

Life cycle service for HVDC systems

GUILHERME MEDRADO
ABB Ltda
CLEBERSON MODELLI
Enel CIEN

Brazil

HANS-JOACHIM KARL
ABB AG

Germany

HANS BJÖRKLUND
ABB AB
ERIK JANSSON
ABB AB
URBAN ELGQVIST
ABB AB

Sweden

1. SUMMARY

This paper presents a life cycle approach to industrial service, based on real operating experiences, digital services, refurbishment, upgrades of existing high-voltage direct current (HVDC) transmission systems, and consideration of total cost of ownership. It also covers service and operational experiences of converter stations, including offshore platforms. The paper starts with real operational examples, co-written with an owner from the Americas region, and describes a future vision for digitally-enabled systems and life cycle services. Service principles are described from an HVDC perspective, but is also applicable to flexible alternating current transmission systems (FACTS).

HVDC systems (onshore and offshore) and FACTS transmission assets have lifetimes that are many decades long. Over that time, the development of newer and more advanced components and technologies can improve an older system's performance and security, adding many years to its lifetime and delivering new functionalities that further increase its availability and reliability. Digital upgrades enable systems to benefit from connection to the Internet of Things (IoT), and integration with modern asset management and data analytics systems.

Life cycle service is a process that efficiently maintains and optimizes a system throughout its life-cycle, from cradle to grave. Integrated solutions for systems and services, in which a system is designed for service and vice versa, are very important. Well-integrated life cycle service strongly influences overall equipment effectiveness, while day-to-day operations rely on measures that ensure resiliency, efficiency, safety, security, and sustainability. Life cycle assessment and inspection can provide a clear understanding of system condition, reconfirm installed components, and identify needed safety improvements. It increases awareness of service, upgrade, and maintenance requirements, and helps to identify the need for digital and data-driven services as well as the potential for remote monitoring, diagnostics, analytics, cybersecurity, and IoT. HVDC applications have much to gain from a thorough life cycle management process, in terms of technical, operational and financial advantages.

KEYWORDS

HVDC, Service, FACTS, Offshore, Industrial, Life cycle, Asset Management, Upgrades, Maintenance, Digital, Remote Access

2. OPERATIONAL EXPERIENCE

Real operational examples include an HVDC country interconnection (onshore) and an HVDC offshore wind interconnection.

2.1 HVDC Life cycle service support for Brazil - Argentina HVDC interconnection

The HVDC interconnection between Argentina and Brazil, owned by Enel CIEN, demonstrates the advantages of a modular, back-to-back HVDC interconnection concept in support of a cross-border energy trading project between two countries.

The transmission system comprises more than 1,000 km of 500 kV AC overhead lines between the substations of Rincón de Santa María in northern Argentina and Itá in southern Brazil, also passing through the Santo Ángel AC substation and the Garabi HVDC converter station in Brazil, near the border. Argentina's power system operates at 50 Hz, and Brazil's operates at 60 Hz. The asynchronous interconnection is through HVDC frequency converters in a back-to-back configuration at Garabi.



Figure 1: Brazil and Argentina HVDC interconnection.

The Enel CIEN business model relies on a skilled operations and maintenance (O&M) engineering team to ensure excellent performance at the Garabi HVDC station. General O&M services at Garabi station and related AC substations in Santo Angelo and Itá were normally outsourced. This model has proven effective, generating availability results higher than 99% during the last five years of operation.

Enel CIEN encountered extra difficulties along the way as a result of the particularities of back-to-back stations. It was a big challenge to keep the asset running during periods of underutilization by the Brazilian government following the 2011 contract remuneration scheme.

For these and many other reasons, Enel CIEN was pushed to the limit in its efforts to improve O&M to the next level of quality and performance. All preventive and corrective maintenance support had to keep pace with relentless demands for reliable operational performance. An innovative contract type was presented based on remunerated activities instead of man-hours, with the overall goal of securing long-term availability and reliability at the facilities.



Figure 2: Garabi station - the largest back-to-back HVDC installation in the world.

The contract scope consists of O&M services for the back-to-back Garabi converter station and the Itá and Santo Angelo substations over a three year period, using relevant expertise and experience in HVDC systems, processes and tools to extend asset life. The big challenge is to provide top service performance in terms of time and quality, and reduce the number of open reported service cases that could lead to a failure.

Enel CIEN has a future life cycle approach to service. It is moving towards digitalization and also concerned with total cost of ownership and cybersecurity, in relation to availability and uptime. It proactively identifies issues in its facilities, conducts equipment assessments to extend life cycles whenever possible, and feasibility studies to improve small systems focused on lowering maintenance costs, optimizing inventory and enhancing decisions about new asset investments. Enel CIEN plans to use the remunerated activities model in other long-term contracts, because it delivers great performance and results, and is a win-win for the owner and manufacturer.

2.2 HVDC Life cycle service in an offshore environment

In the extreme environment of the North Sea, HVDC equipment and related platform systems are supported by life cycle service, inspections and maintenance where necessary. The Dolwin converter station is housed on an offshore platform, and has the capacity to transmit enough clean energy to power around 1,000,000 households, making it the most powerful installation of its kind in the world. The North Sea’s DolWin wind farm cluster is connected via AC cables to the platform-based HVDC converter, where wind generated power is converted and transmitted over a 45-km DC sea cable and a 90-km land cable to an onshore HVDC converter station at the grid connection point in Germany.

Detailed health and safety procedures are needed to prevent lost time injuries in an offshore environment, including proper helicopter, escape and climbing training. In the confined space of a platform, communication and real teamwork is essential for the safety of all. Continuous efforts are made to reduce the HSE risk on platform work spaces. For example, platform steel above sea level is usually inspected for structural damage, rust or damaged paintwork by a maintenance engineer, who uses climbing equipment (rope access) to make the inspection. This requires a rescue vessel in the water by the platform, in case the worker falls.

Alternatively, pilot tests have been done with drones (drone access), which have distinct advantages over physical inspections, including improved health and safety conditions, more precise forecasts of asset health, and improved repair planning. Aerial inspections reduce the need for employees to work at great height using rope harnesses. Not only is this safer, but the imaging film record from a drone-inspection can be analyzed in detail afterwards, and also be compared with other inspections.



Figure 3: Interconnector between mainland Germany and the offshore wind station.

Service work environments are very challenging and present a higher exposure to risk than regular maintenance work. Life cycle services ensures the right people and processes are available 24/7 to minimize outages and problems. Around-the-clock support provides analysis, instructions, corrective measures, and can also mobilize service engineers within agreed response times. It directs maintenance activities according to a preventive maintenance strategy/plan, which are conducted as monthly, quarterly, biannual and annual inspections and maintenance activities. Behind this, project management provides planning, reports and conducts project reviews. Spare part and asset management are additional needs that are handled. During yearly shut-downs when everything must go smoothly, the successful completion of planned maintenance is key.

Future offshore service strategy will be based on a combination of traditional services, improved offerings and new products for the digital space, such as remote service, drones, and others. An offshore life cycle approach to service will take into account the specific offshore environment, and the requirements for green energy generation at the highest possible level of availability. It will utilize innovative new service products with careful consideration of the total cost of ownership.

3. LIFE CYCLE SERVICES

Life cycle industrial service is needed from a system’s birth to its death, meaning from original greenfield installation to its replacement with a new system. This life cycle is typically 30 - 40 years or longer for primary equipment. Controllers and secondary equipment generally have shorter lifetimes, while software requires frequent functionality and security updates. Life cycle service strongly influences overall equipment effectiveness [1]. Day-to-day operations rely on it to ensure resiliency, efficiency, safety, security, and sustainability.

Industrial services are essentially similar across industries and technologies, although service providers have different areas of expertise. Traditional life cycle services include spare parts, maintenance, repairs, upgrades, software/hardware updates, and training. New services will be even better integrated versions of traditional offerings, adding new innovations like digitalization, industry communication standards such as IEC 61850, cybersecurity and others, including some as yet unknown to us. Digitalization of services is a key enabler, and life cycle service will require a number of service components to efficiently support the system life cycle. These component service products are available throughout the system life cycle, and are used to correct, prevent, and predict issues that may occur. Like a wheel, the relevant service components steadily roll forward along the system life cycle across enabling building-blocks.

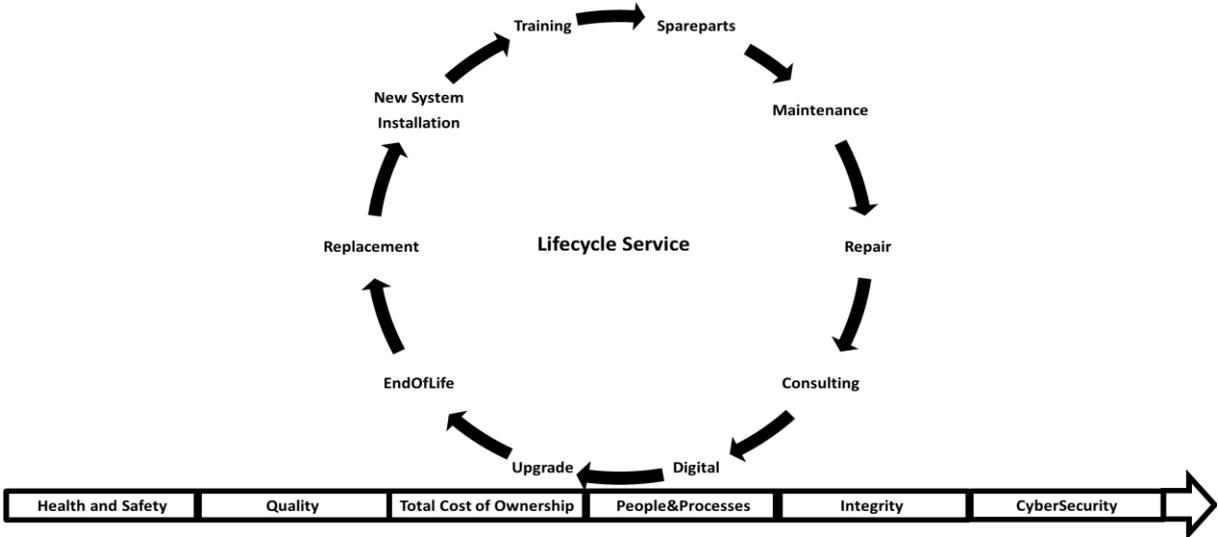


Figure 4: Life cycle service components and enabling building blocks, integrated with systems.

Future life cycle service delivery requires certain enabling building blocks. These include Health and Safety, preventing accidents and injuries by minimizing hazards at work sites and in working environments. Zero injuries is today the expectation. Quality in every aspect of service delivery is supported by proper knowledge, correct processes and system support for service people. The perception of quality by industrial customers is not solely based on technology features and availability. Reliability, responsiveness and empathy are other important components of service quality. An emerging mindset has manufacturers and owners collaborating on a culture change that is turning product-centric organizations into integrated product and service organizations. Total Cost of Ownership (TCO) throughout a system's life cycle must be relevant with respect to system capacity and performance requirements. Capital expenditures incurred when investing in a system must be balanced with operational expenditures - the ongoing service cost of running the system. For example, it may prove economically justifiable to replace, based on their condition, some components with high usage rates (duty cycles) earlier to avoid the major disruption of more frequent service. Day-to-day operations rely on service for availability, process performance, and quality. Owners need cost certainty to plan capital and operating expenditures, as well as a framework for measuring owner value. Life cycle services and the enabling building blocks noted above are part of TCO input, in addition to other costs generated on the owner side, such as people, processes, land, financing, regulatory requirements, licenses, etc. This can be addressed fully in a collaboration between manufacturers and owners.

Service people are essential assets, which includes the entire ecosystem of contractors, operators and subcontractors, whose professional collaborations make life cycle services a reality. They are supported by organizational standards, ethics, principles, values and norms that shape their actions and comprise the foundations of a successful life cycle services business. Service is built on a framework of processes targeting different service levels and methods. Life cycle services are created onsite in collaboration with the owner/partner. It is a product concerned with preventive maintenance, corrective maintenance, repair, replacement, upgrades and updates.

Integrity is a fundamental, core competency for any successful life cycle services collaboration, and makes cybersecurity service products possible. These help to mitigate cyber threats and vulnerabilities [2] and prevent malicious, unauthorized access to networks, computers and controllers, etc, where the objective is to steal, modify, delete, or manipulate. To be effective, cybersecurity protections must be implemented in systems, services, people and processes, and then continuously updated in line with national and international rules and regulations. Founded on trust and mutual collaboration, they are based on several lines of defense to handle a continually evolving threat. NERC CIP standards address the security of cyber assets necessary for the dependable operation of North America's electricity grid. The NIS directive is the first piece of EU-wide legislation on cybersecurity, which aims to raise Europe's capacity to deflect cyber incidents.

4. UPGRADES

An HVDC station is a complex, well-integrated system comprising many components and advanced subsystems. Many components are well understood in the power industry, such as breakers, disconnectors, arresters, measuring equipment, transformers, reactors, filter capacitors, etc. These component lifetimes are typically well known to utilities – the life expectancy of most is well beyond 40 years. However, in some cases lifetime depends on usage. For example, it may be economically justifiable to replace circuit breakers with heavy switching requirements earlier, as the alternative would be frequent maintenance and major overhauls. Systems unique to HVDC stations are HVDC valves, and control and protection systems.

The earliest HVDC valves in commercial use were the mercury arc valves installed in the Gotland Link in 1954. This project was followed by nine others using mercury arc valve technology until the mid-70s. All of these valves have now been replaced or retired. Although they operated successfully throughout their lifetimes, they did require substantial and continuous maintenance. The longest to

remain in use were ASEA valves installed in a New Zealand project, which were finally decommissioned in 2012 after 47 years of successful operation.

Starting in 1968, thyristor valves began to replace mercury arc valves in HVDC installations, including the original Gotland HVDC link. Most replacement thyristors remain in operation with the original HVDC equipment, but now we are starting to see some of the oldest replacement valve installations being upgraded, meaning older thyristors are being replaced with new valves using the latest water-cooled thyristor designs. The decision to upgrade the valves is sometimes based on the difficulty of locating spare parts, but more often because thyristor performance is developing so rapidly, owners can increase power capacity and reduce losses in their assets by using a smaller valve that easily fits into the same building that housed the original valves [3][4].

Since 1999, we have also seen a large number of voltage source converter (VSC) projects using IGBTs - a pioneering technology that also made its debut in Gotland - installed around the world. None of these valves has yet reached the age where an upgrade is justified, except for an insurance replacement after fire damaged one converter in Mullumbimby (Terranora Interconnector) in Australia in 2012.

Also unique in HVDC installations are control and protection systems. Because an HVDC station needs several very fast and continuously operating closed loop control systems as well as very fast protections, these systems are quite different from conventional AC protection and control equipment. The technical lifetime of the control and protection system in an HVDC link is in the range of 30-40 years. Thus, if an owner plans to use the HVDC link investment for 50-60 years, it would be wise to plan for one control system upgrade during this time, at around the 25 year mark for an optimum return on investment. But if the plan is to retire the plant after 40 years, much of the control equipment could probably be used during its complete operational lifetime, and scrapped at decommissioning. There can be other reasons or opportunities that could create a need to upgrade control systems at an earlier date, such as a power upgrade, or the addition of more converters, etc. [5]. An important part of a modern control and protection system is the Human Machine Interface (HMI), which is almost exclusively built using state-of-the-art computers with modern operating systems (OS), such as Windows or Linux. This offers the advantage of high resolution on multiple screens, excellent communication capabilities and access to many office-type programs that are often used to administer an HVDC station. The down-side is that software development is very fast, and within a short time (perhaps 5-10 years), the installed operating systems will no longer be supported by manufacturers or development communities, and security patches will no longer be available. This will force an OS upgrade, but then it is often not possible to load new OS versions onto original computer hardware, which forces an additional upgrade of operator workstations, gateway computers, servers etc. Future digitalization efforts with connections to cloud-based maintenance services via gateways will further stress the need to always keep equipment at this level updated, to ensure quick installation of the latest security patches.

To confront these issues, a model has been introduced with a layered control and protection system architecture, enabling different upgrade intervals for different parts of the control and protection system.

For example, at the supervisory layer are HMI computers and servers, which can expect an upgrade interval of 5-10 years. The next layer are high-performance, real-time computers and Digital Signal Processors (DSP), where a longer lifetime can be predicted, but as discussed above an upgrade interval of 20-30 years must be expected to match the availability of components and spare parts. The last layer includes input/output (I/O) units, which are closely tied to main circuit equipment such as breakers and disconnectors, transformers and measuring devices (CTs, CVTs, etc.) In many cases, I/O devices can be kept in operation as long as the main circuit equipment operates, or is replaced with identical devices. However, in some cases we have seen main circuit configurations expanded or changed in such a way that it becomes necessary to replace parts of or even the entire I/O system. Therefore, upgrade intervals for I/O systems can also be expected to fall in the 20-40 year range. It is important to consider these different upgrade intervals, which should be part of any well-managed, proactive life cycle plan for an HVDC station.

Experience shows that the outage times needed to complete control or valve upgrades can be very short, and will ensure an HVDC asset operates successfully for a very long time before it needs to be totally replaced [5][6][7]. A control and protection upgrade can be performed during a pole outage of

2-3 weeks, while the valves in one converter can be replaced in 4-6 weeks. The layered upgrade of an HMI system can usually be performed during operation, and does not require any specific outage at all.

5. CONCLUSION

The future has already started. We must continue to develop traditional services, existing digital and new services, which together with HV systems constitute integrated solutions. This is necessary to fulfil the evolving needs of an ecosystem comprising the high-voltage industry, owners, partners and other stakeholders. Integrated solutions of systems and services are important, in which systems are designed for services, and services for systems, because a well-integrated life cycle service strongly influences overall equipment effectiveness.

New services and technologies, such as Industry 4.0, the Internet of Things (IoT), augmented reality (AR), remote services, data analytics and predictive maintenance have entered the industrial service space alongside existing services and technologies, and there will be further evolutions. All are integrated with the system, components and advanced subsystems, such as valves, cooling, and control and protection.

Step-by-step, new services are increasing the expectations of utility and industry owners, who are demanding the shorter response and resolution times and higher performance outcomes they promise. The new services will be supported from local/regional/central centers that collaborate to provide front-end services to owners.

Further developments in internet connectivity, such as the IEC 61850 standard that enables communications between different vendor products in substations, and fifth generation (5G) wireless systems [8] will also have an effect where more control in edge-of-grid sites is needed. Real-time analysis of onsite alarms and events paves the way for life cycle management, service automation, and availability increases. The demand for cost certainty will require total-cost-of-ownership models, based on capex and opex calculations, to merge and evolve with value-based parameters.

New industrial use cases are emerging in this ecosystem between energy, communications, data analytics and other players. As collaboration of service-centric and product-centric mindsets accelerates, the value of integrated service and systems solutions will increase, for a better future, together.

BIBLIOGRAPHY

Type here the bibliography at the end of your text, according to this presentation (see sample references below). Font to be used is always Times or Helvetica 11 or 12.

- [1] Bjorklund H., Thelenius A., Elgqvist U., Kjaergaard J.P., Collin R., "A Commitment Throughout the HVDC and FACTS Life Cycles" (IEEE Power and Energy Magazine, Volume: 14, Issue: 2, March-April 2016)
- [2] Industry Cybersecurity Standards:
 - NERC-CIP (North American Electric Reliability Corporation-Critical Infrastructure Protection)
 - NIS Directive (The European directive on security of network and information systems)
- [3] Eriksson K., Saksvik O., Holmgren T., Mitch K.A., "Celilo Pacific DC Intertie Upgrade presentation" (Paper 114, CIGRÉ Paris 2014)
- [4] Goosen P., Reddy C., Jonsson B., Holmgren T., Saksvik O., Bjorklund H., "Upgrade of the Apollo HVDC Converter Station" (Paper 107, CIGRÉ 6th Southern Africa Regional Conference, August 2009)
- [5] Bjorklund H, Beshir M.J., "Upgrading the Intermountain HVDC Project to handle 480 MW additional Wind Power" (Paper 108, CIGRÉ Paris 2012)
- [6] Bjorklund, H. "Upgrading the Control System of the Square Butte HVDC Transmission" (Paper 214, CIGRÉ Osaka Symposium, November 2007)
- [7] Galibois D, Chiasson P-E, Barry A.O., Jansson F, Bjorklund H, "Control System Upgrade of the Québec - New England Multiterminal HVDC link" (Paper 68, CIGRÉ Colloquium Winnipeg 2017)
- [8] Industry Communication Standards:
 - Communication: IEC 61850 family (International Electrotechnical Commission - Communication networks and systems in substations)
 - "5G Readiness Survey" (An assessment of operators progress on the road to 5G), Global mobile Suppliers Association (GSA), 2017