Power Grids

1 Moving towards Carbon-neutral HV Switchgear by Combining Eco-efficient Technologies

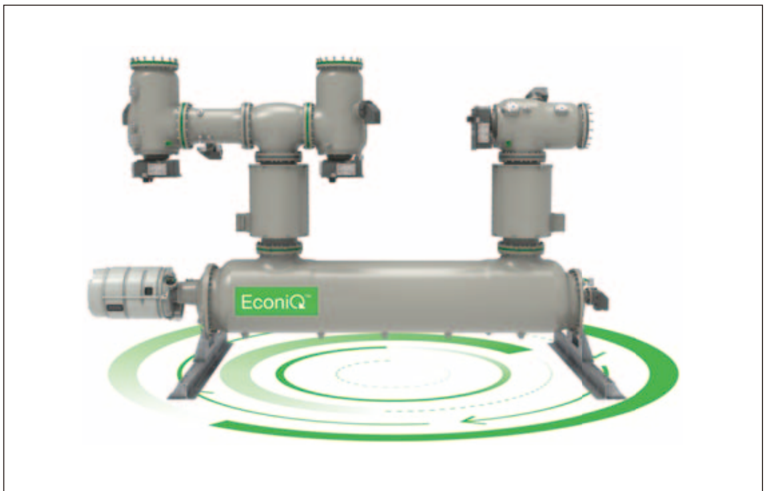
The transition towards a carbon-neutral energy system requires sustainable equipment and services for the power grid. Sulfur hexafluoride (SF_6) technology has been very successful by enabling compact, reliable, and scalable high-voltage (HV) switchgear. In more than a decade of research and development, Hitachi Energy Ltd. has developed an alternative technology to SF_6 for the EconiQ high-voltage portfolio. EconiQ metal-encapsulated switchgear uses an innovative gas mixture with 99% lower carbon dioxide (CO_2)-equivalent, while retaining the compact footprint, low material consumption, and scalability of modern SF_6 equipment. With excellent dielectric and arc quenching properties, the gas mixture of fluoronitrile, CO_2, and oxygen represents the solution for a complete platform of HV switchgear including circuit breakers. It can lead the way to an industry standard for new equipment. The gas mixture enables manufacturers and users to build on decades of experience with SF_6 in dielectric design, gas circuit breaker technology, material choice, operational health and safety, and gas handling. Additionally, an optimal service was developed and implemented for the installed base using the mixture of fluoronitrile, nitrogen, and oxygen. Large volumes of SF_6 in 420-kV gas-insulated lines can be "retrofilled" in existing installations, significantly reducing future CO_2-equivalent emissions.

(Hitachi Energy Ltd.)

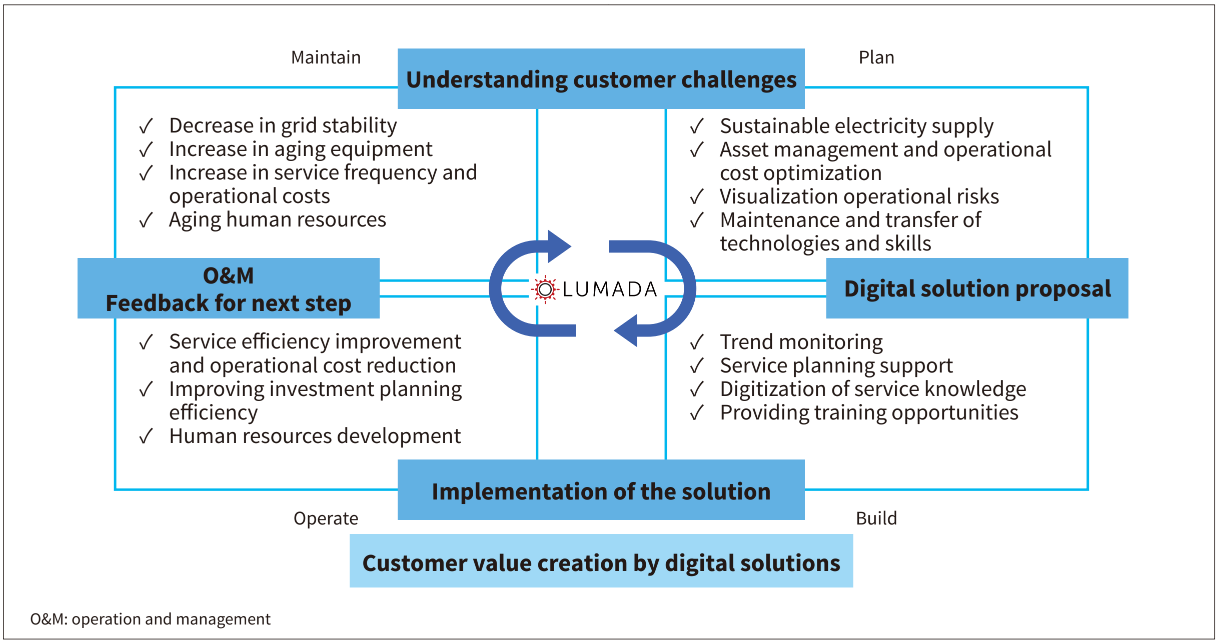
2 O&M Optimization, Operational Risk Reduction of Aging Equipment, and Technology Transfer Utilizing Digital Technology

In recent years, the importance of substation facilities for power plants and key substations has been increasing due to the decline in the stability of the power system owing to the increase in renewable energy and the tightening of power supply capacity. Furthermore, increasing aging equipment in the field conflicts with meeting revenue cap regulations, reducing equipment maintenance and renewal costs while maintaining a sustainable electricity supply. In addition, there is an increasing need for condition assessment for evaluating operational risks of aging equipment, and efficient measures to maintain and pass on expert skills to the next generation.

Hitachi provides the solution for these social issues with Hitachi Energy's online monitoring system, TXpert, and modular switchgear monitoring (MSM), which enables equipment condition analysis, operational risk



1 Eco-efficient circuit-breaker for application in SF_6-free EconiQ 420-kV gas-insulated switchgear



2 Hitachi and utility future vision

assessment, and maintenance rationalization solutions, as well as a maintenance knowledge support system utilizing artificial intelligence (AI) to improve operator efficiency with remote support, digitized know-how, and a knowledge database.

Hitachi also provides a global standard digitalized transmission and distribution equipment package, which realizes customer value for new substations and existing equipment renewal.

(Hitachi Energy Ltd.)

3 Installation of World's First 145-kV Dry-type Transformer in a Hydro Power Station

Hitachi Energy has collaborated with Duke Energy Corporation to renew an old substation at Jocassee Power Station, a 780-MW pumped storage plant located in Salem, South Carolina (USA). The target of the project, in addition to extending the life of the substation, was to eliminate the risk of oil-spill water contamination from the 50 year-old transformers located on the shore of the lake.

The solution involved the development of the first 145-kV dry-type transformer in the world.* It is a unit with a rated power of 3,000 kVA and a nominal voltage of 100 kV. The project is the culmination of several years of development related to the high-voltage insulation in dry-type cast-coil transformers.

The old outdoor substation was converted into an indoor one, freeing the footprint for other uses. The result is the safest solution for people, property, and the environment; with an excellent response to short-circuit mechanical efforts and reduced maintenance costs.

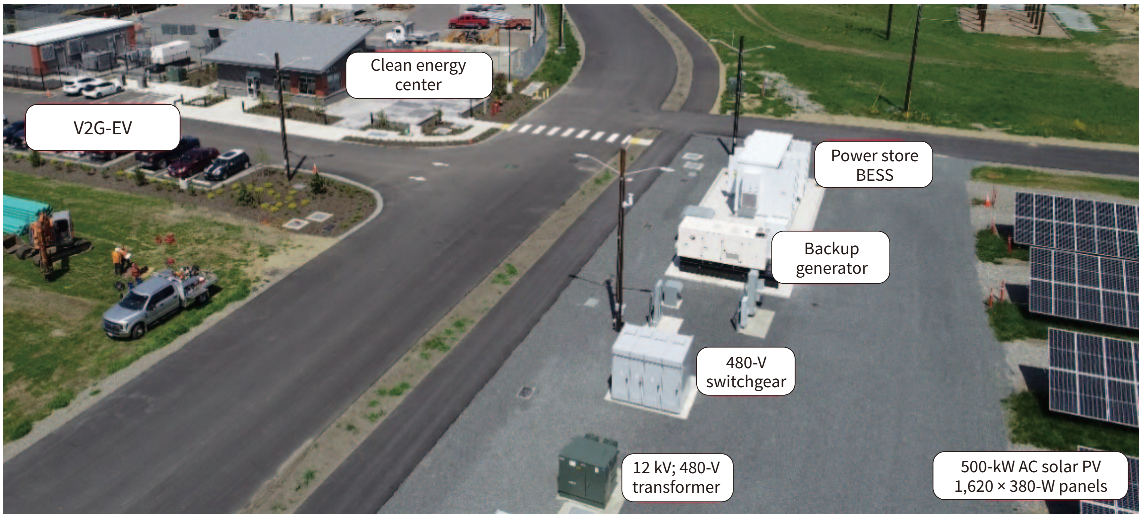
(Hitachi Energy Ltd.)

3 145-kV dry-type transformer after factory acceptance tests with customers

* Based on research by Hitachi Energy Ltd.

4 Microgrid Platform for V2G: Lessons Learned from the Arlington Microgrid

The year 2022 may be remembered as the year of the electric vehicle (EV). Recognizing the importance of EVs, one of the USA's largest public electric utilities, Snohomish County Public Utility District (SnoPUD), unveiled a state-of-the-art microgrid demonstrating how digital technology supports a sustainable future. The Arlington Microgrid pairs Hitachi Energy's e-mesh PowerStore grid-forming battery energy storage system (BESS) with onsite community solar photovoltaic generation, integrated with a vehicle-to-grid (V2G) enabled



AC: alternating current PV: photovoltaic system
Photo courtesy of Snohomish County Public Utility District.

4 Overhead view of the Arlington Microgrid

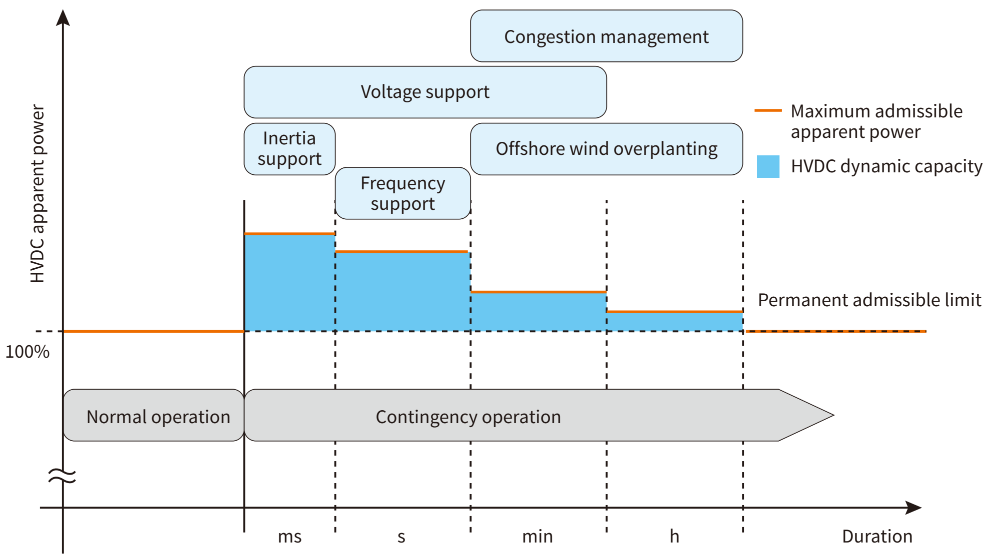
EV fleet. Automation from Hitachi Energy's e-mesh portfolio delivers on the promise of an electrified future—from resilient power and V2G EVs to critical infrastructure operating on 100% renewable power.

With Hitachi Energy's grid edge solutions, SnoPUD unlocked the benefits of pairing EVs with local solar; the vehicles serve as distributed energy resources (DERs) for the microgrid while the microgrid serves as a resilient, renewable hub for EVs. In addition to hardened EV infrastructure, the microgrid hosts critical facilities receiving secure, failsafe power. The Arlington Microgrid is a milestone in SnoPUD's journey to catalyze grid edge technologies across its service territory and beyond.

(Hitachi Energy Ltd.)

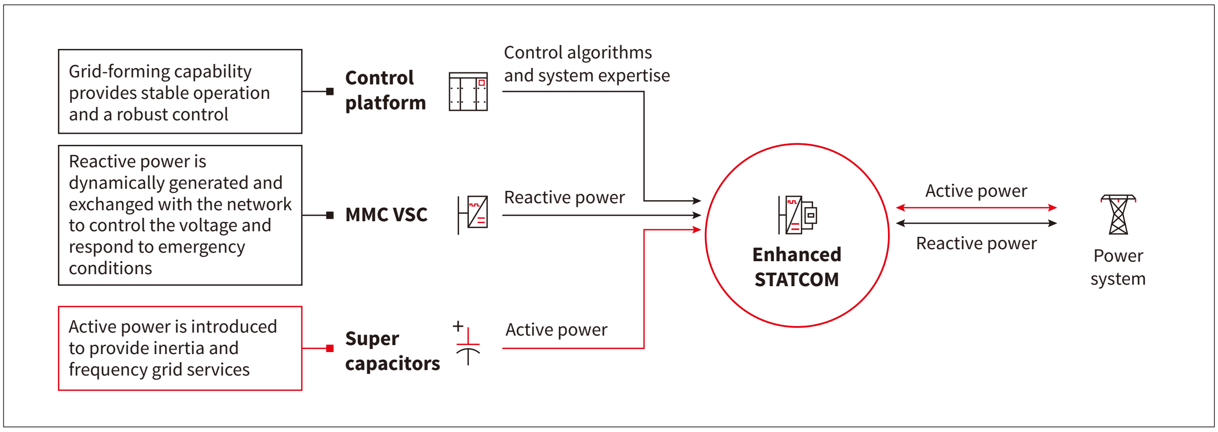
5 Online Estimation of Dynamic Capacity of VSC-HVDC Systems

More efficient use of power system assets is becoming increasingly important on the path towards a fossil-free power system. Hitachi Energy's pioneering HVDC Light is utilized for various applications around the world to accelerate the energy transition. The dynamic capacity*



VSC: voltage sourced converter

5 Power system use cases for dynamic capacity of VSC-HVDC systems



6 SVC Light Enhanced key building blocks

of HVDC Light addresses emerging challenges in the power systems of the future, such as flexibility, controllability, and resilience, and in general, helps operate the power system more efficiently.

Dynamic capacity was tackled from a system perspective with respect to the influence of multiple components and their interaction to provide a proof-of-concept relying on real-time operational data from MACH information management system (MIMS) data loggers installed at the high-voltage direct current transmission system (HVDC) interconnector, NordLink, in Germany. A software prototype was developed to estimate the dynamic capacity depending on ambient temperature and grid voltage to improve transmission system operators' (TSO's) system operations of curative congestion management. In the future, such a feature could be utilized as a curative remedial action to reduce the need for preventive redispatch measures among others.

* Temporary capability to perform beyond their guaranteed capabilities.

6 Energy Storage Enhanced STATCOM for Secure and Stable Power Grids

The modern power system is facing stability and reliability challenges due to lack of inertia. These new challenges create great opportunities to support Hitachi Energy's customers with power quality solutions. The company launched SVC Light Enhanced in 2021 with active power capability and grid-forming behavior. It is expected to play a contributing role in supporting its customers to achieve required inertia levels in the transmission grid. SVC Light Enhanced consists of the following building blocks:

(1) Modular multilevel converter (MMC) solution enables high power and high voltage integration to transmission grid

(2) Power-intensive energy storage technology extends the conventional MMC static synchronous compensator (STATCOM) with an active power capability

(3) Hitachi Energy's power modular advanced control for HVDC (MACH) control platform facilitates system integration and control

(4) Grid-forming control capability provides instantaneous inertia response and voltage response

SVC Light Enhanced is designed to be:

(1) an all-in-one solution for the transmission grid that can provide diverse functionalities including, but not limited to, inertia response, frequency response, voltage regulation, etc.,

(2) a highly flexible, modular, and scalable solution,

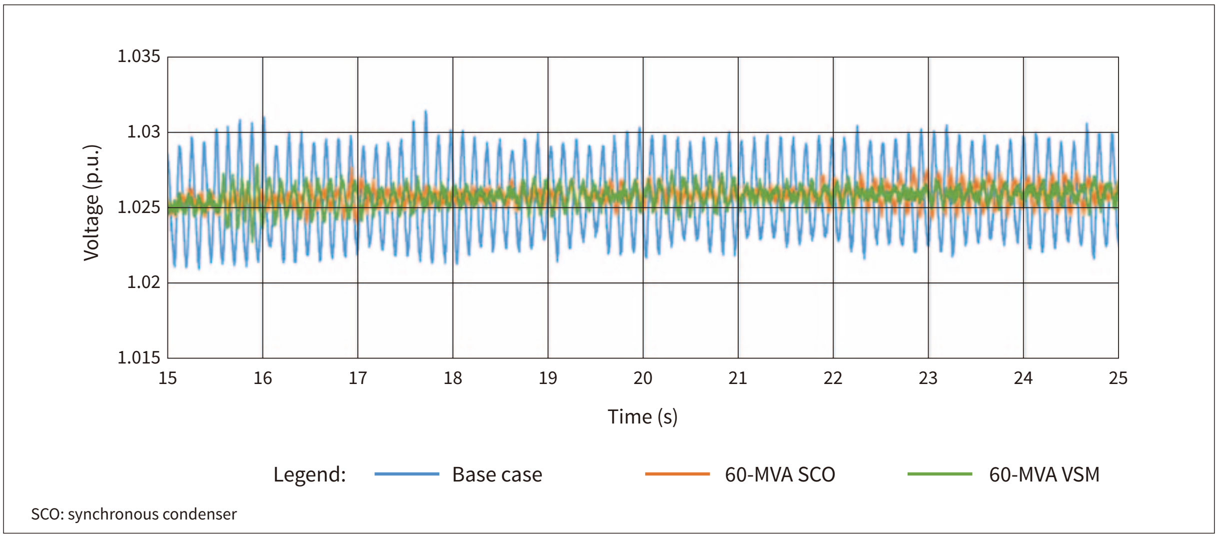
(3) a preferred solution from the ownership perspective—compact footprint, low power loss, long lifetime, and simple maintenance.

(Hitachi Energy Ltd.)

7 System Strength Support Using Grid-forming Energy Storage for High Penetration of Inverter-based Resources on Weak Networks

Hitachi Energy and the Australian Energy Market Operator (AEMO) collaborated in early 2021 to conduct one of the first studies globally into the effectiveness of virtual synchronous machine (VSM), advanced inverter technology to support system strength and enable high penetration of renewable energy to operate on weak electricity networks. The study was motivated by the performance of the Dalrymple BESS – the first National Electricity Market (NEM) connected advanced inverter BESS and the system strength challenges seen in the West Murray Zone (WMZ).

According to the study, a 60-MVA VSM and a 60-MVA synchronous condenser were found to provide



7 Post-disturbance voltage oscillations suppressed by VSM to same extent as SCO

similar system strength support in damping post-fault voltage oscillations in the WMZ. As such, a VSM is a viable solution for connecting and operating large amounts of renewable energy in weak areas of the NEM, with the added ability to provide market services. The results have moved the industry's understanding of advanced inverter technology forward significantly and reinforced this technology's key role in enabling a zero-emissions grid.

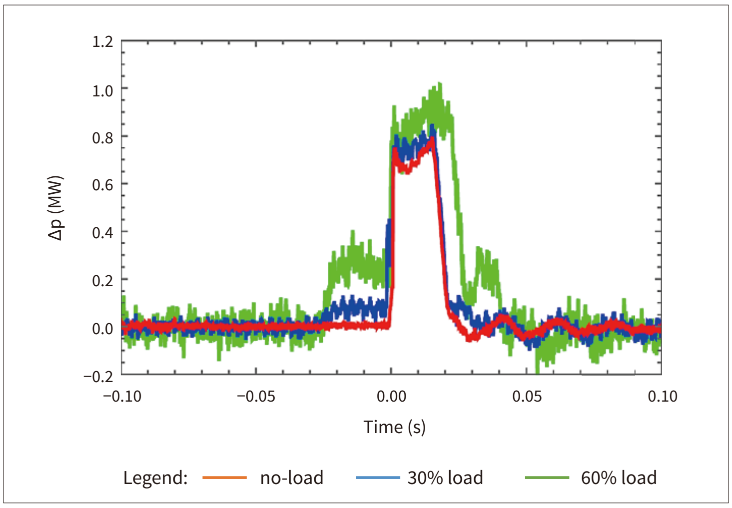
(Hitachi Energy Ltd.)

8 On-load Tap Changer Monitoring and Protection by Extra Power Loss and Circulating Current Analysis

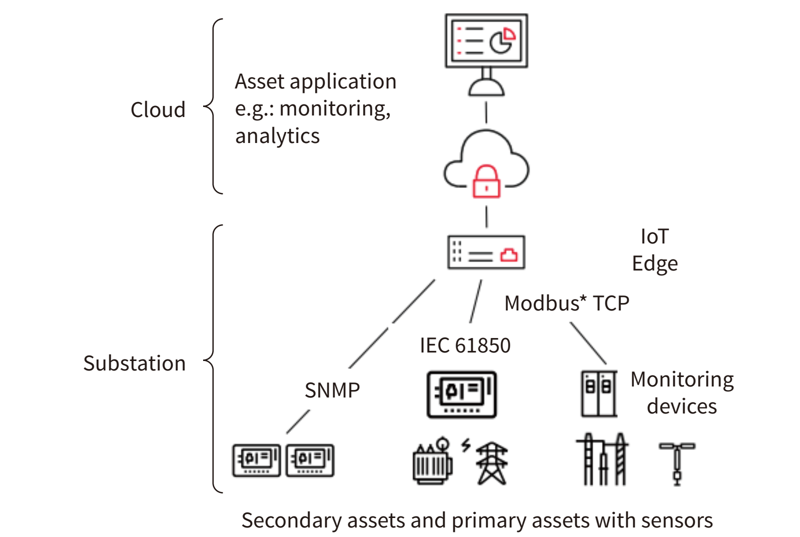
The on-load tap changer (OLTC) used for voltage regulation is the only moving part of a transformer, accounting for more than one third of transformer failures every year, and thus requires frequent care and maintenance.

Hitachi Energy Research has developed a novel method for OLTC operation monitoring on-line and a protection function against incomplete tap operations based on ordinary protection grade instrument transformer signals digitized by modern substation numerical protection relays or disturbance recorders. Thus, in most cases, no additional sensors, acquisition hardware, or outage is required for the implementation.

The monitoring algorithms were tested and verified based on more than 20,000 field-recorded tap operations of a few different tap changer models and they are able to extract monitoring parameters with enough precision to observe subtle differences in each contact position of certain tap changer models and also to monitor long-term trends. The protection function is designed in such a way that it can be implemented on a modern numerical



8 Instantaneous extra power loss during a tap change operation of a 63-MVA transformer



9 IoT reference architecture

protection relay, meeting the standard requirements for such an environment.

(Hitachi Energy Ltd.)

9 Integration of Digital Substation IoT Sensor Data into a Digital Enterprise

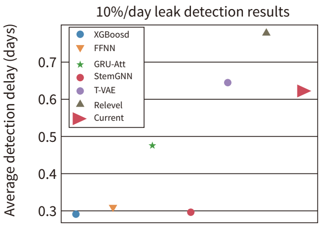
With the increasing interest and implementation of digital substations, the amount of digital information coming from substations has dramatically increased. Asset owners are realizing that intelligent electronic devices (IEDs) are becoming an equally important asset to be managed with full support of enterprise asset management and online connectivity to the installed base. Their health condition must be analyzed from cybersecurity and other aspects with full traceability of condition monitoring and changes happening in the asset lifetime. The fleet of IED assets will further increase. Therefore, it is crucial to focus on assets with highest risk and importance. This will ensure that resources and people are used more effectively.

Additionally, cybersecurity regulation is one of the main drivers and requires asset owners to ensure they know the asset status and risk related to it. Connecting digital information to utility enterprise business processes enhances the operation and maintenance of assets in the substation. For digital assets like IED, this is required to comply with cyber-security regulations. The proposed concept of integrating IEDs into existing Lumada Asset Performance Management (APM) will create new visibility and insights of the assets in the substation that will require operation and maintenance during the entire life cycle of the substation.

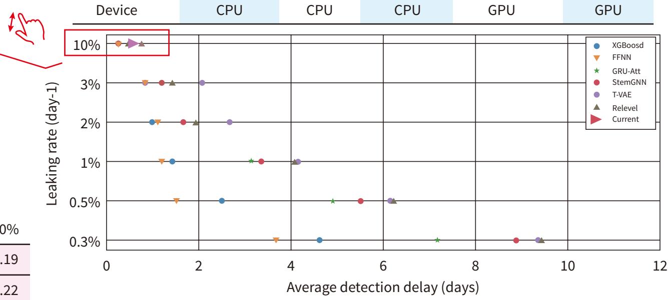
(Hitachi Energy Ltd.)

10 Computing Intelligent Insights about Station Subsystem Health with Data Analysis and Lean IIoT

With the main focus on ensuring availability, the topmost priority for transmission network operators is to ensure a high level of in-service availability in HVDC stations. Thus, more work is needed towards condition monitoring and predictive maintenance for HVDC systems considering the latest technology improvements. The traditional scheduled maintenance approach is a weak concept and new approaches and strategies are being explored and adopted. With the industrial IoT (IIoT) as an enabler for digital transformation, new business models and services are emerging on data analytics platforms for both greenfield and brownfield stations. One such computationally promising solution is the application of data-driven approaches using machine learning (ML) algorithms where several advanced, efficient, and intelligent learning algorithms are developed based on many real use cases. These algorithms are used to analyze the condition of equipment and its components in complex HVDC domains such as to detect anomalies upfront in transformer tap changers based on tap switching data,



Methods	XGBoost	FFNN	GRU-Att	StemGNN	T-VAE
Training time (min)	< 1	< 1	up to 3	up to 10	up to 30
Device	CPU	CPU	CPU	GPU	GPU



Leak detection delays on new data validation

Methods	0.3%	0.5%	1%	2%	3%	10%
XGBoost	5.33	2.07	1.31	0.76	0.38	0.19
FFNN	6.81	2.05	1.22	1.01	0.74	0.22
GRU-Att	6.23	4.24	2.96	1.54	1.06	0.33
StemGNN	10.52	5.44	3.94	2.72	1.85	0.58
T-VAE	6.51	4.03	2.92	1.94	1.78	0.58
Relevel	11.46	5.67	3.60	2.60	1.79	0.83

Pink shade denotes big leak detection is first triggered, while blue shade denotes small leak detection is first triggered

CPU: central processing unit GPU: graphics processing unit

10 Sample results on leakage detection

a deep learning classifier to detect faults in the station, quick leakage detection in HVDC valve cooling systems with the goal of developing a robust ML algorithm to detect small leaks accurately, detecting large leaks more quickly than traditional methods, avoiding false positives, and many other use-cases.

Such methods to detect anomalies could be used to create advanced maintenance services spanning a wide range of areas including not only HVDC power assets, but also at the system level since health indicators may vary depending on the application [e.g. flexible alternating current transmission systems (FACTS)] and location profile (e.g. offshore, onshore). Thus, maintenance can be carried out in response to the observed degradation in the component condition.

(Hitachi Energy Ltd.)