The Environmental Benefits of Remanufacturing: Beyond SF_6 Emission Remediation

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Summary
As scientists and citizens become more concerned with global warming and the impact that "greenhouse gases" are said to have, those companies involved in the transmission and distribution of energy will be required to respond. This paper presents an alternative to a greenhouse gas remediation policy, which focuses solely on the detection of sulfur hexafluoride (SF_6) emissions during the manufacturing and operating life of the power circuit breaker. By looking beyond the detection and field resolution of the SF_6 leaks to the total life cycle of the breaker, we can have a much larger impact on the issue of global warming. Remanufacturing is a solution that goes beyond detection and provides substantial benefits environmentally, economically and systemically.

Introduction
Circuit breakers play a vital role in the protection and operation of the electric transmission and distribution system. Circuit breakers interrupt the flow of electrical current in transmission lines for normal switching of transmission circuits, and for emergencies in the event of short circuits on the system.

SF_6 has been used for insulation in electrical equipment for more than 40 years. SF_6 provides the insulation medium for thousands of power circuit breakers, each having voltage ratings of up to 800 kV, in the electricity supply systems around the world today. In fact, the first high-voltage circuit breaker using SF_6 was put in service in 1956 at 115 kV. These first SF_6-insulated circuit breakers were dual (or two-pressure) breakers that were derived from the air blast two-pressure circuit breakers. More recently, the single-pressure puffer circuit breaker has evolved as the predominant configuration of high-voltage circuit breaker equipment.

Sulfur hexafluoride's main characteristics make it very suitable for use in electrical equipment. These desirable characteristics include:

- High dielectric strength
- Excellent arc-quenching properties
- Good chemical stability
- Nontoxic

SF_6 as a Greenhouse Gas

Unfortunately, some of the very characteristics that make SF_6 a desirable solution for arc interruption and insulation of electrical equipment also have been found to cause environmental concerns. Sulfur hexaflouride has been characterized by the U.S. Environmental Protection Agency (EPA) as "a very powerful greenhouse gas" with a global warming potential of 23,900 (EPA Global Warming Site, 2000). Many scientists are concerned about what is being characterized as a global warming trend. These scientists point to an increase in global mean surface temperatures since the late 19th century - and recent data showing that the 20th century's 10 warmest years all occurred in the last 15 years - as evidence of a dangerous trend. Many are concerned that the rising global temperatures will raise sea levels, change precipitation, and contribute to alteration of forests, crop yields and water supplies (EPA Global Warming Site, 2000).

SF_6 Leakage Detection Efforts

Given the data supporting the assertion that SF_6 has some lasting presence in the Earth's atmosphere and the potential impact of greenhouse gases on the environment, the electric utility industry and those in the electric utility supply chain have taken measures to reduce the escape of SF_6. The ABB Group, a global technology company and supplier to the world's utilities, has reported several measures taken by manufacturers to reduce the level of SF_6 escaping into the atmosphere. Marchi, et al. present these measures in a paper titled "Design, Manufacturing, Practice and Information to Minimize SF_6 Release From Electric Power Equipment." These measures include:

- Design for minimizing leakage during operation
- Gas emission monitoring during testing, manufacturing and commissioning
- Gas loss monitoring in service
- Gas recovery and recycling procedures
- Gas recovery from equipment
- SF_6 recycling

These measures allow for improved detection of leakage during the life cycle of electrical equipment. Other efforts lead to the elimination of leakage once detected.

Remanufacturing and Remediation of Emissions

Remanufacturing is a process of rebuilding (and in some cases upgrading) equipment that has previously been utilized in an electrical system. This process (as performed at ABB High-Voltage Switchgear Service) involves disassembly of the breaker to the basic components, comparing those components (and their parts) dimensionally with the original manufacturing specifications, and rebuilding, replacing or machining any parts that demonstrate nonconformities. All components and vessels are cleaned and restored. The refurbished or replacement components are then reassembled and tested to original equipment specifications. Because the breaker is completely remanufactured, it returns to the customer with the same warranty as was originally granted when the breaker was sold new.

A Case Study: Two-Pressure SF_6 Breakers

A two-pressure circuit breaker (produced up to 1985) maintains an insulating pressure of 45 psig to 60 psig and an internal arc extinguishing pressure of 240 psig to 280 psig. The device-opening process directs the high-pressure gas across the contacts into the low-pressure system, and a compressor system transfers this gas back into the high-pressure side. The SF_6 volume in the two-pressure breakers ranges from 760 lb. for a 242 kV circuit breaker to more than 1,500 lb. for an 800 kV circuit breaker.

There are several thousand two-pressure circuit breakers in service in the electric power transmission grid today, each ranging from 138 kV to 800 kV. One of the unique capabilities of the two-pressure SF_6 breakers is the ability to interrupt very high short-circuit currents in the

network resulting from faults in the system, such as lightning strikes, power line failure resulting from high wind and snow, and equipment failures. There are more than 100 of these two-pressure breakers installed in critical circuits with short-circuit current ratings of 90 kA throughout the United States. The present single-pressure puffer circuit breakers cannot handle these large currents and, if designed for this duty, would become extremely expensive. Thus, remanufacturing of these circuit breakers is the only viable option.

The two-pressure SF_6 breakers have been found to be contributors to SF_6 emissions on some systems, leading some observers to assume that the two-pressure design is inherently faulty. In reality, all manufacturers of two-pressure SF_6 breakers recognized in the late 1970s that the gasket system in the low-pressure portion of these breakers was resulting in leakage of low-pressure gas to the atmosphere. In time, this gasket material corroded the adjoining metal, resulting in leakage from the low-pressure system. Following the recognition of this issue, all manufacturers implemented the use of seal material with a demonstrated long-term performance.

The recognized corrective action for this early seal system problem involves the machining of all seal surfaces and reassembly using the corrected gasket material. This leak repair process entails the remanufacturing steps previously detailed. In the case of emissions remediation, the testing performed by ABB in the factory of the remanufactured circuit breaker is more stringent than the tests performed on new equipment. The remanufactured equipment utilizes vessels fabricated from steel plates, as opposed to the use of aluminum castings. Therefore, the leak test technique can be more specialized because it needs to be focused only on the flanged joints and welds. ABB's factory leak testing used in equipment remanufacturing is a process of isolating or 'bagging' each flange/seal joint for a prescribed time period and then testing the 'bagged' volume with a device that will detect a leak rate of $1/60^{th}$ of 1% per year (by weight). New equipment manufacturing cannot use that 'bagging' technique due to the large surface areas that must be checked. Field experience during many years has shown that the remanufacture techniques are a viable solution to SF_6 leakage.

Other Environmental Benefits of Remanufacturing

Manufacturing any complex product requires the use of a tremendous amount of energy and material. When considering the supply chain and material requirements of power circuit breakers, we find that they can contain more than 9,800 lb. of steel, 7,500 lb. of aluminum, 4,000 lb. of porcelain and 200 lb. of copper. Each of these building blocks of the circuit breaker requires raw material mined from the Earth, and that those raw materials be processed into the finished material required to manufacture the circuit breaker's components. As stated earlier, the two-pressure SF_6 breakers require as much as 1,500 lb. of SF_6 gas. In processing each of these materials, carbon dioxide (CO_2), the most abundant greenhouse gas, is emitted.

Remanufacturing does not require the same material inputs as original manufacturing, therefore eliminating the need for the supply chain. In addition to using lower levels of energy and raw materials, remanufacturing allows for the recycling of the SF_6 gas that is already in the circuit breaker. In fact, it is estimated that remanufactured goods conserve the equivalent of 400 trillion Btu of energy per year. Remanufacturing accomplishes this conservation by saving 85% of the energy required to produce a new product (Automotive Parts Rebuilders Association). As an indication of the impact that conservation through remanufacturing is having, the 400 trillion Btu of energy saved is enough to power 6 million passenger vehicles each year (Automotive Parts Rebuilders Association). Finally, an obvious benefit of remanufacturing is the reduction of solid waste that is produced by the disposal of decommissioned electrical equipment and their spare parts inventories.

Remanufacturing: The Economical Solution

Having demonstrated the environmental benefits of remanufacturing, we now turn our attention to the economical rewards to the industry. Because remanufacturing does not have the same material requirements as original manufacturing, it is considerably less expensive. The cost of

remanufacturing is about 1/3 that of original equipment (see comparison of estimated cost chart, below). In addition to the savings resulting from the material difference, the user will also reap lower site preparation and construction costs, engineering costs, and the elimination of the need for new spare parts inventories. By using equipment familiar to the maintenance crews, retraining costs can be avoided as well. Remanufacturing can also include upgrading the capabilities of currently operating equipment. These upgrades and life extensions have been conducted on oil circuit breakers as well as circuit breakers containing SF_6. By upgrading an oil circuit breaker, the utility gains the benefits mentioned above and continues to enjoy the same or enhanced service from a time-tested technology that does not contribute to the current SF_6 emissions issues.

ECONOMIC COMPARISON

REFURBISHED VS. NEW BREAKER
362,000 VOLTS

	Refurbished Breaker	**New Breaker**
Prep. /Site Construction Work (using same foundation)	N/A	**16 man-days at $60/hour $7,680**
Engineering	**N/A**	**10 man-days at $60/hour $4,800**
Disposal of Breaker Carcass	**N/A**	$3,000
Refurbishment	$75,000	**N/A**
Installation/Test	$37,500	$65,000
New Product	**N/A**	$200,000 to $300,000
Spare parts	**N/A**	$3,000
Training	**N/A**	**5 Employees at** $1,600 each **$8,000**
TOTALS	$112,500	$291,480 to $391,480

Conclusions

Although SF_6 continues to perform as the best insulator and current interrupter for the electrical transmission and distribution industry, it has raised some environmental concerns. Remanufacturing is a solution that goes beyond the remediation of SF_6 gas emissions by providing the added benefits of reducing CO_2 emissions, solid waste generation and raw material usage. Remanufacturing can be accomplished at a fraction of the cost of producing new, while providing quality that rivals that of newly manufactured goods. Finally, the systems, spare parts, and human resource requirements of new technology are avoided when existing technology is remanufactured.

References

"EPA Global Warming Site: Glossary for Climate Change Terms." Available at http://www.epa.gov/globalwarming/glossary.html.

"Remanufacturing: An Answer to Global Warming." An internal White Paper of the Automotive Parts Rebuilders Association. Available at http://www.remanufacturing.org/Global_Warming.