Turning the wheel of circularity: Extending the life of transformers

Drivers and benefits of life extension of power transformers

As the world continues its transition toward a more sustainable energy future, the transformer industry finds itself at the crossroads of innovation and necessity. With the global push to decarbonize, integrate renewable energy, and electrify traditionally fossil-fuel-reliant sectors, the demand for reliable energy infrastructure has never been higher. However, this surge in demand brings its own challenges, particularly in managing the aging fleet of power transformers and the time, logistics, and sustainability related aspects associated with their replacement.

Extending the life of existing transformers offers a viable and sustainable solution, aligning operational needs with environmental goals.


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The critical importance of transformer lifecycle management

Power transformers are essential components of the electrical grid, facilitating electricity transmission and distribution at various voltages. Historically, these assets have been designed for decades of service; however, many are now operating beyond their intended lifespan. This aging infrastructure presents operational risks, including unplanned outages and reduced efficiency. Simultaneously, the global demand for transformers has surged due to renewable energy integration and expanding electrification, straining manufacturing capacities and raw material supplies.

These dynamics have led to material shortages, price volatility, and limited manufacturing capacity, putting pressure on operators to maximize the use of existing assets.

Replacing aged transformers with new ones is not always the optimal solution. Transformer manufacturing is resource-intensive, relying heavily on materials like copper, steel, and insulating oils. These materials are increasingly scarce and environmentally costly to procure. A single large power transformer can contain tens of thousands of kilograms of steel and copper, and the extraction and processing of these materials result in greenhouse gas (GHG) emissions.

Extending the life of transformers bridges this gap, allowing operators to keep existing infrastructure functional without the environmental and financial burden of new manufacturing. Life extension emphasizes repair, refurbishment, and upgrading components to meet modern operational demands, preserving the embedded carbon in existing assets and moving towards circularity.

Assessing transformer health: The first step toward lifecycle extension

Extending the life of a transformer begins with a thorough condition assessment. Operators face the dual challenge of maintaining aged assets while minimizing costs and operational risks. Traditional maintenance approaches, such as reactive or time-based strategies, are increasingly giving way to predictive and condition-based maintenance. These modern strategies leverage advanced diagnostics to anticipate and

address potential failures before they occur.

Transformers operate under varying conditions, and their aging process is influenced by factors such as load profiles, maintenance practices, and environmental stressors. Accurately assessing the condition of each transformer is critical to determining whether life extension is feasible and cost-effective.

The condition assessment can be performed on a single transformer, but it can be executed on a larger scale with fleet screening where a large population of transformers is evaluated based on easily accessible data, such as nameplate information, oil analysis, and operational history. This step helps prioritize units for detailed assessment, focusing resources on the most critical assets.

Advanced diagnostics that required extensive expertise and know-how to be evaluated properly like Furans, SFRA, FDS, Partial Discharge, along with dissolved gas analysis (DGA), thermal simulations, and short-circuit strength evaluations, are then used to pinpoint vulnerabilities.

Through this detailed assessment, operators gain a comprehensive understanding of each transformer's health, identifying components that may need replacement or refurbishment. This data-driven approach not only enhances reliability but also informs investment decisions, helping asset managers optimize their maintenance and replacement strategies.

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Life extension vs. replacement: A sustainable choice

One of the most compelling arguments for transformer life extension is its environmental benefit. Manufacturing a new transformer involves carbon emissions, primarily from raw material extraction, processing, and transportation. In contrast refurbishing an existing transformer can reuse between 60 to 90% of its components, including core, tank and dielectric fluid. This provides a significant reduction of the carbon footprint.

Consider a large power transformer undergoing on-site repair versus being replaced with a new unit. On-site refurbishment avoids the emissions associated with manufacturing and transporting a new transformer. Furthermore, it often requires less downtime, enabling operators to restore capacity more quickly and cost-effectively. For instance, a project involving active part (core and windings) refurbishment might take 12 months compared to 22 months for a new unit's delivery and installation.

Beyond the immediate environmental benefits, life extension aligns with the principles of a circular economy. By reusing existing materials and minimizing waste, it reduces the demand for virgin raw materials such as copper, steel, and insulating fluids. This is particularly significant given the material-intensive nature of the energy transition, which has led to increased competition for resources.

Hitachi Energy Lumada APM helps prioritizing transformers fleet condition assessment with a structured approach around electrical, mechanical, thermal condition, ageing of the insulation and status of the key components in the transformer with reliable Transformer Condition Assessment

Transformer Carbon Footprint - Climate Change Kg CO2 eq		
	Large power transformer, 400kV	**Power transformer, 230kV**
	On site refurbishment vs new transformer	On site refurbishment vs new transformer
Manufacturing upstream	-60%	-21%
Manufacturing core	-67%	-67%
Manufacturing upstream transportation	-81%	1%
Downstream transportation	-100%	-71%
Downstream operation	0%	0%
Downstream end of life (EoL)	-18%	-23%
Total reduction	**-2%**	**-8%**

Data are referring to an extended study executed by Hitachi Energy on two reference cases where two scenarios were analyzed to determine the footprint of extending the life of existing transformer vs replacing the transformer with a new one (including manufacture a new unit and decommission and dispose the old unit).
The results are showing the decrease in carbon emissions for lifetime extension activities compared to manufacturing a new unit and decommissioning the existing one.

Manufacturing a new transformer involves significant carbon emissions, primarily from raw material extraction, processing, and transportation

Hitachi Energy's advanced refurbishment techniques

Extending the life of a transformer requires meticulous planning and execution. At the heart of this process is the ability to replicate factory conditions at the refurbishment site. Hitachi Energy has developed advanced tools and techniques to achieve this, ensuring that on-site refurbishments and repairs meet or exceed the quality standards of new transformer manufacturing.

- **Component replacement and upgrades:** Aging components, such as bushings, tap changers, and cooling systems, are often the first to be replaced. These upgrades not only improve reliability but can also enhance transformer efficiency, together with the reduction of the maintenance required.
- **Core and winding refurbishment:** When a transformer's core or windings show significant wear, they may be replaced or retrofitted. Core retrofits often involve unstacking and restacking core sections with modern materials. Similarly, windings can be replaced with new, more robust designs that extend the transformer's operational lifespan while improving energy efficiency and reducing transformer operational energy losses.
- **On-site refurbishment:** Advanced technologies now allow many refurbishment activities to be performed on-site, eliminating the need to transport the transformer to a factory. This reduces downtime, transportation costs, and associated emissions. On-site refurbishment replicates factory conditions, using mobile equipment for heavy lifting, drying, and high-voltage testing.

Time, environmental and economic impact

Life extension not only supports operational and financial goals but also contributes to broader sustainability objectives. Carbon footprint assessments of refurbished transformers consistently show significant reductions compared to new units. For example, refurbishing the active partspart of a large power transformer on-site can result in 1.7% fewer carbon emissions over its lifecycle compared to manufacturing a new unit. While this percentage may seem small, it translates into hundreds of tons of CO_2 avoided for each refurbished transformer.

Economic benefits are equally compelling. The cost of a refurbishment project is significantly lower than a new transformer, typically less than 50%, making them a financially attractive option for utilities and operators. Additionally, they reduce downtime and the associated loss of revenue, particularly for critical infrastructure such as generator step-up transformers.

Moreover, repairing and refurbishing existing transformers not only reduces

By focusing on reliability, costs, and delivery time, extending the life of transformers can significantly contribute to sustainability. This is achieved through re-usability, avoiding embedded carbon of virgin materials and circularity

Asset Performance Management (Lumada APM) for condition assessment and onsite life extensions and repairs for power transformers helps users keeping a high standard of energy delivery while contribute for Sustainable, Circular, and Future-Ready Energy Infrastructure

costs and carbon emissions but also offers a significant time advantage. Unlike the lengthy process of manufacturing a new unit, which can take several months, refurbishment projects can be completed much faster. This means that a refurbished transformer can be back in operation in a fraction of the time, minimizing downtime and ensuring that critical infrastructure remains functional and efficient. This quicker turnaround is particularly beneficial for utilities and operators who need to maintain continuous service and avoid the financial losses associated with prolonged outages.

Challenges and future trends

Despite its advantages, transformer life extension comes not without challenges. The process requires specialized equipment, skilled personnel, and strict quality controls to ensure success. Logistics can also be complex, particularly for large transformers located in remote areas. However, advancements in assembly and testing technologies are helping to address these challenges.

Looking ahead, the role of life extension is expected to grow as the energy sector embraces sustainability. As grids become increasingly decarbonized, the emissions associated to operational losses from transformers will decline, but the importance of material efficiency will remain. Collaboration across the supply chain will be crucial to developing new technologies and business models that support circularity.

Conclusion

The transition to a sustainable energy future demands innovative solutions that balance environmental, operational, and financial considerations. Transformer life extension embodies this balance, offering a practical and impactful way to optimize existing assets while reducing the sector's carbon footprint.

By investing in advanced refurbishment techniques and embracing a circular economy mindset, the transformer industry can play a pivotal role in the global energy transition. As demonstrated by Hitachi Energy's extensive experience, life extension is not only a proven technical solution but also a forward-looking strategy that aligns with the goals of reliability, sustainability, and resource efficiency. In this way, extending the life of transformers becomes a cornerstone of a resilient and sustainable energy system.

Discover Hitachi Energy's broad range of customized transformer service solutions