HYOSUNG HEAVY INDUSTRIES

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POWER TECHNOLOGY MAGAZINE

2024 VOL.4

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Contents

Preface

Today, we released the 4th issue of Power Technology Magazine from Hyosung Heavy Industries. Every year, we introduce Hyosung's solutions that lead the electric market trends to our valued customers through this magazine.

Around the world, AI is drawing people's attention. Compared to digital processing in the past, AI data centers require almost 4-5 times more electric power consumption. In this regard, due to the digital transformation utilizing artificial intelligence (AI), power consumption, which has been gradually increasing amidst trends in energy conservation and urbanization, is expected to soar, especially in developed nations, in the future.

In terms of electric power infrastructure, it takes a considerable amount of time to prepare and build it up. Until recently, the establishment of infrastructure had been drawing the attention of relevant industry personnel only. However, as skyrocketing power consumption demand has become an issue worldwide, there is increasing social interest regarding the necessity to construct this infrastructure. To date, the energy transition towards renewable energy has been at the center of trends as a critical method to achieve carbon neutrality. Nevertheless, the supplementation of the grid based on electric power energy is now becoming a very imperative topic across the world.

As a living history of the heavy electric industry on the Korean peninsula, Hyosung Heavy Industries has been preparing to respond to this market situation for a long time by investing in Research and Development (R&D) and fostering enhancements in the globalized manufacturing capabilities of T&D (Transmission & Distribution) facilities. Our customers around the world are facing the task of operating grids stably amid of an unprecedented increase in renewable energy resources and changes in electric power consumption. In this regard, we have actively provided support to boost the stability and enhancement of grids, meeting our clients' needs.

Our company has supplied a range of products in the business sector, such as ESS (Energy Storage System), reactive power compensators (STATCOM), DC transmission and distribution systems (HVDC/MVDC/LVDC), and IT-based electric power asset management (ARMOUR) to meet customers' demands based on the company's various new technologies as the industrial environment continues to advance. Accordingly, we will put our best efforts into fostering innovation in customers' power operation systems through diverse engineering solutions while valuing the achievement of much higher customer satisfaction.

Moreover, the most significant strength of our company is our DNA of satisfying customers' needs by focusing on the VOC (Voice of Customers). Thus, we are establishing mutual trust and collaborating with electric power companies in major nations around the world, based on the company's product quality and technical competitiveness.

To maintain close communication with customers and boost our responsiveness in local areas, we will do our best to deal with external environmental changes flexibly and engage with customers by considering their perspectives. This will be achieved by expanding localized working groups at our different manufacturing bases in the US, China, India, and other regional areas. In the coming days, we will push forward to seize new opportunities with our clients and strive to be an authentic partner to our customers, prioritizing their satisfaction through continuous innovation.

Hyosung Heavy Industries Co. Ltd.,
Executive Vice President
Takeshi Yokota

Hyosung Heavy Industries Is Prepared for the Opportunity

Power Transformer Technology has Become a Bridgehead for Europe's Performance

After the COVID-19 crisis in Europe, a market situation developed where demand for electricity equipment increased rapidly due to the recovery of the electricity market and the expansion of renewable energy generation coincided with the Ukraine crisis, which caused a serious supply shortage of power transformers. To solve this problem, European customers turned to other regions, and it was an opportunity to change their view on power transformer purchasing in Europe. Opportunities are starting to emerge for non-European manufacturers who can meet European customers' technical standards, and Hyosung Heavy Industries' global top-level power transformer design and manufacturing technology combined with flexible customer response are excellent merits for European customers to come to us with more opportunities.

| Development of Eco-Friendly Insulation Oil Transformers |

Due to global greenhouse gas regulations, the demand for eco-friendly designs in the transformer industry has grown dramatically. Europe needs eco-friendly insulation oil transformers due to environmental problems, and power transformers with self-extinguishing capabilities due to risks identified through the Russia-Ukraine war. Hyosung Heavy Industries has already secured technology for eco-friendly insulation oil transformers since 2015 and has secured an extensive track record since then. In 2022, we developed 400kV eco-friendly insulation oil transformers for the first time in Korea. Hyosung Heavy Industries has completed rigorous evaluations of various oils, and secured product characteristics of different eco-friendly insulation oil companies. We have laid the foundation for providing customers with a variety of options of eco-friendly insulation oil.

Figure 1 | Korea's first 400kV eco-friendly insulation oil transformer

| Explosion Proof Analysis Techniques |

There are a number of measures applied to Hyosung power transformers, to ensure supreme quality. However, due to extra attention required to safety and the environment in the European market, in the event of an accident, there should be at least Plan B and Plan C to minimize its risks. One of these is explosion proof technology. Due to internal failure, leakage due to external damage occurs in the event of an arc explosion inside the transformer, this can cause fires and secondary explosions, which can be a major cause of environmental pollution. Hyosung Heavy Industries is delivering products that meet European transportation constraints by improving the accuracy of dynamic explosion-proof design technology as well as static interpretation to ensure stability through verification of vulnerabilities in transformer tanks and prevent over-design of enclosures. In addition, transformer tank demonstration tests are underway for mineral oil and eco-friendly insulation oil, which will ensure the reliability of explosion-proof design and analysis technology verification of our products. Our ultimate goal is to ensure the explosion-proof stability of both traditional mineral oil and eco-friendly insulating oil transformers, delivering products that cater to our customers' needs.

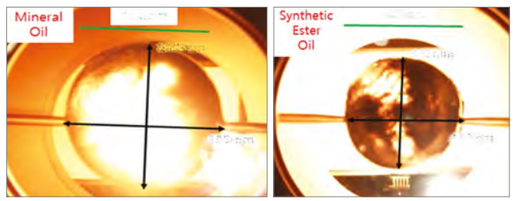


Figure 2 | Explosion proof test, Determination of the bubble sizes for each energy of mineral oil and eco-friendly insulation oil

| A Variety of Low-Noise Technologies |

Unlike the US, Middle East, and Australia, where space is relatively abundant, Europe is sensitive to noise because many power plants and substations are located near urban areas. In Europe, there is a growing trend of restricting transformer noise levels to guaranteed values by conducting environmental impact assessments when designing substations. Rather than relying on passive noise reduction technologies such as conventional methods of limiting core flux density and utilizing double-walled tank structures to block noise, Hyosung Heavy Industries secured low-noise transformer design technology by actively controlling noise sources such as analyzing the vibration of the internal core, the coil structure and the external tank of the power transformer, reinforcing the structure or isolating the vibration. In addition, a transformer with a soundproof room structure was recently developed to secure technology to respond to specifications below 45dB for a substation in Japan.

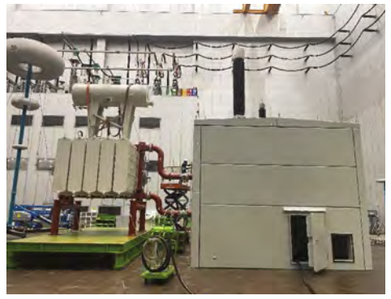


Figure 4 | Test of the structure of the soundproof room

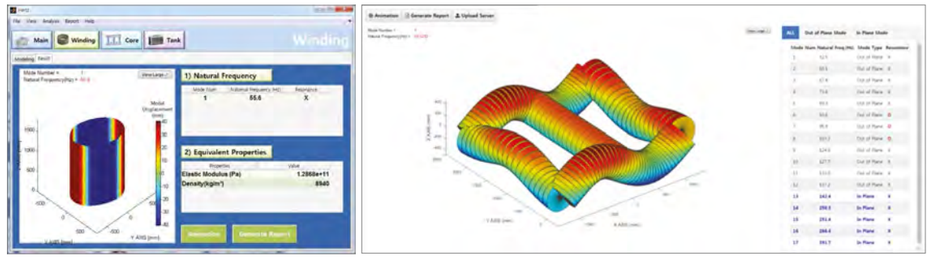


Figure 3 | Resonance Avoidance Design with Natural Frequency Prediction

| Reliability of GIC (Geomagnetically Induced Current) Analysis Technology |

The electricity grid in northern Europe, which is close to the polar region, is greatly affected by Geomagnetically Induced Current, which enters the transformer connected to the power grid, causing problems in the quality of the power grid and the soundness of the transformer itself. In particular, the magnetic flux leaked by the core saturation phenomenon enters the iron structure near the core, causing overheating. This generates internal dissipation and combustible gases, causing serious transformer damage. By securing interpretation technology based on equivalent magnetic circuits, Hyosung Heavy Industries is conducting a health evaluation of transformer core, windings, and iron structures according to each customer's GIC specification. The reliability of our analysis technology has been verified through DC input demonstration tests using mock-up transformers.

Figure 5 | GIC Mock-up Test

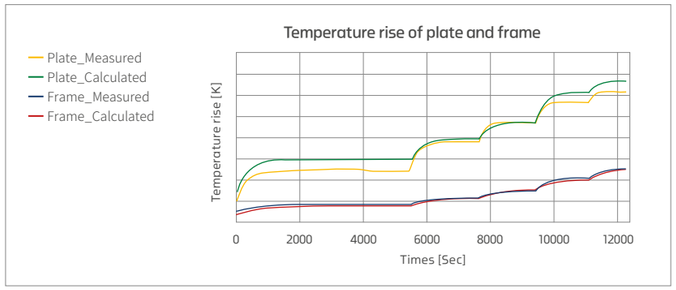


Figure 6 | GIC Impact Temperature Analysis & Measurement Result Comparison

Figure 7 | Norway Auto Transformer

| VSR (Variable Shunt Reactor) Technology and Performance |

Europe is seeing an increase in demand for renewable energy generation, and the UK, a leader in the European market, aims to expand its offshore wind power scale to 50GW by 2030. With this, the demand for variable shunt reactors, that can effectively compensate for reactive power, is expected to increase. Variable Shunt Reactor (VSR) can automatically adjust reactive power in renewable power generation systems, with irregular power production and power lines where reactive power consumption fluctuates due to changes in load conditions, to keep the voltage level of the power system constant. It is possible to minimize stress during circuit breaker switching and compensate for reactive power stepwise, thereby improving system reliability and reducing device failure rates. Hyosung Heavy Industries has developed, delivered, and operated a 345kV standard variable reactor for the first time in Korea, and continues to discuss related businesses with European customers with trust in VSR design technology based on its supply record of supplying high-quality, low-noise VSRs to the United States, Australia, and Saudi Arabia.

Figure 9 | VSR with OLTC

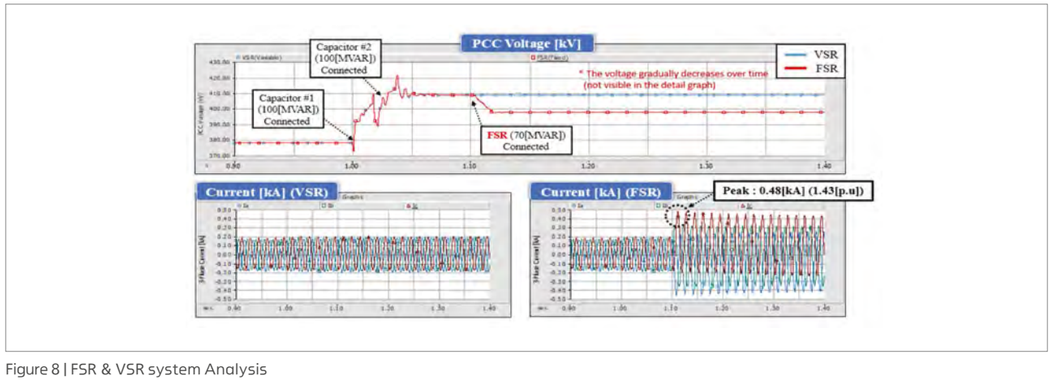


Figure 8 | FSR & VSR system Analysis

| PST (Phase Shifting Transformer) technology and Performance |

PST is a transformer that is connected in series to a transmission line to control the active power (power flow) flowing through the line by adjusting the voltage phase at both ends. As power generation facilities using highly volatile renewable energy sources such as wind and solar power increase, and power demand for decentralized load such as electric vehicle charging increases, the volatility of transmission power also increases, and the demand for PSTs to control it is increasing. Economically, PST has an advantage in providing stability and efficiency in power transmission network operation because it has a smaller installation space and a simpler structure than other facilities, like HVDC, that can control power flow. Hyosung Heavy Industries has delivered 330kV PST to the Australian market, and it is cooperating with customers from the review stage of PST introduction in relation to PST application in European markets as well as the Americas and the Middle East.

Figure 10 | Phase Shifting Transformer 330kV

| Transformers with Safety-Critical External Structures and Universal Functions |

In the case of European customers, they want to ensure safe access to various structures, especially through platforms or stairs, for operating and maintaining power transformers as large as building structures on site. Hyosung Heavy Industries already has a track record of delivering power transformers in forms of building structures at the request of certain customers in the UK and France, and it is satisfying customer needs by abiding to safety standards for related structures. In addition, due to the characteristics of Europe, where power consumption fluctuates, it is sometimes resolved by moving transformers. Currently, customer satisfaction is increased by flexibly responding to customer special requirements through a design that enables the structure of universal functions to meet all parts of different voltages, different power system connections, and different installation location structures.

Figure 11 | Safety Structure

Figure 12 | Installation of voltage and structure changes according to site conditions

Euijin Hong
Performance Leader
Team manager of Power Transformer Project Engineering Design Team

Hyosung Heavy Industries has already secured various design technologies in the field of power transformers and has a supply record of producing and delivering products using them, based on the data obtained through actual tests for development. We are discussing various types and designs for transformers with European customers. European customers' trust in our most cutting-edge technologies is manifested by the number of orders to our Changwon factory from European customers, steadily increasing since 2022. Through our experience in new European markets, we look forward to further developing our technology and continuing communication with our customers to establish our position as the major supplier of power transformers in Europe.

Korea's First 72.5kV GIS Meets GWP 0

The nation's first development of 72.5kV GIS designed for offshore wind power with GWP 0 applying VI + Dry Air

To respond to the global warming crisis around the world, various policies are being implemented to achieve carbon neutrality. Korea, the EU, and the US are phasing out SF_6 products and are demanding SF_6 Free, eco-friendly GIS with low GWP. In addition, as the portion of renewable energy generation increases, the power generation capacity is expanding in order to increase the economic feasibility of wind turbine power generation, and there are evolving GIS requirements for stable operation and protection of wind towers and related systems for offshore and onshore substations. As the wind power generation industry is classified as High Voltage, GIS products with a rated voltage of 72.5kV or higher are emerging as a new market. In order to respond to these changing market demands, Hyosung Heavy Industries has introduced Korea's first GWP 0 eco-friendly 72.5kV GIS.

* GWP (Global Warming Potential) : A value that indexes the global warming impact of greenhouse gases based on the contribution of C02 to global warming (GWP of C02 = 1)

Figure 1 | Layout 1Bay for substation

Figure 2 | Layout 1Bay for Wind Turbine

| Korea's First Eco-Friendly 72.5kV GIS Meets GWP 0 |

The GIS industry has generally used SF_6 gas, which has excellent insulation and breaking performance. However, SF_6 gas is one of the six major global warming gases and is a regulated gas with a GWP of around 23,500. The market requiring GIS with low GWP value is gradually expanding, and Hyosung Heavy Industries has developed Korea's first eco-friendly 72.5kV GIS that meets GWP 0 by applying VI (Vacuum Interrupter) and Dry Air.

Dry Air consists only of N_2 and O_2, so it is a representative eco-friendly alternative gas with a GWP of 0. However, the lower breaking and insulation performance compared to SF_6 gas makes it more difficult to secure breaking performance with a general way of gas injection.

Therefore, VI (Vacuum Interrupter) using vacuum characteristics was applied.

VI is a breaker that is mainly used for voltage range below 36kV, but it has been expanding up to the high voltage ratings due to the global warming issues. Hyosung Heavy Industries developed the 72.5kV VI with its own technology through simulation of insulation, conduction, and breaking performance and actual testing using internal and external testing laboratories, and this 72.5kV VI has confirmed durability of over 30,000 operations. It also satisfies an E2 Class for extended electrical endurance that doesn't require maintenance of the interrupting parts for 30 years.

Dry Air has a lower breaking and insulating performance than SF_6, so we were able to secure performance that meets the standards by attempting various improvements in the Disconnectors and Earthing switches with switching functions among the components of GIS.

Figure 3 | SF_6 is the World's Most Potent Greenhouse Gas

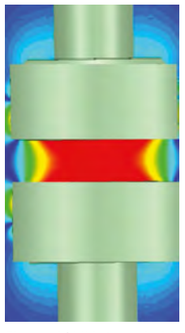


Figure 4 | VI interpole Magnetic flux density simulation

| 72.5kV GIS Designed for Offshore Wind Power Plants |

Conditions for use in a marine environment were taken into consideration when developing the product, such as corrosion caused by salt damage, vibration and shock considering marine operation and transportation, and confirmation of suitability through performance evaluation tests under harsh environment compared to land operation and installation conditions. In addition, vibration testing is a test of operating and transportation conditions for marine equipment and mechanical parts. We conducted and successfully completed testing under conditions harsher than Category 1 and 2, which are the conditions specified in the IEC standard.

Figure 5 | Vibration Test

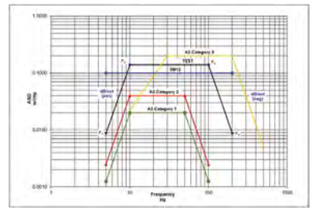


Figure 6 | Test Condition

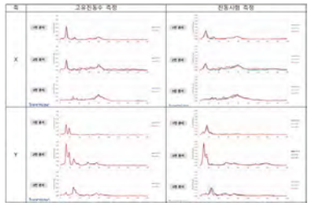
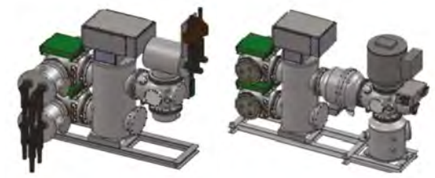


Figure 7 | Resonant frequency measurement graph

GIS consists of a circuit breaker, disconnector, earthing switch, bus, current transformer, voltage transformer, cable head, and other components depending on the required function. Hyosung Heavy Industries' eco-friendly 72.5kV GIS is developed using a modular GIS method and can be flexibly applied to configure layouts to meet various customer needs.



Rated Voltage [kV]	72.5
Phase Configuration	3Phase common
Frequency [Hz]	50/60Hz
Short Circuit Withstand duration [s]	3
CB Mechanism type	Spring
Basic Impulse Leve [kVp]	325
Insulation media	VI+Dry Air
Applied Standard	IEC/IEEE

Figure 8 | Eco-friendly 72.5kV GIS Spec

In the case of GIS substations, the general bay single-line diagram (SLD) configuration form is standardized, however, GIS wind towers require other configuration forms because GIS wind towers receive power through cables from the turbine mounted on the top of the tower which then go through the GIS protection system, and then again through the cables to adjacent wind power generators or offshore and onshore substations.

Hyosung Heavy Industries took this into consideration when planning the development of an eco-friendly 72.5kV GIS product, selected the product concept as a functional module combination GIS, and completed the development. Thanks to R&D planning, it can be applied not only to the single-line diagram of wind towers, but also to offshore and onshore substations related to wind power generation.

Seungwan Son
Performance Leader
Team Manager of High Voltage Switchgear R&D Team

Jongho Kim
Performance Manager
High Voltage Switchgear R&D Team

To meet the needs of the changing power equipment market due to global warming, Hyosung Heavy Industries has developed an eco-friendly 72.5kV GIS with GWP 0 that can be applied to eco-friendly GIS and offshore wind power towers and connected substations.

The eco-friendly 72.5kV GIS developed through proprietary technology can contribute to the development of power equipment suited to the Korean wind power market and can also be applied to global markets such as the US and Europe with product certification that satisfies all IEC/IEEE standards. Based on this development, we have won an order for a pilot project in Europe, and we plan to continue to expand and distribute eco-friendly GIS to the global market to participate in protecting the global environment.

We already have an eco-friendly 170kV 50kA GIS, and it is being applied to the Korean power grid, contributing to efforts to achieve carbon neutrality. Hyosung Heavy Industries is continuing fundemental technology research and performance testing to develop eco-friendly products and is conducting research and development to supply SF_6 Free GIS to all power systems.

Hyosung Heavy Industries' DAIS Reduces Greenhouse Gases for a Sustainable Earth

MV GIS with SF_6-Free Solution

Medium Voltage Gas Insulated Switchgear (MV GIS) products are evolving rapidly to meet the demands of a changing industrial environment and the rapid growth of demand for eco-friendly technologies. Hyosung Heavy Industries is dedicated to innovative product development for achieving zero carbon emissions and promoting green technology. We have developed and supplied to customers an eco-friendly MV GIS using SF_6-Free technology, which replaces SF_6, the existing insulating material, with Dry Air, which has a GWP of "0".
Dry Air Insulated Switchgear (DAIS), Hyosung Heavy Industries' eco-friendly MV GIS product, provides the optimal solution to meet various customer needs through customized design. In addition, we have the world's highest level of technological competitiveness by developing DAIS products with various ratings and products with a maximum capacity of 38kV 40kA 3150A.

| Efforts by Hyosung Heavy Industries to Reduce Carbon Footprint |

SF_6 gas, an insulation medium usually applied to MV GIS, is one of the strongest greenhouse gases with a GWP index of about 23,900(C02 GWP=1). As greenhouse gas reduction activities are underway around the world, electrical power facilities using SF_6 gas are likely to be restricted in the future.
Dry Air, the optimal insulation material to replace SF_6 gas in the MV GIS field, presents difficulties for compact design as it has only 30-40% of insulation and 60-70% of thermal radiation characteristics compared to SF_6 gas. However, Hyosung Heavy Industries is making efforts to apply eco-friendly technology to the power equipment sector, which is the core of realizing decarbonization.
Hyosung Heavy Industries contributed to the reduction of greenhouse gas emission by independently developing DAIS, which replaced traditional SF_6 gas with eco-friendly Dry Air. Hyosung Heavy Industries' efforts to reduce carbon footprint are bearing fruit as the supply of MV GIS, which applies eco-friendly gas with GWP '0', is gradually expanding to overcome the climate change crisis.

| Development of Eco-Friendly MV GIS |

Hyosung Heavy Industries has established optimal design criteria for DAIS products by conducting numerous tests and analyses on gas dielectric and thermal radiation characteristics of the gas under varying pressures to apply dry air to MV GIS. As a result, we succeeded in developing MV DAIS products with similar size and performance to conventional SF_6 gas MV GIS while using eco-friendly dry air by applying optimal insulation design technology.
Since 2013, when Hyosung Heavy Industries developed the first DAIS (25.8kV 25kA) products in Korea, we have delivered more than 1,000 bays to Korea Electric Power Corporation (KEPC0), which requires high reliability and safety. Building upon this technology, we achieved another milestone by developing the world's first product with maximum capacity using Dry Air as an insulation medium in 2021: the 38kV 40kA 3150A DAIS.

Model	D242	D252	D272	D384
Insulation Medium	Dry Air (GWP=0) & V.I			
Rated Voltage (kV)	24	25.8	27	38
Rated Normal current (A)	Up to 1250	Up to 2000	Up to 2000	Up to 3150
Rated Short time current (kA)	25	25	25	40
Gas Pressure (MPa)	0.1	0.2	0.13	0.17

Table 1 | Hyosung Heavy Industries Eco-Friendly MV GIS(Pro series D) Line up

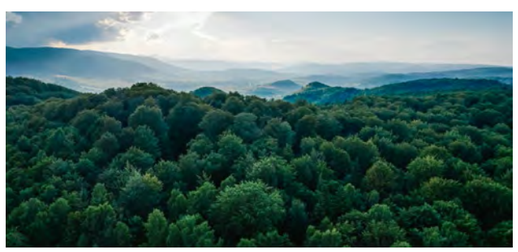
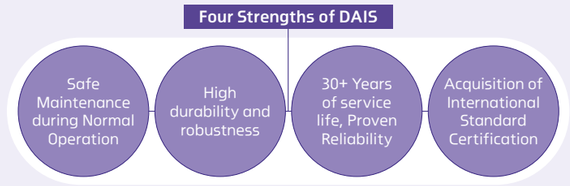


Figure 1 | Installed DAIS Product

Reliable Hyosung Heavy Industries Eco-Friendly MV GIS

Hyosung Heavy Industries, which has been verified for reliability, stability, and operability through international standards, always provides optimal solutions for customer safety and environmental protection.

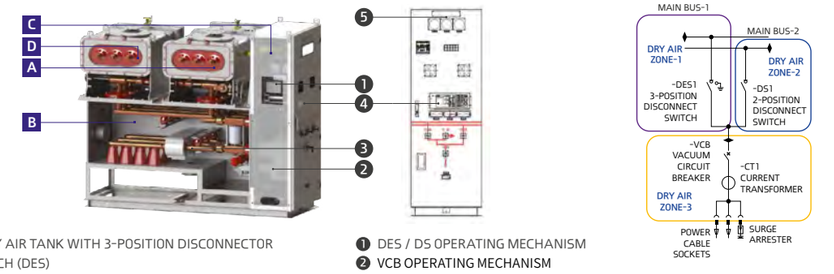
Eco-Friendly DAIS from A to Z



Dry Air Insulated Switchgear (DAIS) was developed to have a compact size as well as excellent performance comparable to SF_6 gas GIS.

Figure 2 | Advantages of Hyosung Heavy Industries Eco-friendly MV GIS

| Features of Eco-Friendly Medium Voltage GIS |



- A MAIN BUS-1 DRY AIR TANK WITH 3-POSITION DISCONNECTOR EARTHING SWITCH (DES)
- B CB AND CABLE DRY AIR TANK
- C LOW VOLTAGE COMPARTMENT
- D MAIN BUS-2 DRY AIR TANK WITH 2-POSITION DISCONNECTOR SWITCH (DS) OR 3-POSITION DES

1. DES / DS OPERATING MECHANISM
2. VCB OPERATING MECHANISM
3. PLUGIN CABLE / SIB SOCKET (INNER CONE) / CURRENT TRANSFORMERS (CT)
4. LV FRONT DOOR AND DEVICES
5. DRY AIR DENSITY MONITOR (ZONE 1 ~3)

Hyosung Heavy Industries' eco-friendly MV GIS provides customers with optimal solutions that can satisfy diverse requirements. We provide customized solutions to meet performance and structure for diverse technical requirements, including safety-focused maintenance and the application of VCB that can be removable, and provide optimized designs individually to each substation's system. Based on years of design experience and know-how, Hyosung Heavy Industries' eco-friendly MV GIS products boast the following advantages:

① Product certification through Short-circuit Testing Liaison (STL)
We have completed product development to meet customers' specifications under international standards (IEC & IEEE/ANSI).

② Internal Arc design and certification
Using in-house arc simulation technology, the optimal arc flow for each component was derived and the optimal design was performed based on the results derived by analyzing the arc release pressure, and the performance verification was completed according to international standards.
- IEC 622271-200: Max. AFLR 40kA 1s
- IEEE C37.20.7: Max. Type 2B 40kA 1s

③ Application of high-performance insulation materials
Thanks to the use of insulation materials with excellent electrochemical properties such as high tracking resistance and high glass transition temperature (Tg 120℃ or higher), product performance does not deteriorate even after long-term use.

④ Reliable High Performance VCB
Spring or Permanent Magnet Actuator (PMA) mechanisms can be freely selected and high-performance VCBs satisfying E2, M2, and C2 can be provided.

⑤ Modular and Cubicle Type Enclosure
The modular design of each gas component can limit the spread of accident areas and allow rapid replacement of affected parts. Convenient maintenance is possible by applying removable VCB.

⑥ Providing solutions that can meet the diverse customer requirements
Various functions can be applied, such as a preventive diagnosis system with a partial discharge detection sensor, an interlock system to prevent malfunction of mechanism (VBC/DES), and a viewport camera system to check the condition and location of the DES mechanism.

Yoonki Jang Performance Manager
Electrical Panel R&D Team

Seungchan Lee Performance Manager
Electrical Panel R&D Team

DAIS, Hyosung Heavy Industries' eco-friendly MV GIS product, is recognized for its quality as it is supplied to various places, including the national utilities market, where higher reliability and safety are required. The compact size DAIS product, developed by reflecting customer feedback and continuous R&D efforts, has obtained international standard certification (IEC, IECC, etc.). As a result, DAIS products that reflect our efforts to prioritize customer safety and our customers' diverse technical requirements provide the best value to our customers. Hyosung Heavy Industries will continue to provide the best solution to achieve both technological advancement and environmental preservation so that life-enriching technology does not devastate our home the Earth.

High Voltage Direct Current (HVDC) Transmission Technology for Power Supply Stabilization and Integration of Renewable Energy sources

Korea's first domestically produced HVDC - Yangju 200MW BTB VSC HVDC

The HVDC (High Voltage Direct Current, for voltages over 100kV) system is a power transmission system that converts alternating current to direct current for efficient and safe power transmission. Despite the high investment cost, HVDC has the significant advantage of lowering transmission losses over long distances compared to AC transmission, as well as reducing the area and number of transmission towers and being free of electromagnetic waves, which expands community acceptance of this technology.
The demand for large-scale and long-distance transmission has recently increased due to the connection between remote renewable energy sources and high-demand areas. Additionally, there is a need for inter-country grid connections to achieve carbon neutrality by 2050. In this context, the introduction of HVDC has become indispensable to address the instability of existing AC systems and to facilitate proactive transmission system operation.

| HVDC Market and Development Trends |

To meet energy demands driven by end-use electrification and economic development in emerging countries, global annual power generation is expected to more than double from 27,000TWh in 2020 to 70,000TWh by 2050. Remarkably, the contribution of renewable energy sources is expected to increase from 22% of the total power generation to close to 72% by 2040. (https://eneroutlook.enerdata.net/)
For efficient energy production, transmission, and distribution, massive financial investments and continuous development of power grid infrastructure are necessary. Efficient long-distance, large-volume energy transmission is crucial, particularly as major power plants are inconveniently located far from high-demand areas. Moreover, the output variability of most renewable energy sources is high compared to conventional power plants. This necessitates the role of transmission equipment in regulating the output of power stations. Additionally, the interconnection of regional and national power markets, is raising the importance of energy security and facilitates wider access to clean and affordable energy for all.
While both HVAC and HVDC links can be used for large-volume energy transmission and interconnection, long-distance connections' efficiency, proactive controllability, and energy security make HVDC superior to HVAC, leading to HVDC market expansion. Since first commercial HVDC operation in 1954, approximately 170 projects with a capacity of over 300GW have been built and are still in operation. The HVDC market is projected to grow from $12 billion in 2023 to $19 billion in 2030, reflecting a 6.9% growth rate (Research and Market, 2024).

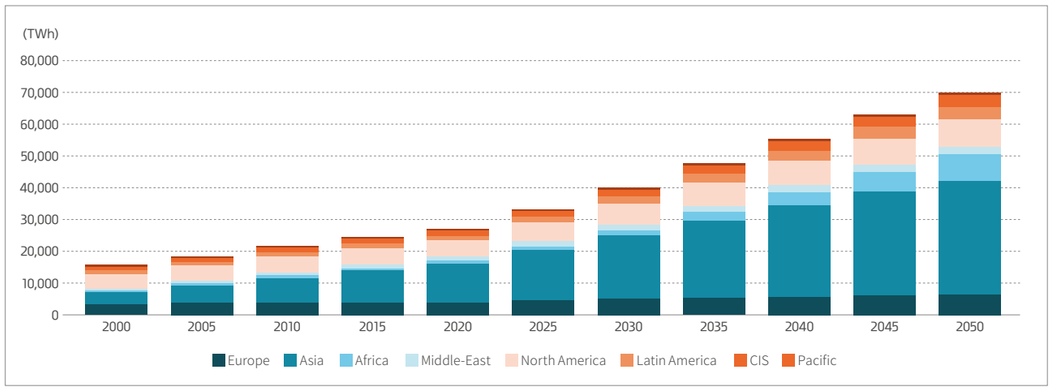


Figure 1 | Global Electricity Generation (sorce : Enerdata)

HVDC is technically divided into LCC-HVDC based on thyristors and VSC-HVDC using IGBT (insulated-gate bipolar transistors). Until 2015, LCC-HVDC accounted for 90% of the cumulative capacity. However, as multi-level converter technology was applied to VSC-HVDC, the VSC-HVDC market rapidly grew, and the annual installation capacity began to surpass that of LCC HVDC since 2019.
Looking at regional market trends, China accounts for 59% of the world's cumulative HVDC installation capacity. HVDC is the dominant form in long-distance, large-scale power transmission from northern and western China, where coal and renewable power generation is plentiful, to eastern and southern China, where demands are highly concentrated. Within the electrical equipment manufacturing industry, domestic players such as Rongxin (RXHK) and NARI (NR Electric) are the leading suppliers in China.
In the Americas, HVDC systems are utilized for long-distance power grid interconnection, stabilization, and the integration of renewable energy sources. In Europe, HVDC is currently being applied to renewable energy integration and cross-border grid interconnection. For cross border connectivity, the InterOPERA (enabling interoperability of multi-vendor HVDC grids) project is chartered which will establish technical standards for connecting VSC HVDC from various manufacturers into MTDC (Multi-terminal HVDC), a technology linking three or more HVDC converters. The Hyosung Heavy Industries R&D Center is actively participating in this project.
In Korea, since the introduction of the current source converter HVDC with Jeju-Haenam #1 in 1998, followed by Jeju-Jindo #2, North Dangjin-Godeok, Yangju BTB, a total of 3.9GW has been installed and is currently operating. Additionally, a 4.7GW is under construction for the East Coast-Singapyeong (EP1) project, etc. The Ministry of Trade, Industry and Energy's 10th Basic Plan for Electricity Supply and Demand outlines South Korea's energy mix with plans to install 10GW of VSC HVDC, aligning with the expansion of power generation through nuclear and renewable energy. This anticipates a market value exceeding 5 trillion after 2028. The West Sea backbone network is planned in the MTDC format, preparing for renewables integration and cross-border interconnection.

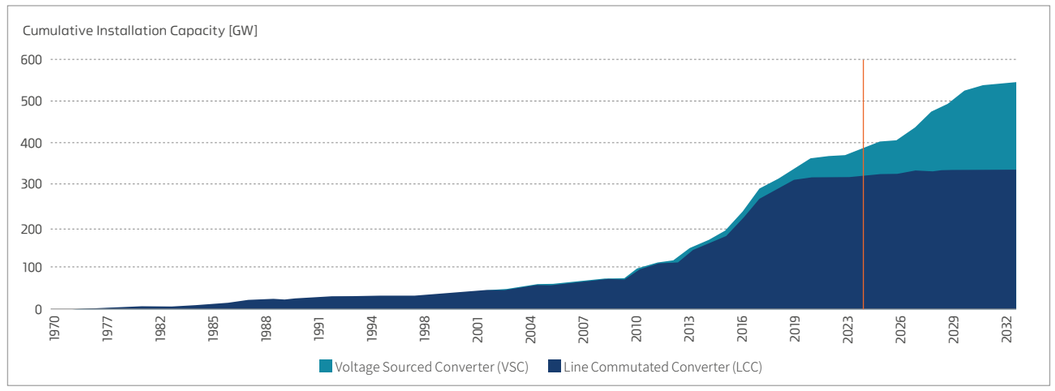


Figure 2 | Cumulative Installation capacity by Type (source :DNV)

| Yangju ±120kV 200MW HVDC Project Introduction |

The HVDC system integrates various technologies, including grid connection, converter valves, control and protection system, and the cooling system. Consequently, this type of project has higher technical barriers and the market is dominated by suppliers such as: H, S and G companies, along with Chinese suppliers.

Currently, two construction projects are underway for operational voltage sourced converter HVDC systems in Korea. H company is involved in a 200MW PTP (Point to Point) HVDC project connecting Jeju to Wando, while G company is working on a 500MW BTB HVDC project at the Shin-Bupyeong substation. Additionally, Hyosung Heavy Industries is actively working on 200MW BTB (Back- to-Back) HVDC project at the Yangju substation.

HVDC systems can be categorized into BTB (Back-to-Back), PTP (Point-to-Point), and MT (Multi-Terminal) configurations based on the connection line setup. The Yangju, ±120kV/200MW) project employs a BTB HVDC system consisting of one station: a Rectifier Station for converting AC to DC and an Inverter Station for converting DC back to AC.

An HVDC station comprises converter valves for power conversion, a C&P System (Control and Protection System) for converter control and protection functions, and various yard devices, including transformers and a cooling system (Figure 3). To achieve 100% localized production, Korea Electric Power Corporation (KEPCO) is responsible for civil engineering and construction works, while Hyosung Heavy Industries handles HVDC system design, converter/control unit design and manufacturing, yard system design and procurement, installation, and testing.

The Type Test and Routine Test of the converter valve have been completed at the Changwon Plant according to the insulation test and operational test specifications (IEC62501), with Hyosung receiving the MMC HVDC voltage-sourced valve Type Test certification from the Electrical Research Institute in 2022. The converter valve forms an Arm by integrating 108 submodules into a three-layer structure. This results in the installation of 6 units of Arms per station inside the valve room. The internal configuration of each valve room involves connecting a series of 6 units of valve sections, each having 6 units of submodules. It then adopts a three-layered stacking layout, as shown in Figure 4.

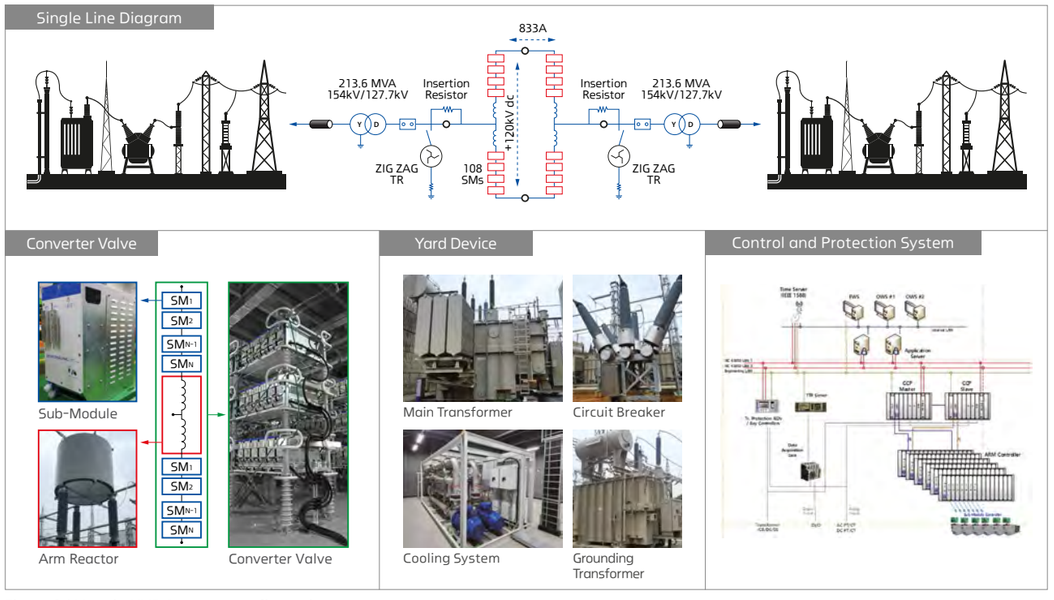


Figure 3 | Yangju HVDC system configuration

The Control and Protection (C&P) system comprises an operating system that performs operator and interface functions, a converter control system that manages the converter and performs protection functions based on the operator's commands, and a protection system that handles AC line protection and CB/DS/ES operations. A controller, expandable up to 1GW, has been developed and cross-validated through four tests: PSCAD simulation, PSSE simulation, RTDS HILS, and large-scale system interconnection DPS test. Additionally, Hyosung has developed a 154kV Interface transformer and a 127.7kV grounding transformer which are currently in the application stage.

All unit equipment and subsystem tests were completed by the end of 2023. If the online test is completed by March 2024, the Yangju HVDC project will mark the first case of VSC HVDC installation in Korea, as well as the first HVDC system developed entirely using domestic technologies.

Once BTB operation commences, KEPCO, our customer, is expected to benefit economically from system stabilization in the northern Gyeonggi region, estimated at 78.5 billion won. Additionally, KEPCO projects annual savings of 18.1 billion won in power purchase expenses, attributed to the resolution of overload issues, reduction in fault current, and improvement in voltage stability.

Moreover, this project is anticipated to lay the groundwork for overseas business expansion and technical independence, positioning us to meet the expected increase in domestic demand for VSC HVDC technology.

Figure 4 | Yangju Converter Valve

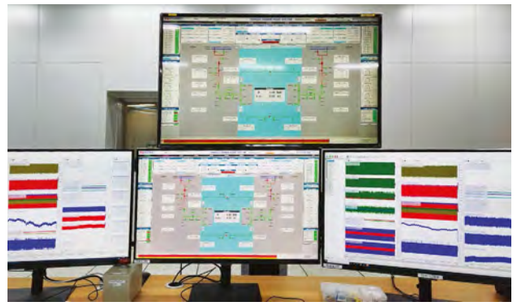


Figure 5 | Control & Monitoring room

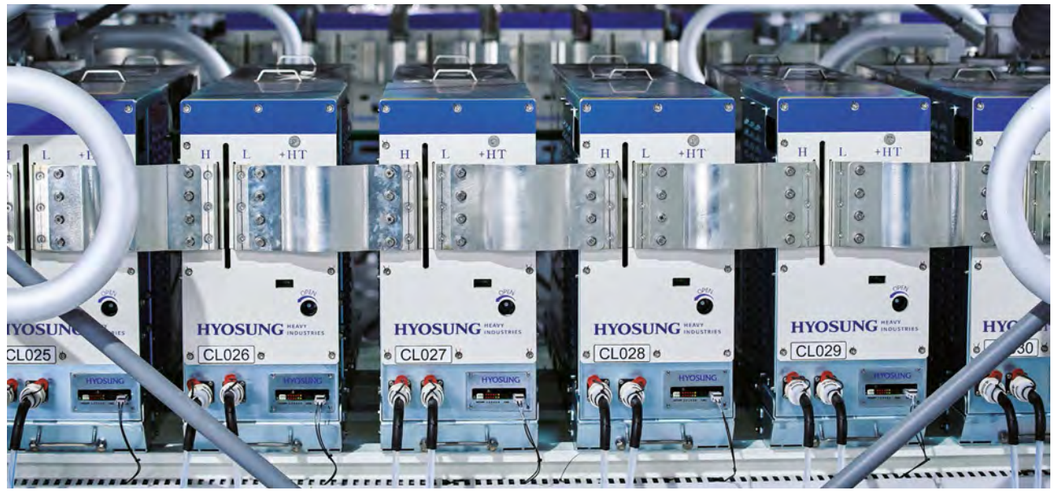


Figure 6 | A close-up view of Yangju converter valve

Hyunho Yoo
Performance Leader
Team Manager of D1 TFT

Misook Ham
Performance Manager
D1 TFT

The HVDC market is positioned for continued growth due to the increasing demand for asynchronous system interconnections driven by offshore wind power. There is a growing need for transmission efficiency, system stability, large-scale transmission, and eco-efficient technology. However, the market has been dominated by three global companies H, S and G excluding China, as they have secured orders through the late 2020s, owing to the high demands for stability and reliability.

Despite holding a smaller market share, Hyosung Heavy Industries' ownership of proprietary HVDC technology, extensive experience commissioning projects within the KEPCO system, and global power infrastructure setup expertise confidently position the company as a compelling alternative for newly planned projects.

To this end, Hyosung Heavy Industries plans to explore potential market opportunities by identifying customer needs, developing and commercializing additional technologies that can participate in various projects, and making efforts to expand its DC products in the growing power industry market.

Hybrid STATCOM: Improving Renewables Integration in Power Systems

Multifunctional (Reactive Power + Inertia) Solution Combining Synchronous Condensers and STATCOM

Globally, there is an increasing necessity for decarbonization. To achieve this, nations are transitioning from fossil fuel-based generators to inverter-based renewable energy sources. The rise in renewable energy has led to challenges in the power system, such as reduced system inertia, lower, short circuit current, and limited voltage control capabilities, prompting various efforts to resolve such issues. The Hybrid STATCOM system enables effective operation by combining the rapid voltage adjustment capacity of a STATCOM with the inertia support and voltage adjustment functions of a synchronous condenser through its optimal control. To prevent mutual interference and performance degradation when individually controlling synchronous condensers and STATCOMs individually, Hyosung Heavy Industries' Hybrid STATCOM master controller is a solution. It actively adjusts the output for reactive power and inertia support roles according to different situations for both devices.

| Trends in Domestic Grid Network |

According to the Energy Economic Research Institute's 'Monthly Energy Statistics (February 2024 issue)', domestic renewable power generation has continuously increased by 2 to 5GW annually since 2015.

To accommodate the increase in load from 2010 to 2015, the capacity of combined cycle power plants on the outskirts of Seoul was increased. Since 2017, amid the global push towards decarbonization and in response to environmental concerns, the capacity for fossil fuel power generation has been maintained, while renewable sources have steadily increased. The transition from conventional synchronous generator-based sources to inverter-based sources can lead to a lack of system inertia. Insufficient inertia can cause significant frequency fluctuations in the event of load variations or sudden loss of generation sources; therefore, recent efforts are being made to maintain minimum system inertia by integrating synchronous condensers.

According to the 'Yearbook of Energy Statistics (2022 edition)', domestic transmission and distribution losses were recorded at 8,651GWh in 2021, indicating significant energy losses annually. South Korea faces geographical disparities between generation and demand, leading to substantial power being transmitted from non-capital regions to the Seoul Metropolitan Area. This structure can result in increased transmission losses and voltage stability issues due to transmission constraints. STATCOMs can resolve these transmission constraints and compensate for voltage instability at the fastest rate. The Hybrid STATCOM is anticipated to be a multifunctional solution capable of mitigating future frequency and voltage issues in systems composed of long-distance AC networks with large-scale renewable energy installations.

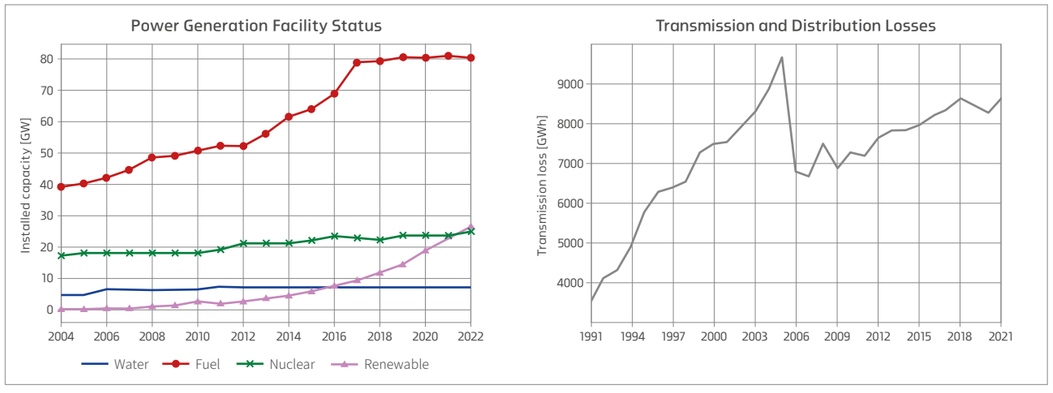


Figure 1 | Domestic power generation facility status and transmission losses (Korea Energy Economics Institute Report)

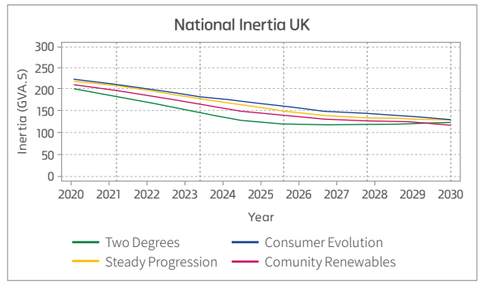


Figure 2 | UK's inertial reduction trend by 2030

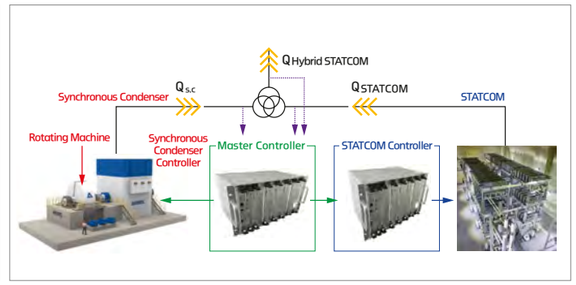


Figure 3 | System configuration of Hybrid STATCOM

| Hybrid STATCOM Solution |

The Hybrid STATCOM was first commercially installed by Hitachi (formerly ABB) as part of the PHOENIX project in the United Kingdom. The UK pursued this hybrid project, combining synchronous condensers and STATCOM, to address several objectives, including: securing system inertia, providing reactive power, enhancing the control performance of power electronic devices, and ensuring fault current for protection. Notably, the continuous decrease in inertia, as shown in Figure 2, was identified as the top priority issue that we must resolve from the perspective of frequency stability.

Recently, projects to install new synchronous condensers or convert decommissioned fossil-fuel generators into synchronous condensers have emerged in South Korea and the USA to resolve inertia issues, indicating the growing necessity for hybrid solutions capable of providing inertia in future power systems.

Hyosung Heavy Industries has already equipped itself with stable STATCOM technologies, as evidenced by the successful delivery of the product to international and domestic systems, including those in India, Panama, Saudi Arabia, and others. Therefore, the company is currently engaged in research and development activities for master control, aiming to achieve comprehensive and cooperative control by integrating synchronous condensers into the platforms, leveraging its technical expertise. This effort aims to complete the ultimate Hybrid STATCOM solution, proactively addressing future grid changes.

Figure 3 illustrates the system configuration of the Hybrid STATCOM, which adjusts the necessary reactive power and voltage for the system and provides inertial energy in response to system changes.

The Hybrid STATCOM can perform a wide range of control modes required by power system operators. It can strategically supply specific amounts of reactive power to the grid according to the operator's control signal and effectively restore voltage through rapid voltage control in response to abrupt voltage changes.

Additionally, when frequency variations occur, it prioritizes the inertial support function of the synchronous condenser to aid in stabilizing the system's frequency. The master controller regulates operational situations tailored to the differing response characteristics of the synchronous condenser and STATCOM.

Figure 4 displays the frequency changes due to the inertial support provided by the Hybrid STATCOM.

The left graph shows tht the use of Hybrid STATCOM can smoothen the rate of frequency change and reduce the magnitude of frequency drops, improving system frequency stability. The right graph reveals that active power output occurs for inertial support during frequency fluctuations, where the master controller ensures the synchronous condenser primarily provides inertia.

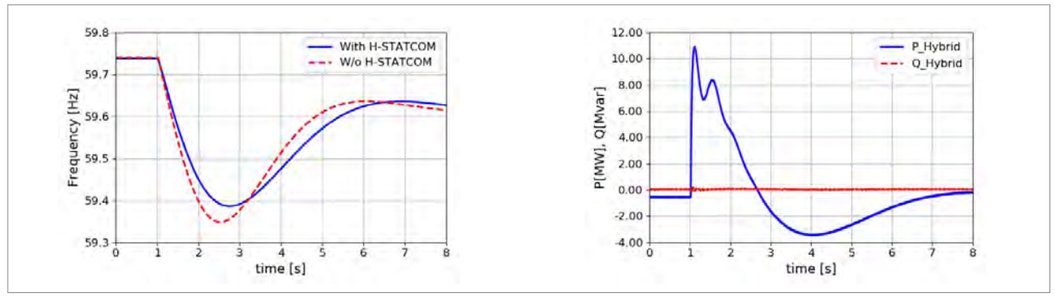


Figure 4 | Effect of Inertia Supply into System by Hybrid STATCOM

Jooyong Jung Performance Manager
Power and Industrial Systems R&D center

Wooseok Seo Performance Manager
Power and Industrial Systems R&D center

The increase in renewable energy sources is causing voltage and frequency issues in transmission networks. With the anticipated rise of inverter-based renewables, the receptivity and stability of grids are expected to degrade. A proposed solution to alleviate these issues involves using STATCOM and synchronous condensers to compensate for reactive power and provide inertia, thereby enhancing system reliability and stability. Hyosung Heavy Industries intends to continuously pursue R&D and commercialization efforts to contribute to the variability and stability improvement of future power systems. This will be achieved by leveraging its accumulated STATCOM product and technology expertise, as well as taking advantage of the synchronous condenser manufacturers or transitioning technology through the use of decommissioned generators.

Emerging Trends in ESS: ‘Long-Duration Solutions and Flow Batteries’

A long-duration operation system that enables the use of solar power electricity all night long

Recent global trends in energy storage systems are characterized by 1) higher system capacity, 2) demand for grid-forming solutions, 3) expansion of microgrids and virtual power plants, and 4) the need for long-duration energy storage systems. Among these, long-duration energy storage refers to systems designed for operations exceeding 4 hours, particularly around 10 hours, differing from systems primarily employing lithium-ion batteries for a short duration of less than 4 hours, and focusing on improving power system stability. Hyosung Heavy Industries is at the forefront of this new trend, establishing systems that utilize vanadium flow batteries (flow cells) as a long-duration operation solution. The company plans to lead the rapidly growing market for long-duration storage by supplying systems that ensure reliability over long-term operation. Unlike lithium-ion batteries, flow batteries are aqueous and non-flammable, with no degradation and a substantially longer lifespan, which are very competitive advantages for applications requiring substantial energy output over their entire life.

| Energy Storage System (ESS) |

There's a saying in power system operations that consumption drives generation, implying that "the amount of consumed power determines the amount of generation." This principle has long been considered an immutable truth. However, advancements in power electronics and embedded system technologies have transformed this truth by utilizing large batteries. The stored energy can now be injected into the power grid whenever required, reflecting various demands through an energy storage system. This changes the formula from "consumption capacity equals generation capacity" to "consumption capacity equals generation capacity plus storage capacity," allowing for a flexible generation transformation and providing opportunities to integrate intermittent or uncontrollable renewable energies into the grid on a significant scale.

Energy storage systems, composed of transformers for grid connection, power conversion systems (PCS) for electricity conversion, and batteries in a low-voltage system (~690Vac), require embedded systems like Battery Management Systems (BMS) and Energy Management Systems (EMS), along with high-speed data sharing through networks. While connecting multiple systems in parallel to increase system capacity might appear simple from a hardware perspective, from a software standpoint, it's quite complex due to the need to develop applications for various demands, reflect multiple requirements simultaneously, and ensure availability to guarantee stable customer revenue.

Ultimately, accelerated deployment of renewable energy in response to meet COP28 and IPCC (Intergovernmental Panel on Climate Change) requirements by climate challenges continuously drive the market need and growth of the energy storage system market.

| Long Duration Energy Storage (LDES) |

IEEE suggests over 20 different operational modes for energy storage systems. While the application varies by country, based on the power grid configuration and electricity rates, they are fundamentally employed for demand charge reduction or revenue through arbitrage due to the price differences in electricity rates. The application required by the power grid changes with the penetration rate of renewable energy. Fundamentally the higher the renewable energy penetration rate, the greater the need for long-duration energy storage systems. Up to 40% penetration, energy storage systems of less than 4 hours are needed for grid stability. Up to 60% penetration can be achieved with 10-hour energy storage systems to ensure grid flexibility. Beyond 60%, energy storage systems capable of up to 100 hours (seasonal storage) are required to ensure grid resilience. These systems operating between 4 to 12 hours are referred to as Long-Duration Energy Storage (LDES) systems. A key application of LDES is charging surplus solar power during the day and discharging it during the evening and night, which can be used for managing generation peaks, grid congestion, and climate change resilience.

Long-duration systems require appropriate storage technologies, including flow batteries, pumped hydro storage systems, thermal storage devices, hydrogen storage, and compressed air energy storage.

Long Duration Energy Storage families

	Electrochemical	Thermal	Chemical	Mechanical
Description	Energy storage systems generating electrical energy from chemical reactions	Solutions stocking thermal energy by heating or cooling a storage medium	Systems that store electricity to drive a chemical reactor that produces liquid fuel	Solutions that store energy as a kinetic, gravitational potential or compression/pressure medium
Examples	• Flow battery • Metal anode • Non-metal • Chemical storage	• Sensible heat • Latent heat • Thermochemical	• Green hydrogen • Methane • Ammonia • Methanol	• Compressed air energy storage • Liquid air energy storage • Pumped hydro storage • Gravity based pumped storage • Liquid CO2
Advantages	• Flexibility • Declining long-term costs • Wide operating range	• **No degradation** • Cycling throughout the day • Modular options available • **Considered safe** (low risk for inflammation)	• Potential range of footprint and RTE with relative higher C-rates • Technology options either have **inexpensive** materials or require less expensive materials than LiB	• **Proven** via established technologies (pumped hydro) • Considered **safe** • Attractive economics

Source: LDES Council, Roland Berger

Figure 1 | Types and Characteristics of Long-Duration Storage Devices (Source: LDES Council)

The technology readiness level of LDES technologies*

technology	technology	technology										
		Concetp			Small to large prototype			Demonstration		Market uptake		Maure
		1	2	3	4	5	6	7	8	9	10	11
Electrochemical	VRFB									■		
	Na-S batteries									■		
	Iron flow batteries									■		
	Matal-air batteries						■					
Mechanical	Advanced-CAES							■	■	■		
	Gravity energy				■	■	■					
	LAES							■	■			
	Liquid CO_2 storage					■	■					
Thermal	Sensible heat					■	■	■	■			
	Latent heat				■	■						

Figure 2 | Technological Development Status of Long-Duration Storage Devices (Source: LDES Council)

Flow batteries are considered the most promising solution based on their low initial CAPEX investment, highly flexible installation and operation, and inherent safety features that eliminate the risk of fire, a major concern with lithium-ion batteries. Pumped hydro storage systems face challenges in securing suitable installation sites and require high upfront costs for the power plant, making them less feasible for medium/low-capacity applications. Hydrogen storage has low round-trip energy efficiency and requires substantial infrastructure investment.
Prominent flow batteries include vanadium, zinc-bromine, and iron-air. Based on current technology readiness, vanadium flow batteries are the most commercialized and have proven track records. Thus, Hyosung Heavy Industries is building solutions using vanadium flow batteries and proposing standardized systems (EMS/PCS/Battery) to clients, including Balance of Plant (BOP) facilities for grid connection.

| Vanadium Flow Battery (VFB) |

A vanadium flow battery consists of a cell stack, the assembly of cells comprising anode/cathode, a separator, and carbon felt, utilizing a flow of vanadium electrolytes with different oxidation states (4-5+ at the anode and 2-3+ at the cathode) to achieve charging and discharging. Thanks to the flow of electrolytes, which are contained in tanks with pumps, the operational duration can be freely adjusted by controlling the volume of electrolytes. Unlike lithium-ion batteries that require scaling up the entire battery product to increase operation time, this system only requires increasing the amount of electrolyte, which makes it advantageous for long-duration systems. However, the system has a few drawbacks, including the use of a maintenance-prone pump, the requirement for tanks and assemblies, which reduces the overall energy density and requires a large installation footprint. There is also a drawback that the efficiency is lowered by the pump that needs to be continuously operated and the DC/DC converter used to step up the DC voltage.

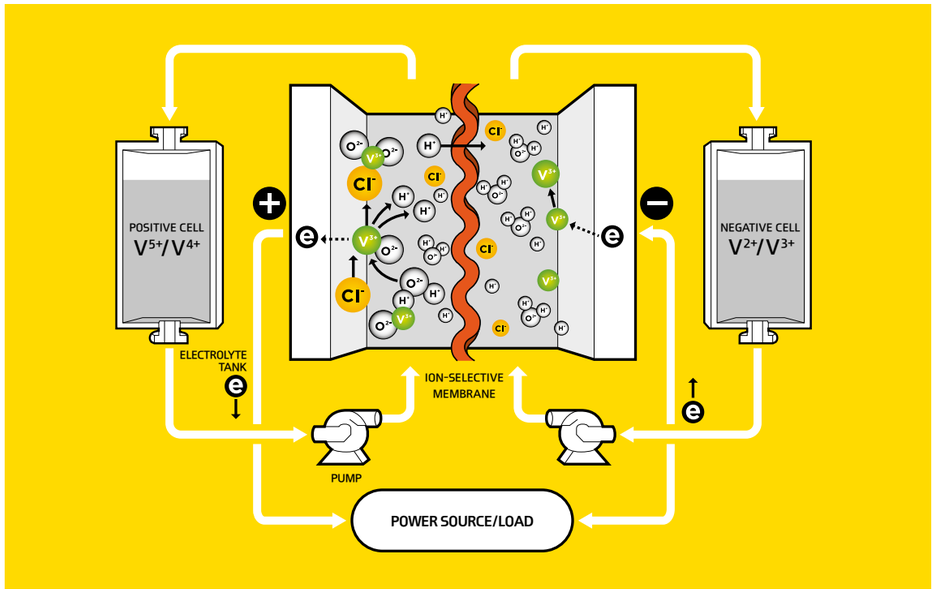


Figure 3 | Structure of Vanadium Flow Battery

Hyosung Heavy Industries is collaborating with Invinity Energy Systems, based in the USA and UK; and Invinity Energy Systems has recently completed the development of a new product that mounts both cell stacks and electrolytes on a 20ft container. To ensure reliability, this product is manufactured entirely in the factory, transported, and designed with simplified maintenance procedures to stack during installation, thereby increasing energy density and removing DC/DC converters by increasing the serial connection of cell stacks to improve system efficiency.

| System Solution Proposal |

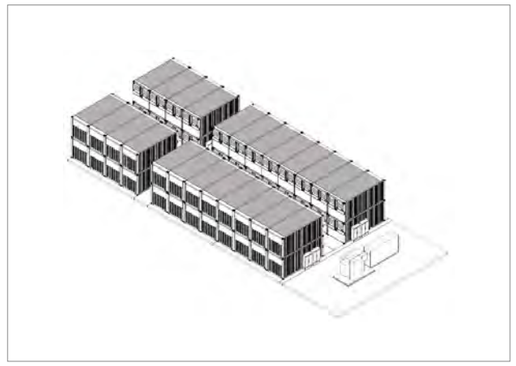


Figure 4 | Standard System Proposal (Source: Invinity 3.6MW/14.4MWh)

Systems utilizing vanadium flow batteries are essential for sites vulnerable to fire hazards, such as chemical plants. By leveraging standardized systems, Hyosung Heavy Industries proceeds with swift customer proposals and optimizes system operation time to reflect customer requirements. Unlike competitors, Invinity Energy Systems's product can be installed by stacking containers and allows for maintenance to be performed solely from the front, enabling tight side-by-side installation to reduce the footprint. Eliminating DC/DC converters has enhanced the system's round-trip energy efficiency. Using standard ISO containers technically allows for stacking up to seven layers, although, from a maintenance perspective, 2 to 4 layers are deemed optimal. Battery companies propose a 14.4MWh system as standard, applying a general ESS PCS of 3.6MW capacity with a two-layer stack (Figure 4).
However, Hyosung Heavy Industries, accommodating recent customer needs, proposed a system stacked to four layers within the same space, configuring a 7.2MW/28.8MWh system for the customer. Due to fire safety concerns, the customer preferred an alternative to lithium-ion batteries and Hyosung Heavy Industries proposed four layers to minimize the installation area.

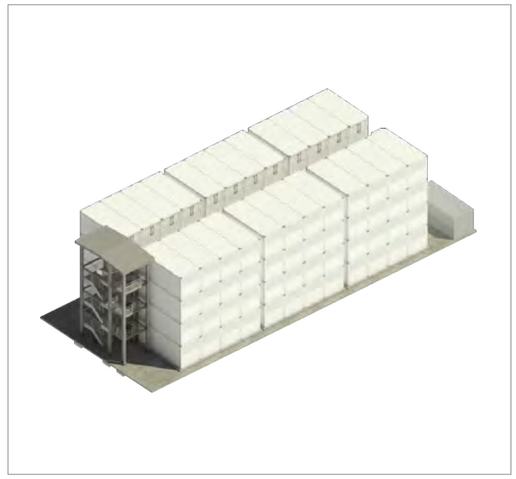
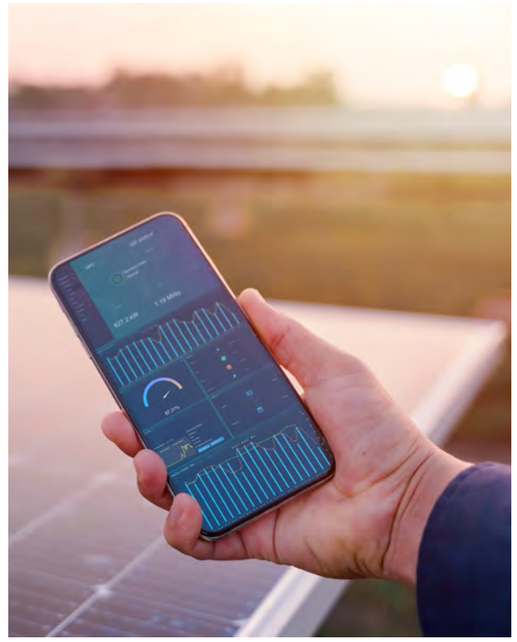


Figure 5 | Customer System Proposal (7.2MW/28.8MWh)



Daehee Choi
Performance Leader
ESS Business Department Director

The continuous growth of renewable energy, particularly solar power, necessitates the role of energy storage systems for long-duration operations, requiring battery systems with different characteristics from those of conventional lithium-ion batteries. Among various storage technologies, the optimal solution is the vanadium flow battery, for which Hyosung Heavy Industries provides system solutions. We offer a differentiated and long-lasting solution by securing flow battery products that compensate for their inherent drawbacks of large installation area and lower efficiency and applying our System Integration & EPC capabilities and BOP products. The long-duration energy storage systems market is poised for rapid growth, and Hyosung Heavy Industries is set to lead the global market by capitalizing on its expertise and solutions.

Upgrade Project from AIS to GIS Substation in Chile

GIS Proposal Solution in the AIS Market

Most South American electricity markets operate under project financing models such as BOT (Build-Operate-Transfer). Consequently, air-insulated switchgear (AIS) facilities have been preferred thanks to their lower initial investment costs. However, this preference has led to negative environmental assessments owing to the extensive land use, increased maintenance costs from frequent upkeep, and a relatively higher probability of failures disrupting the stable supply of electricity. Moreover, with the rise of renewable energy, power producers have a growing demand for reliable equipment to ensure a stable electricity supply. Hyosung Heavy Industries offers optimized solutions that meet customer needs by providing various technical supports to transition AIS substations to reliable Gas Insulated Switchgear (GIS) substations based on our extensive experience and know-how in GIS delivery.

| Upgrade Project from AIS to GIS Substation in Chile |

Chile is experiencing a rapid increase in power demand due to the activation of the mineral industry, coupled with a continuous rise in the power sector linked to renewable (solar) generation. Hyosung Heavy Industries provides a solution that offers highly reliable GIS-based substations from the design stage of substations in electricity markets. We support minimizing the installation cost of substations and ensuring a more reliable power supply through ongoing collaboration with our customers.

Designing GIS substations presents challenges, especially in the South American region, where there is limited experience with GIS substations. Recognizing this, we have engaged in continuous technical meetings and various technical cooperation activities with our customers discussing optimal configuration of substation and GIS-applied specifications from the initial design stage in Chile. This collaboration led to the final approval of the upgrade project to transform two AIS substations, La-Ligua and Totiue, into GIS substations under CEN (National Electricity Coordinator of Chile). We are currently preparing for production and delivery. This GIS substation upgrade project has reduced land use by more than 58%, and outdoor GIS has allowed for a 19% reduction in initial investment costs compared to AIS. This example demonstrates that GIS substations can incur lower initial investment costs than AIS substations, and considering the Life Cycle Cost (LCC), the application of more reliable and economically efficient GIS enables the supply of more stable electricity.

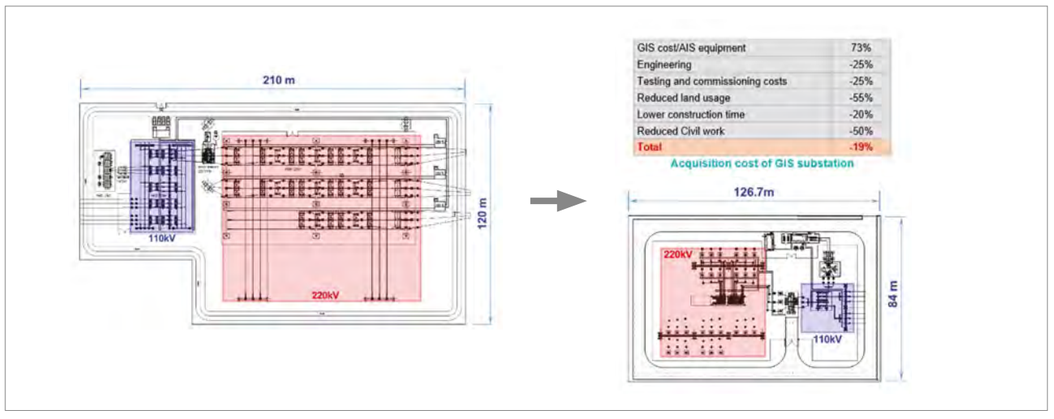


Figure 1 | 220/110/23kV GIS Substation in Chile (La-Ligua Substation)

| Outdoor GIS Proposal and Considerations |

Although applying an outdoor GIS can reduce initial investment costs when considering a GIS substation, it may face operational and maintenance challenges when exposed to natural external environments and extreme conditions. Additionally, varying installation environmental conditions compared to more stable conditions for indoor GIS can lead to corrosion and accelerated deterioration, undermining quality reliability and hindering stable power supply. Thus, such solutions can be proposed by manufacturers with years of operational experience, accumulated high-level technical expertise, and reliability in outdoor GIS. In this respect, Hyosung Heavy Industries, with extensive operating experience in various climate and environmental conditions for GIS up to 800kV, can supply GIS that meets customer specifications based on over 30 years of outdoor GIS operation experience.

Factor	Issue	Solution
Rain	·Flange corrosion ·SF_6 gas leakage	·Double sealing system: O-ring with Waterproof grease ·Waterproof structure of boxes
Low temperature	·Change of phase or physical characteristics of insulating materials	·Selection of O-ring and grease for low temperature ·Application of Tank heater → Prevention of liquefaction
Industrial/ Salt pollution	·Corrosion of the metallic material. ·Surface contamination of insulator	·Anti-Corrosion painting and grease ·Sealing structure of boxes ·Coating on insulator surfaces preventing contamination
Vermin/ Insect	·Intrusion of insects and small animals ·Failure due to nesting of small animals	·Fill the control cable lead-in port with a putty ·Cover to PRD
Snow and ice	·Penetrated water freeze and form ice which induce crack	·Installation of cover to avoid snow piling up ·Double sealing system
Solar radiation	·Additional temperature rise and thermal expansion	·Reducing temperature rise by installing sunshades ·Attaching ultraviolet prevention film
Humidity and Condensation	·Moisture intrusion into boxes	·Install heater ·Sealing the panel/ box opening
High temperature	·Thermal expansion of enclosure ·Temperature rise limit	·Absorption of enclosure expansion by using bellows ·Apply equipment of larger capacity

Table 1 | Notable Considerations for Applying Outdoor GIS

Figure 2 | Key Achievements of Hyosung Heavy Industries' Outdoor GIS

| Various Proposal Solutions for Upgrading from AIS to Outdoor GIS Substation |

GIS is applicable for new substation installations and can serve as a replacement or an addition to existing AIS-operated substations due to various operational requirements. Applying a GIS substation could be the optimal solution when replacing or upgrading substation equipment to accommodate increased power demand, aging equipment, or adding new equipment because of increased power demand when there is a lack of space. This approach can minimize downtime while replacing power equipment and allow for installation without additional space due to the compact-sized GIS, making it more economical.

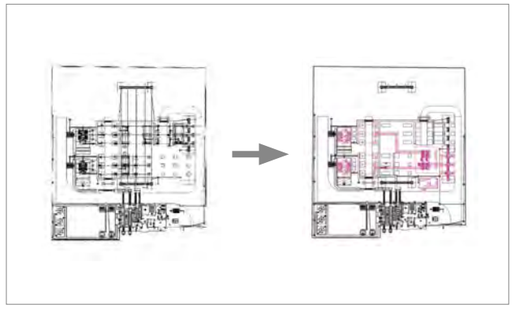


Figure 3 | Upgrading a 110kV AIS Substation to a 220kV GIS Power System

Taesung Rho Performance Leader
Global Solution Engineering Team

With the shift towards renewable energy in electricity markets driving a growing demand for new substation equipment and the replacement of aged AIS equipment, applying compact and reliable outdoor GIS can be an optimal alternative. Hyosung Heavy Industries, with over 30 years of rich GIS design and operation experience and extensive technical know-how, is capable of offering a variety of technical proposals to meet customer needs. Considering the Life Cycle Cost (LCC), an outdoor GIS substation can be more economical than AIS substations and provide a stable power supply by applying its high reliability. Hyosung Heavy Industries delivers the finest solution from the initial design stage of the substation through technical support to ensure the successful operation of the substation facilities.

Power equipment supply chain with reliability for the era of offshore wind power

Hyosung Heavy Industries' Offshore Wind Power Solutions

Since electrification is emerging as a pivotal strategy to achieve net-zero emissions goals, the power generation capacity produced from renewable energy resources is increasing.
In line with this trend, the offshore wind power industry is expected to grow significantly as it can be large-scale and freely located. Hyosung Heavy Industries has know-how in conventional power products including gas insulated switchgear (GIS) and transformer. In order to meet the market's needs, we have astable and reliable supply chain that can supply various solutions such as eco-friendly GIS, eco-friendly transformer, compensator (shunt reactor, STATCOM), BESS/PCS, and many others based on the strength of our products and our understanding of offshore systems.

| Global Trend in Offshore Wind Power |

In the era of eco-friendly energy, offshore wind power is expanding owing to its large-scale energy generation and high-quality stability. Offshore wind power plants are installed in the ocean with consideration for wind volume, wind speed, and wind continuity, so there are fewer site selection constraints. This advantage has led to active new installation and investment in offshore wind power worldwide.

- United States: Achieve 30GW in offshore wind capacity by 2030 and 110GW by 2050
- EU: Require 510GW of offshore wind capacity by 2030

Country	'23-'32 addition plan (MW)	Country	'23-'32 addition plan (MW)
Germany	31,688	Iceland	10,000
Netherlands	19,040	Vietnam	6,000
Poland	10,900	Ireland	4,975
Denmark	10,600	Belgium	2,917

Table 1 | Key countries with OSW addition plans
Source: Global Electricity Transmission Report and Database, 2023-2032

| Overview of Offshore Wind Power Business |

For offshore wind farms with smaller capacity and shorter distance to land, the internal power grid consisting of inter-arrays is often connected directly to the grid (via onshore substation). However, for larger capacity and installations further offshore, the voltage is increased to reduce power loss in the line for grid connection. The transformers and GIS on an offshore substation must ensure suitable capacity and performance while withstanding marine-specific environments.
Moreover, long-distance submarine cables (export cable) connecting offshore substations to onshore substations may cause voltage rise due to their capacitive component, negatively affecting grid stability. Installation of a Shunt Reactor (Sh.R) at the offshore substation can enhance grid stability. In onshore substations, grid connection is completed by stepping up or stepping down to a voltage equal to the grid voltage through a transformer.
Additionally, reactive power compensators such as Variable Shunt Reactors (VSR) and STATCOM should be considered to maintain the grid voltage constant.

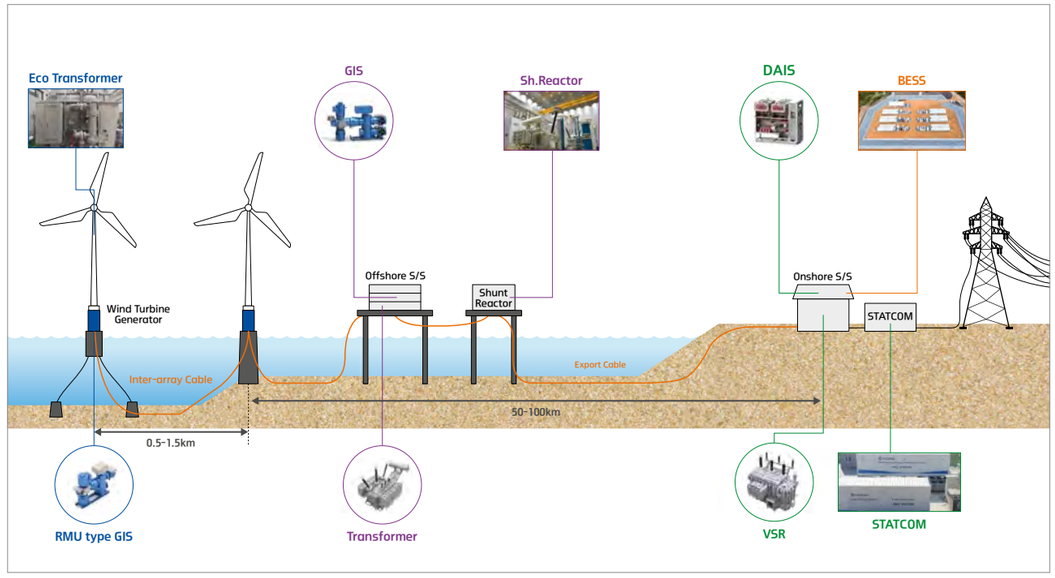


Figure 1 | Configuration of an Offshore Wind Farm

| Hyosung Heavy Industries Product Lineup |

Hyosung Heavy Industries offers stable and reliable global solution engineering capable of delivering a comprehensive package of power equipment essential for offshore wind power, as depicted in the configuration of an offshore wind farm above. The strengths of our main product lines that supply are outlined below.

▪GIS

Hyosung Heavy Industries has supplied over 16,000 GIS units globally since 1980, which satisfy international standards such as IEC, IEEE, and KS. Our product lineup, voltage range from 72kV to 800kV and breaking current up to 80kA, can meet customer demands for reliability, stability, and cost-effectiveness.
Specifically, we have developed eco-friendly 145kV GIS with GWP=0 using Vacuum Interrupters (V.I) and dry air, and making it suitable for wind turbine applications through the supply of Ring Main Unit (RMU) Type GIS. This approach can be expanded to propose customized solutions for offshore and onshore substations.
Additionally, aligning with digital transition goals, we can provide digital solutions having the advantages of space, installation, and maintenance through our in-house developed Low Power Instrument Transformers (LPIT) and Merging Units (MU).

72.5kV SF_6-Free GIS

145kV SF_6-Free GIS

Figure 2 | Eco-friendly GIS

▪Power Transformers

With over 60 years of experience in supplying ultra-high voltage transformers, Hyosung Heavy Industries has developed highly reliable in-house design programs. This enables us to propose designs that meet customer requirements. We can design and manufacture mineral oil, synthetic and natural ester oil transformers.
Eco-friendly transformers, using eco-friendly insulating oil, offer high self-extinguishing properties and a longer expected service life due to higher moisture saturation than mineral oil. Their high biodegradability makes them an optimal solution for environmentally sensitive offshore substations. For eco-friendly transformers, we are available up to 400kV 1,100MVA.

▪Shunt Reactors

Electrical power from various sources like wind and solar can negatively affect grid stability when integrated via cables.
To counteract this, Fixed Shunt Reactors (FSR) are commonly used in offshore substations to compensate for the capacitive component of submarine cables. In contrast, Variable Shunt Reactors (VSR) are used in onshore substations where reactive power compensation varies with generation. VSR, which can adjust capacity by changing taps, offer an economical and highly reliable response to such situations.
Hyosung Heavy Industries has supplied VSRs capable of broad voltage adjustments to countries like the USA, Australia, and Korea, with voltage rating up to 765kV and capacity of single-phase 110MVar and three-phase 250MVar.

Figure 3 | Variable Shunt Reactor

▪STATCOM (Static Synchronous Compensator)

STATCOM is crucial in preventing grid instability and maximizing transmission capacity by meeting the Grid Code of renewable energy sources like wind and solar power. Notably, employing Modular Multilevel Converter (MMC) voltage source converter technology achieves higher performance, lower loss, and lower harmonic generation than traditional 2-3 level converters.
Based on our in-house developed technology, Hyosung Heavy Industries supplies reliable products to Europe, the USA, and the Middle East. Our containerized mobile STATCOM, developed through Voice of Customer (VOC) and market analysis, offers a customized economical solution. Based on these technologies, we are expanding our business more actively into the global offshore wind power market.

Figure 4 | Building Type

Figure 5 | Container/Mobile Type

▪BESS/ PCS

Connecting a Battery Energy Storage System (BESS) to wind power generation, which has high output variability, can induce frequency regulation, output stabilization, and peak power reduction. Hyosung Heavy Industries possesses a wide range of CE/UL-certified products for the Power Converter System (PCS), the core component of BESS. This enables us to propose solutions that maximize customer satisfaction by understanding various countries' Grid Code and reflecting the grid situation.
Hyosung Heavy Industries has installed a total of 2.7 GWh of BESS in over seven countries, including the USA and the UK. It notably constructed the largest BESS project on the African continent in South Africa.

Figure 6 | BESS System Installed in South Africa

Ryunki Kwon
Performance Manager
Global Solution
Engineering Team

Jiwon Lee
Professional
Global Solution
Engineering Team

The movement towards decarbonization is accelerating in response to the global warming crisis and the introduction of renewable energy is intensifying worldwide. In line with this trend, countries are planning investments and projects for large-scale energy generation and offshore wind power with requirements for high quality power and grid stability.
Offshore wind farms are typically 400-500MW, but projects exceeding 1GW are expanding, especially in Europe. Customer requirements are becoming increasingly diverse depending on the varying scales of offshore wind power capacity. Hyosung Heavy Industries can propose power products that cater to these evolving needs. Moreover, by developing eco-friendly power equipment, we support constructing sustainable, eco-friendly infrastructure for humanity and the environment.

Building an Intelligent Quality Inspection System through the Introduction and Utilization of Augmented Realty (AR Based Vision Inspection Systems)

Enhancing Quality and Maximizing Production Efficiency with Next-Generation Equipment

Along with the Fourth Industrial Revolution, including control automation, IoT/networks, big data, AI, etc., our way of working is gradually shifting from manual processes to digital/automation. The AR-based vision inspection system has been developed to respond flexibly to the changing manufacturing environment, replacing human inspections with 3D modeling and inspection equipment to improve quality and production efficiency. Hyosung Heavy Industries is committed to enhancing quality and maximizing production efficiency by introducing next-generation equipment.

| Background for the Introduction of AR-Based Vision Inspection Equipment |

The manufacturing environment is undergoing rapid transformation due to changes in the management landscape resulting from labor hour restrictions, declining productivity due to population aging, a shortage of young talent,population decrease, entry into a global low-growth era, and the shift toward a contactless and remote society spurred by COVID-19.
Major developed countries are actively responding to changes in manufacturing trends with the expansion of smart factories and their advancement by establishing government-led manufacturing revival strategies, and multiple-variety flexible production plans and other developments. To keep up with these environmental changes, building a smart factory utilizing IT technology for manufacturing competitiveness and innovation is crucial for corporate survival in the era of the Fourth Industrial Revolution.
Hyosung Heavy Industries strives to realize customer-centric management, meaning an organization that responds quickly to environmental changes, and acceleration of digital transformation (DX) for database management.' By integrating digital technology into all areas, from product design to shipment, constructing a DX operating system, and pursuing activities for a smart factory to enhance competitiveness through data digitalization and process automation, we are dedicated to establishing a flexible and efficient production system.

AS-IS: Existing Work Methods

- Utilizing 2D drawings with poor intuitiveness, limited work efficiency
- Consuming more time to reduce defect rates
- Inspection quality variation according to individual abilities

TO-BE: AR-Based Work Innovation

- Enhancing visual cognition of workers through intuitive display of 3D design information
- Swiftly conducting external inspections with enhanced cognitive abilities
- Automatically extracting performance reports
- Allocating shortened inspection time to more critical inspection items
- Reinforcing communication efficiency related to design

| AR-Based Vision Inspection Equipment: An Innovative External Inspection Tool |

As part of its smart factory initiatives, Hyosung Heavy Industries' Quality Control Team has introduced an innovative external inspection tool the AR-based Vision Inspection Equipment which possesses the following characteristics:

- Increases production efficiency through the onsite application of numerous design information inputs developed for producing similar yet different products
- Easily inspects and proactively addresses product quality issues based on 3D design information, thereby reducing costs and enhancing customer satisfaction
- Supports rapid and efficient external inspections utilizing 3D design information, saving time for more critical inspections such as welding and characteristic tests
- Digitalizes the results of conducted inspections for easy reporting print-out and can be used diversely throughout the production process, including intermediate product inspections and verification of welding direction positions

| Components of AR-Based Vision Inspection Equipment |

Twyn Studio	Twyn View	Twyn Documentation
Desktop Software (Window OS)	Mobile App (iPad)	Inspection Result Report Generating Tool
• Creates a Digital Twin based on CAD design information • Transfers data to external devices	• Visualizes 3D design information and serves as an inspection tool application • Provides automated continuous object tracking	• Generates conformance results reports

| Effects of AR-Based Vision Inspection |

- Enhanced inspection effectiveness: Prevent the transfer of defective goods in external appearance and size to the next processing step
- Improved inspection efficiency: Reduce by 95% on average compared to traditional inspection methods

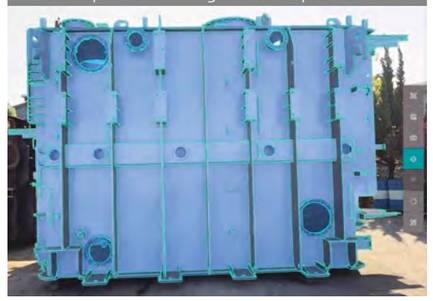
Product Range	Component Name	Inspection Time (minutes)		
		Before Introduction	After Introduction	Reduction Rate
High Voltage TR	Tank	180	6	97%
	Tank Cover	60	6	90%
	Conservator	120	3	98%
General TR	Tank	120	6	95%
	Tank Cover	60	6	90%
	Conservator	90	3	97%
AR-Based Vision Inspection		105	5	95%

| AR-Based Vision Inspection |

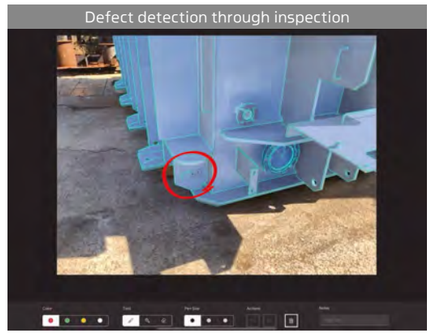
As part of the smart factory activities, Hyosung Heavy Industries' quality control team introduced the 'AR-based vision inspection systems', an innovative appearance inspection tool, to improve productivity and quality, which has the following characteristics.

- Utilization in Incoming Inspection: Components

Overlap of 3D modeling and the inspected item



Defect detection through inspection



- Utilization in Final Inspection: Products

Overlap of 3D modeling and the inspected item

Cheolwoo Baek Performance Manager
Quality Control Team

Hyosung Heavy Industries is innovatively enhancing productivity and quality by automation of inspection processes. It plans to maximize benefits for both customers and the company by analyzing collected data and applying it for product and process improvements.

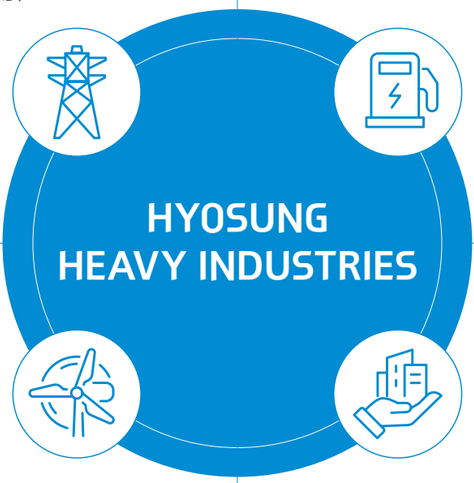
HYOSUNG HEAVY INDUSTRIES

Power Systems PU

- Produces 70% of the core products required for power supply in Korea
- Operates overseas production bases in the United States, India and China
- Power Facilities / Power Systems / Digital Solutions / Welding Solutions

Industrial Machinery PU

- Korea's No.1 electric motor manufacturer and seller
- Performs system engineering business with a wide range of industrial product lineups
- Motors / Generators / Industrial machines / Gear Solutions



Wind Energy Business Division

- Korea's first developer of 750kW, 2MW, and 5.5MW-class wind power generation systems
- Provides total solutions in wind energy such as wind energy core components, wind power turbines, EPC, and O&M

Construction PU

- The first company in Korea to introduce villa-type residential buildings
- Participates in various construction projects such as apartments and office buildings

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