while enhancing overall efficiency. Mostly, these transformers are oil-cooled and designed for outdoor use. It is important to note that blindly imitating Europeans by using cast resin transformers without considering the costs and without any apparent advantage should be avoided.

3. Issue of Input Line Current Harmonics & Power Factor: This has now become an important factor and is present in both the 1st and 2nd types, while the 3rd type exhibits excellent performance in this regard. While there may be some positives and negatives in both the 1st and 2nd types, extensive research in this area has led to techniques that reduce these factors even in the 1st technology without compromising on other parameters. Terms such as 6 pulse/12 pulse/24 pulse, etc., are used to mitigate such harmonics, although they alone may not be sufficient to address the issue. In essence, both of these factors can be addressed at the MV level due to new technologies in the 1st and 2nd type technologies.

4. The power semiconductor topologies, control techniques, reliability, maintainability, and after-sales support: Thyristor-based converters use a single large capacity bridge due to the availability of very large rating devices that are freely available and do not require paralleling. Furthermore, such bridges can be connected in parallel. However, due to the limitation in single IGBT rating, both at the device level as well as the module level, they are paralleled by adding multiple modules to achieve higher amperage. Both the second and third types utilise very complex software-based circuits that are specific to each manufacturer and only allow for the replacement of a failed module, which is then sent to a designated service centre in India or their respective country. The same was witnessed in MW inverters where many companies like Ansaldo Italy, Bonfiglioli Italy, and many more supplied inverters. Even today, most of the solar grid-tie inverters follow the same pattern in India. So, look at the availability of all such before deciding, so as not to regret later, since the fact is promises are made by companies but once the experiment for the aggressive Indian market fails, to exit is the only option left.

5. Efficiency, Ripple, Regulation, Transient response, Current regulation: These are very important parameters expected from a Rectifier and need to be addressed. Ideally speaking, the AC-DC conversion efficiency should be 100% so that whole of the AC supply is available for Hydrogen production. But when attempting to measure at MV (transformer incoming) level, we need to consider the efficiency of this transformer as well. So, by simple mathematics:

Overall AC-DC efficiency = Tx peak efficiency X Converter peak efficiency

= 99% X 98.5% =97.5%

However, it is a known fact that Tx peak efficiency occurs at 70-80% rated load and then there are other circuit losses, filter choke losses and even losses in switchgears and hence, a practical peak efficiency can be considered around 95%. Due to its inherent technology/ topology, the AFE-IGBT converter may give a peak efficiency of around 96^{+}%.

It would also be worth sharing here that it is better to take a transformer with 120% of the power required so that at 100% output DC loading, we work around peak efficiency. This will also help in achieving a significantly longer lifespan for the transformer. Industrial Converter manufacturers generally design their products keeping the same in mind but letting the buyer demand this so as to keep everyone at par.

The **ripple,** as defined, is the ratio of RMS/Average DC. The AC content present in the DC output is best in the 2nd and 3rd technology and is relatively high as compared with the other two. However, generally, this is defined as around 5% by the Electrolyser companies and hence, any value even lower now has an extra advantage. However, this needs to be specified by the Electrolyser manufacturer and all 3 technologies can meet the requirement.

The **Regulation** is the deviation in set (desired) value vs actual value when input supply or output load is varied in the specified range. Generally, this is extremely good in 2nd & 3rd while it is approx. 1% in Thyristor technology. However, the Electrolyser needs 1% and hence, none has an advantage over the other.

The **Transient Response** is defined to ensure that any step change in the incoming supply or load side does not result in the AC-DC converter output becoming unstable or experiencing harmful overshoots/undershoots in terms of amplitude and duration. While the 2nd and 3rd technologies exhibit excellent transient response, the 1st one has relatively poor performance in this aspect. However, the requirements of an electrolyser are not very stringent, and a Thyristor converter can still meet the limits. Furthermore, there are techniques available to improve the transient response, and different converter manufacturers have their own unique circuit designs.

The current regulation, current limit, or constant current feature is a crucial parameter requirement for an electrolyser, where the current needs to be initially set and then gradually increased according to a pre-programmed or externally commanded manner.

The response time to this feature is very good in the 2nd and 3rd technologies, while it is relatively slower in Thyristor technology (in milliseconds). However, the electrolyser does not require an extremely fast response time for this feature, so there are no significant advantages or disadvantages associated with this parameter.

6. Control, Safety/Protection, Operation, Remote monitoring/control, etc.: Since all three technologies use modern DSP-based controls and PLC-based system controls for the aforementioned aspects, with HMI integration, there is no advantage of one over the other. However, different manufacturers offer a lot more ornamental options. Still, a user has to buy and pay for what they need for their use.

7. Environment, Cooling, Mechanical: Though partly discussed in the beginning, with a lot of dust, not-so-good air quality, and high ambient temperature (especially in areas near MW solar plants), special care has to be taken while selecting a Converter. Well, providing air conditioning is a very natural solution, but running it 24 X 7 is a debate worth its cost. So, select a product that is designed to work and the number of years they are in successful operation in India or countries with similar conditions. Developed countries have an entirely different environment and need consideration.

Hence, preference can be given to forced air cooling or even water cooling. Both are good but have their pros and cons. While the former is the best in terms of reliability, maintainability, etc., the latter suffers from items such as chillers, DM water, pumps, etc., which will further affect the reliability.

So, forced air cooling is best but must ensure the avoidance of hot spots in any part/component and should be backed up by proven design.

The mechanical layout, i.e., the type of enclosure, etc., are equally important aspects to be looked into. The debate goes on between free-standing panel type or outdoor container type construction.

The panel type or indoor type has the advantage that it can be simply placed in a room with incoming and outgoing busbars running. Better access for operation and maintenance. However, the challenges are in terms of:

a) Availability of lots of free air inlet and isolated/guided hot-air outlet.

b) Civil work for building large rooms.

c) The MV transformer is likely to be outside the room, and hence long incoming and outgoing busbars/cables.

d) Since a plant will use a large number of such rectifier panels, in order to reduce the room length, a set of panels will have to be kept face-to-face, increasing the challenges of air-in and air-out.

On the other hand, the outdoor type or container type solution has the advantage that it can be placed side by side without the need for civil work. Plus, since the transformer is outdoor type, the AC busbar layout becomes easy and even output cabling becomes easy. But the best part is the air-inlet and air-outlet. Even for air-conditioning, there can be separate air conditioners in each such container which can be run on a need basis. It is advisable to have a simple tin shed over the containers to avoid direct sunlight falling for longer life and better working.

8. Number of MV Transformers, MV Switchgears: In both type 1 and 2 technologies, isolation transformers are required and need methods to reduce input line current harmonics, which necessitates the use of 12 pulse/24 pulse, etc. Having more such transformers means more MV feeders/switchgears, etc., increasing the project costs. Technologies are available to reduce such components and still achieve the same effect. It is important to verify the costs of such MV transformers, MV feeders/breakers/switchgears, and then bus bar costs (up to the Rectifier bridge) in the 1st and 2nd types.

9. The 3rd type occupies lesser space but has been a very recent development without extensive performance credentials of such high voltage-high current converters in operation for 4-5 years under such environments. Also, at present, this will need oil-cooled outdoor type MV transformer.

10. Standards, Certifications, past performance,: The Hydrogen Rectifier is a relatively new subject in India. To clarify this point, low voltage high current rectifiers have been manufactured in India for decades and are in use, with most of them being Thyristor technology-based. However, with the emergence of the Green Hydrogen concept and the emphasis on power quality, in addition to high voltage-high current (DC power in multiples of MW), the entire subject is undergoing a change. Taking cues from the West, we have also started specifying standards such as:

- IEC 60146 for Static Converters, which mainly covers Thyristor converters
- IEEE 519-2014, describing the input line current harmonics
- UL, being required mostly in the USA
- And a few more related to EMI/EMC and environmental considerations are being discussed.

Similarly, many times there is a mention of Certifications found in some European/Chinese products. However, while all these have been in use in India for the last four decades, there is no system of the word “CERTIFICATION” as there are no labs with the facility or authority to issue certificates. This does not mean that the country lacks a culture of third-party validation or quality checks. These are indeed being procured by large power PSUs like NTPC, EIL, ONGC, BHEL, and almost all EPC companies such as ABB, Alstom, GE, Hitachi, etc.

So, this same subject has to be seen with the facilities available in India, rather than just copying the West. The best example of this is in Solar Inverters, where even after 10+ years, we still do not have such Certification facilities and certificates from China are accepted in whatever form they are submitted.

Similarly, the issue of performance certificates for similar products in India, as well as type tests, leads nowhere. The ratings of different electrolyser manufacturers/users may differ, and with the whole thing being in India (and even abroad), such scope should be widened to include similar ranges of output power, including high voltage-high current, for any application. Please understand that the basic circuit of an AC-DC converter does not change, and only some parameters, as explained above, might vary. However, the important aspect to be ensured is the handling of DC power under different environmental conditions prevailing in India.

11. Service life, Reliability, Safety, Aftersales Support, Maintenance: From the experience of the past and looking at the basic design, the Thyristor, as a device, is the most rugged and reliable. It is capable of withstanding voltage and current abuse and its simple 50 Hz switching stands much ahead of its competitors. On the other hand, IGBTs work under high-frequency switching and require a very complex controller and compact PCB. They have limitations when it comes to abuse and adverse environmental conditions, especially those typical to India. Additionally, a Thyristor converter uses just one set of converters to handle multiple MW, which contributes to its better service life for the intended application.

Regarding the reliability and safety of the converter technologies, the first one performs better due to its inherent design, which utilizes fewer components, closed-loop control, and the ability to withstand power line abuse.

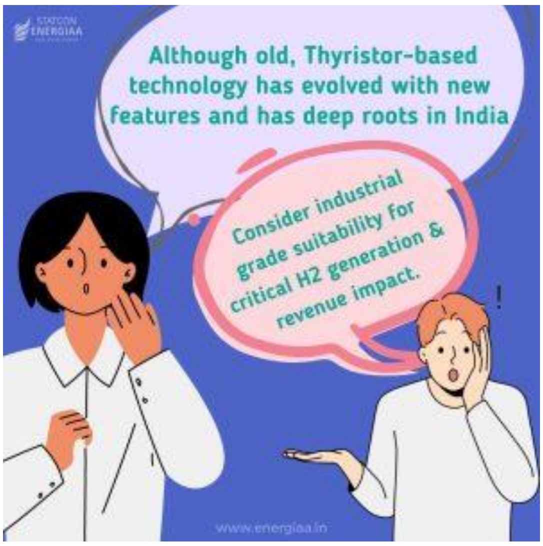
With regard to **after-sales support and maintenance**, including the supply of spares, it is an issue that every buyer has to decide based upon the seller and their own policy. This is because the converters are supposed to have a service life of 20-25 years. Therefore, it is important to judge a technology and manufacturer not just by overall sales or technological jargon, but by the sustainability record of the manufacturer. Remember, you are not buying an EV but a simple converter, which has a very rugged and robust basic design. Avoid paying for things you do not need or will never use. Check the performance of such technology in operation in Indian or similar conditions in any application, ensuring it is designed for regular use. When examining past performance, consider both the oldest and latest records, as technology keeps changing and so do the manufacturer's own designs.

Ensure that the manufacturer provides all electrical drawings and training to replace any component (except the control card components). They should be able to replace control cards individually rather than the entire module. Consider spare prices while negotiating the order, and in the case of a foreign buyer, have the head from the country of origin issue an undertaking confirming the supply of spares for the next 10 years at that price. This is important because, in the case of MW inverters, local offices often provided support later and then charged significantly higher prices upon demand. Similarly, with Indian manufacturers, obtain the same undertakings.

On above account, both diode + chopper and AFE-IGBT have very limited experience in, say, a block of 6 MW. They are all under development/ PC stages.

12. Price and cost comparison: Both price and costs are important factors to consider. Upon comparison, it becomes evident that the price of a Thyristor Converter (including the MV transformer) is likely to be the lowest, while the Diode+IGBT and AFE-IGBT are likely to be the costliest options. (Please exercise caution, as some individuals may import modules from China and stack them in India, claiming it as an Indian product, as seen in the EV charger space. To ascertain the truth, carefully examine their manufacturing process, open the BOM/circuit of such modules, inspect their testing setup, and obtain an undertaking regarding the manufacturing of said modules in their own Indian factory. The truth can be discerned without needing an Einstein-like intellect).

Now, calculate the overall costs by taking into account the actual efficiency, power factor, and actual usage, specifically the DC loads. Factor in the service life, maintenance costs, cycle of component replacements as declared by the manufacturer, manpower costs, and other relevant expenses.



To conclude, we can say that this technology, although old, has evolved with new features and has deep roots in India. It is important to be cautious and not get swayed by catchy parameters or features that may not be relevant to our specific needs. When making a purchase, consider the product's industrial-grade suitability, as hydrogen generation is a critical application with significant revenue implications. Take a holistic approach, considering input power parameters (quality) and the methods used to calculate efficiency, as some may claim even 99%.

High Power Rectifiers for Green Hydrogen production are essentially High Power DC Supplies for electrolyzers that help make hydrogen production robust, simple and cost-efficient. Statcon Energiaa's Military-Grade High Power Rectifiers assure long operability, minimal maintenance, and cutting-edge technology. Read more about Statcon Energiaa's product variants here: https://www.energiaa.in/products/power-products/high-power-dc-supplies-for-green-hydrogen-production/