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**Fast GVPI Stator  
Rewind Experience**

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# 1 Abstract

Siemens has more than 25 years of operating fleet experience with generators utilizing our patented GVPI (Global Vacuum Pressure Impregnation) technology with more than 1700 turbine generators up to 22 kV rated voltage and more than 25.5 million combined operating hours. GVPI stators are designed to avoid the need for re-wedging or retightening of laminated core over the entire life cycle. In the unlikely event, if needed, Siemens has qualified and proven repair procedures depending on situation and customer preference. When options to replace a Global Vacuum Pressure Impregnated (GVPI) generator with a replacement generator do not exist or to meet urgent customer market demands, an innovative fast stator rewind solution is now available.

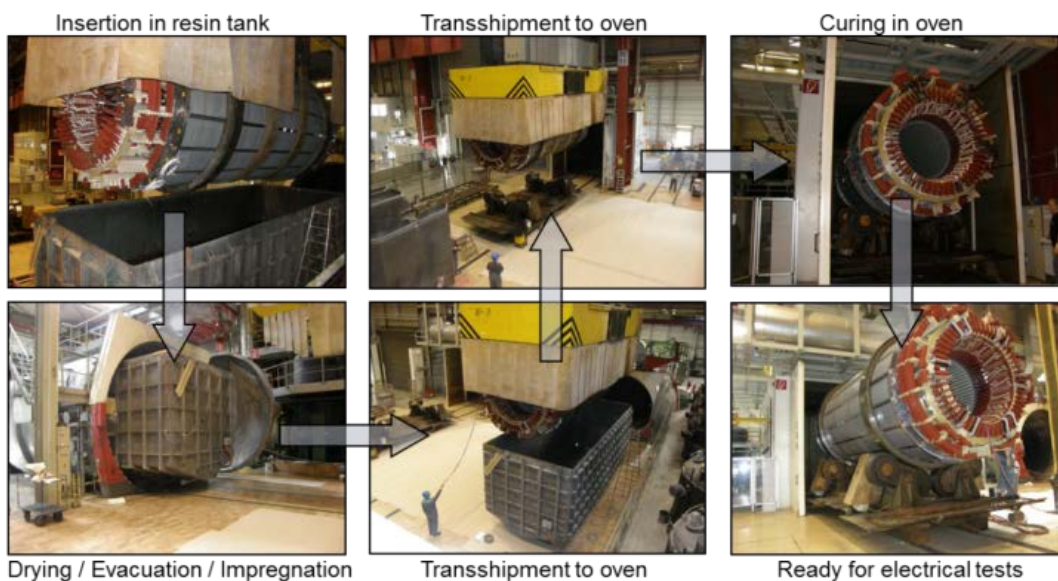
In this paper the successful implementation of GVPI to SVPI (Single Vacuum Pressure Impregnation) field rewinds on two gas turbine generators in parallel required after a forced outage of a 520 MW combined-cycle natural gas-fired power plant with delivery on time for the customer's critical summer operating period is presented.

After a forced outage of one unit in 2017 that was reportedly caused by a winding fault, significant coil damage was reported. Siemens was contacted and inspected the second GT unit at the same site. Siemens found indications of a potential damage winding fault on this second unit, though the unit was still in operation at the time. This customer decided to rewind both units on an emergent basis. The rewinds of the two units began and both units were released for commercial operation within two months. The focus of this paper will be the GVPI to SVPI rewind including the implementation of a new coil design and application of an innovative and patented hydraulic coil removal system and laser cleaning technology.

## 2 GVPI (Global Vacuum Pressure Impregnation) Technology

Compared to the SVPI technology where individual generator stator coils are impregnated and then installed into the stator slots, with the GVPI technology, “soft” stator coils are installed into the slots and then the wound core is impregnated and cured. The copper coils are insulated with a proprietary epoxy-mica insulation system, which is designed to provide high dielectric strength and voltage endurance (see Figure 2).

The inner generator frame with core and winding is pre-dried in a vacuum tank, evacuated and impregnated by being immersed in epoxy resin. The surplus resin is drained until the cooling passages are free from impregnating resin. Then, the complete stator is placed in an oven for curing.



*Figure 1: GVPI Manufacturing Process*

Prior to installation of the inner frame with core and winding in the base frame, a dissipation factor measurement of each phase winding is performed. A final dielectric test is done to confirm proper impregnation and the electrical quality of the stator winding insulation.

The design characteristics of modern GVPI stator winding insulation are:

- Consolidated stator insulation with excellent electrical, mechanical and thermal strength

- Stator coils with specially developed inner and outer corona protection systems ICP and OCP to help avoid electrical discharge erosion and subsequent breakdown

#### Stator bar layering

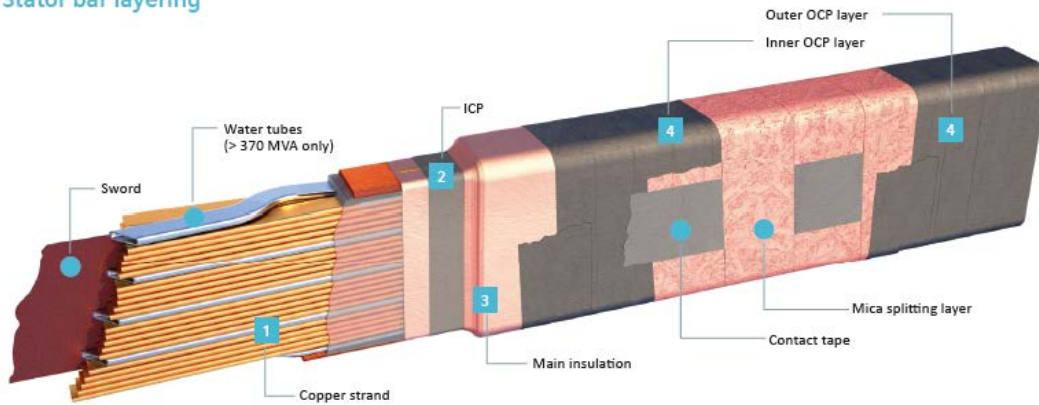


Figure 2: Principle design of a Siemens GVPI bar in slot region

Table 1 highlights more closely some of the intended benefits of this GVPI technology.

Features	Intended Benefits
Greater stator winding / end winding consolidation	Less maintenance, less chance of loose winding components or re-wedging
Resin-sealed surfaces that are less permeable to moisture, surface contamination, oxidation, oil ingress or chemicals	Lower maintenance, higher availability
Tight stator slots, corona slip layer on stator coil, elimination of air gap in slot, & enough spacing in end winding	Less potential for Corona or partial discharges
Proven design	More than 1700 machines in operation since 1988 with outstanding reliability & availability record
More repeatable process, less operator dependent	Faster winding assembly, reduced cycle time

Table 1: GVPI Features and Benefits

## **2.1 GVPI Operating Fleet Experience**

Siemens has more than 25 years of operating fleet experience with generators utilizing our patented GVPI technology with more than 1700 turbine generators up to 22 kV rated voltage with a total output of more than 240,000 MVA, more than 25.5 million combined operating hours and more than 322,000 start/stop cycles at a reliability rate exceeding 99.9% \*. The first GVPI unit was built in 1988. Our fleet leaders have more than 150,000 operating hours and 3,320 start / stop cycles.

This excellent service experience can be attributed to a number of factors such as

- Robust design
- Product quality control
- Continuous improvements
- Customers following the recommended operating & inspection guidelines

## **3 Case Study**

One of the two gas turbine generators in a 520 MW combined-cycle natural gas-fired power plant, which began combined cycle operation in July 1999, reported a forced outage in 2017. Siemens Field Services and Generator Services were contacted to investigate. During the course of the investigation, the air-cooled GVPI generator of the first unit was found to have experienced a winding fault with significant coil damage. The customer requested that Siemens inspect the second unit at this site. Findings on both units were discussed with the customer and the customer ultimately decided to rewind both units.

## **4 Fast GVPI Stator Rewind Solution**

A stator rewind with new bars and new insulation materials can help extend the availability and reliability of a generator. The two original air-cooled generators were manufactured using the GVPI process which impregnates the entire generator wound stator with resin.

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\* “Reliability Rate defined as the degree to which a system, product or component performs specified functions under specified conditions for a specified period of time.”

Since performing a vacuum impregnation of the entire wound stator is not possible for an in field rewind, a new style stator coil needed to be designed. The new windings were SVPI coils which can be installed into a stator core in the field and then wedged without the need of a GVPI of the entire wound core.

Siemens manufactured all newly designed SVPI coils, a full generator rewind kit, shipped them to site and performed two on site rewinds of GVPI units in approximately a two month time frame.

#### **4.1 New Winding Design**

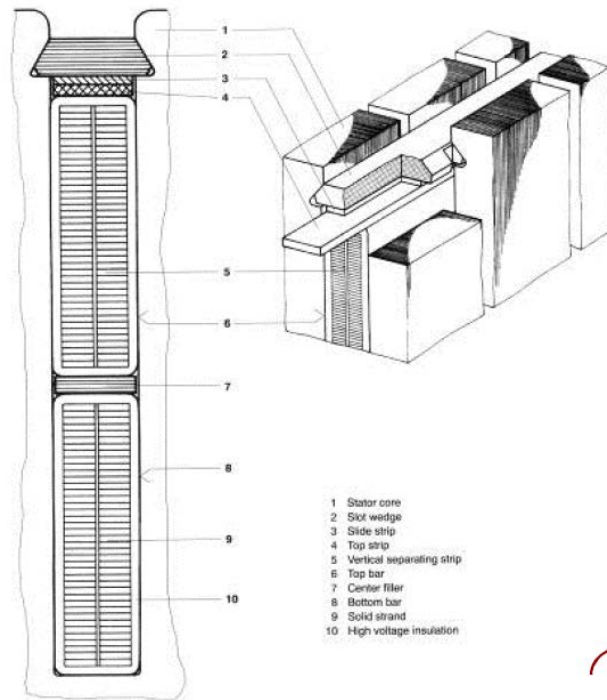
A generator rewind is comprised of stator coils to be installed in the core slots, slot content materials, series and phase connections, end winding basket components and instrumentation. These rewind components will be looked at in the following paragraphs.

##### **4.1.1 Coil Design**

When designing an SVPI winding, provisions to keep the coils tight in the radial and tangential direction need to be implemented. These components are not needed in a GVPI design and take up space that otherwise could be occupied by copper. Therefore, the major challenge with designing a winding to replace the GVPI coils is to design a SVPI coil that fits into the existing slot and can maintain at a minimum the name plate rating.



### GVPI Slot Content



### SVPI Slot Content

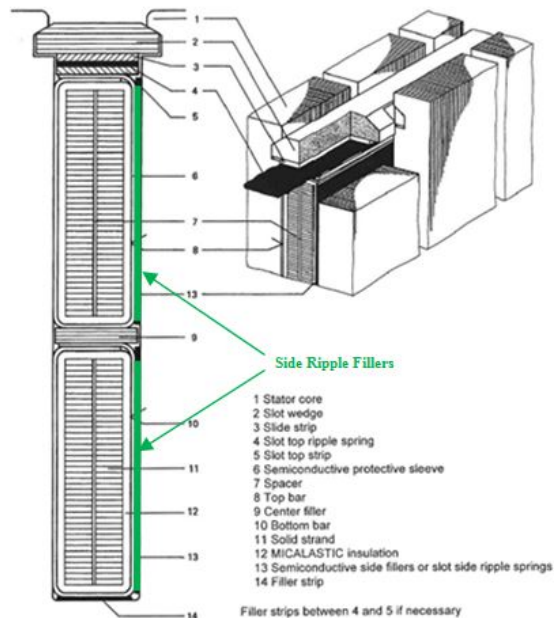


Figure 3: Slot Construction of GVPI vs. SVPI Technology

### **4.1.2 Slot Content**

The purpose of the stator slot wedges is to support the coil in the slot in the radial direction. The new stator winding design utilized body wedges and an end wedge locking design to support the coil in the slot.

Siemens uses a standard pre-stressed driving strip (PSDS) concept under the wedge to help keep the slot contents tight in the slot in the radial direction. The PSDS consists of a top ripple spring filler between the top of the top coil and the bottom of the wedge. There is a feature in the slot wedges consisting of small holes which can be used to check the deflection of the top ripple spring to determine if the slot contents are held tight in the slot. With this design, it is possible to re-wedge and tighten the slot contents if needed in the future.

Side ripple springs are also utilized in the slot to help keep the coils tight in the slot in the tangential direction. This helps to keep the coil tight against the slot wall and help prevent spark erosion from occurring in the slot.

### **4.1.3 Coil Support Structure**

Using Siemens state of the art experience, various end winding coil support components were designed to consolidate the end winding and high tune the end winding basket. The coil support components are designed to allow thermal expansion and prevent resonance conditions that were suspected of causing the original coil issue. Fast Fourier Analysis (Bump testing) is used to verify that the end winding is high tuned and does not have local or global winding modes after the rewind is complete before the unit goes back into service.

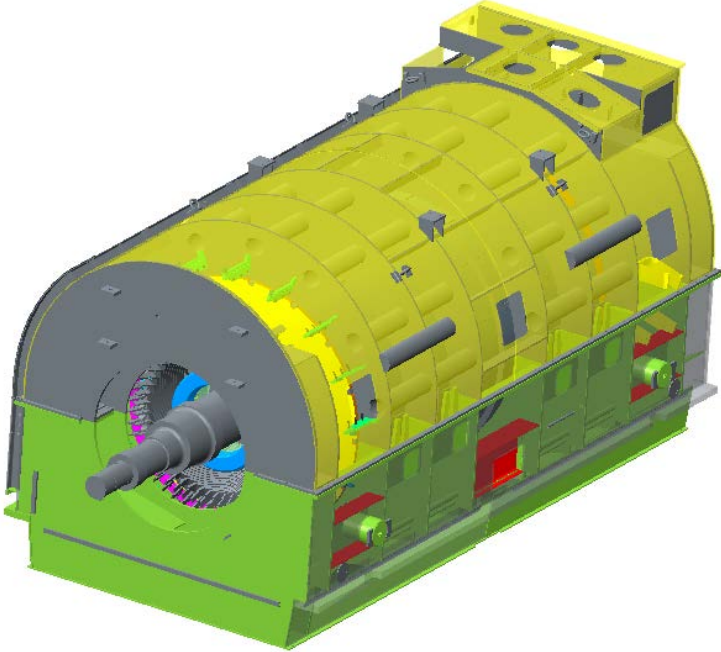
### **4.1.4 Instrumentation**

The main instrumentation installed during the rewind consists of the slot embedded RTD's. These slot embedded RTD's are used for monitoring coil temperatures in an air-cooled generator during operation. The original RTD's were replaced with platinum RTD's.

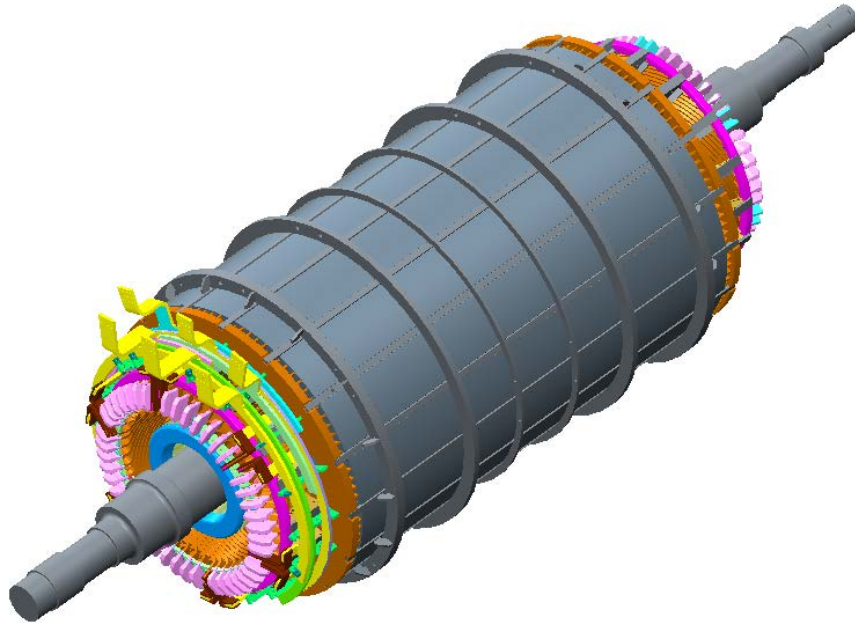
### **4.1.5 Modelling**

Siemens was able to leverage developed R&D GVPI rewind standardized processes and provide a rewind to the customer on an accelerated basis.

Another major driver that aided in the implementation of a GVPI rewind for the two units in a short amount of time was the use of 3-D modelling software. Modelling software was used to verify that all newly designed components would fit into the existing generator frame and interface with existing components before manufacturing and actual installation. In addition, modelling software was used to verify that high voltage components met stringent strike and creep requirements before an actual hi-pot test was done. All of these elements worked in tandem to allow Siemens to provide two rewinds consisting of a technology conversion of GVPI to SVPI in parallel in a two month period.



*Figure 4: Complete 3-D Modelling of the air-cooled Generator*



*Figure 5: Complete Wound Stator Generator Model*

#### **4.2 Fast Winding Manufacture**

Siemens generator manufacturing and service engineering worked closely together to develop a SVPI coil design that could be manufactured quickly to support the customer's schedule requirements. Continuous collaboration between engineering and manufacturing allowed the specific design details to be worked out expeditiously and the use of state-of-the-art automation to manufacture the coils. A design review was held, and the design was approved and released for manufacture approximately five days after the start of the coil design process.

## 5 On-Site Rewind Process

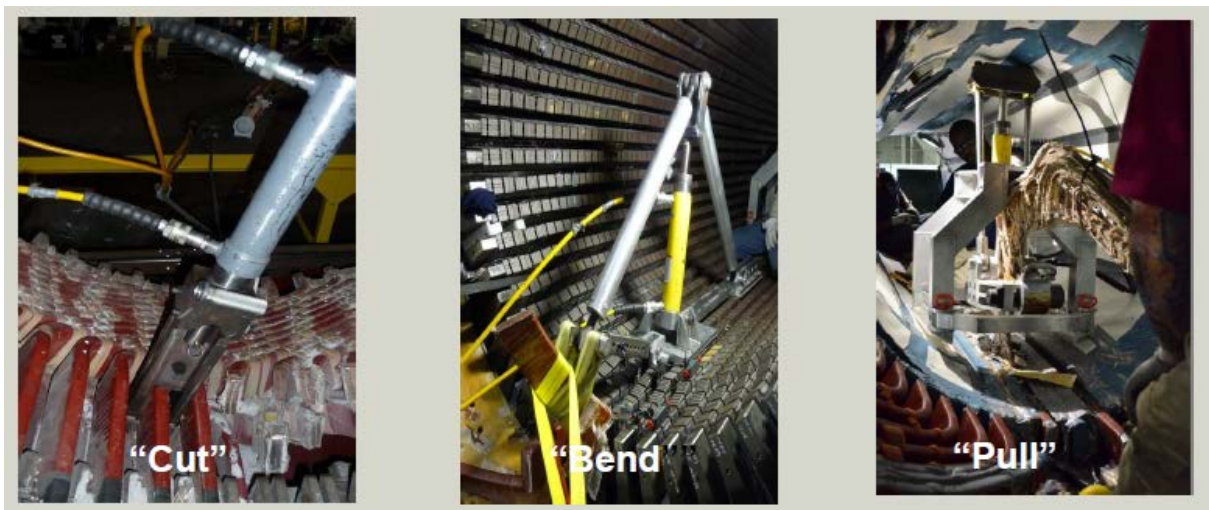
The on-site rewind process includes removing all stator coils, cleaning the stator slot walls, requalifying the core and rewinding with new SVPI coils.

### 5.1 Fast Winding Removal

Due to the very strong bond strength of the GVPI winding process, enormous forces are required to remove coils from the stator core slot. Over the years, various methods have been used to remove these coils. While sufficient for a single bar removal, the speed of removal may not be in line with customer schedule requirements. Siemens has done much work to develop a process that is versatile and fast. Innovative tooling to hydraulically up-end the coils and then hydraulically extract them from the core has been developed.

The coil removal process is comprised of three main steps:

- Cut: Coils arms are cut off on both the exciter end (EE) and turbine end (TE)
- Bend: Coils are bend up with a hydraulic press
- Pull: Coil is pulled out of the slot using a hydraulic clamp and lifting frame



*Figure 6: GVPI Coil Removal Process*

The up ender (coil bending tool) has feet that ride in the wedge groove and are made from a material selected to avoid damage to the stator core laminations. Loading is distributed over a sufficient area to minimize local stress.

This patented process has been utilized on multiple units including a partial rewind to replace one bottom coil. The tooling is easily used in all clock positions with two operators. With two additional operators, bending (up ending) and pulling can be done in parallel leading to improved efficiency and strip speed. All equipment is operated with a remote pendant for operator safety.

## **5.2 Patented Core Laser Cleaning**

When the coils are pulled out of the stator core, there can be some residue from the GVPI process tightly adhered to the stator slot wall. This material needs to be removed for proper fitment and electrical contact of the new stator coils.

Numerous methods were studied to develop a core cleaning method that was fast, efficient, did not generate large amounts of debris, and was compatible with the stator laminations.

A patented pulsed laser ablation process with an automated delivery system was developed and applied by Siemens field service to efficiently remove this residue without damaging the core laminations. The ablation process is a combination of thermal shock and sublimation of the surface coating.

Cleaning the side of a deep narrow slot with a laser required significant development including development of custom components. There were no commercially available systems that could work for this application. This required the development of a beam delivery tube that changed the direction of the beam while down in the slot. A mirror was placed near the bottom of the beam delivery tube to direct the laser beam at the correct angle. Due to the narrow geometry of the slot the mirror was both close to the focal point of the beam path as well as close to the cleaning process itself. These two issues were the critical design considerations that went into development of the beam delivery tube.

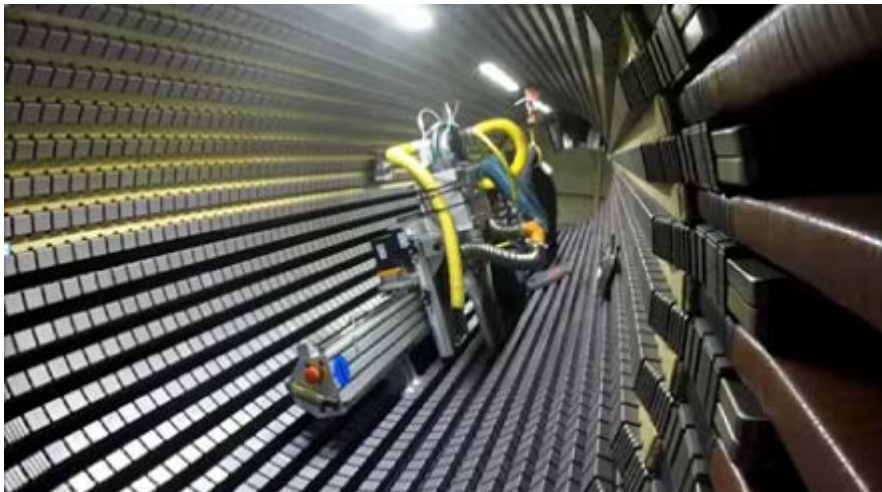
A fully automated system was developed to deliver the laser beam in and out of the slot and traverse along the length of the core. The automation system also supports a vacuum system connected to a HEPA filtration system that removes much of the residue generated from the ablation process. Two operators were needed to move the system from slot to slot. The system required only one person to monitor operation.

The system used in this process is a class 4 laser system so there are strict operator training requirements and EHS considerations.

For this customer's rewind, two laser systems ran in parallel to support the challenging rewind schedule.

In summary this new technology has the following benefits:

- Remote operation of the laser and pulsed technology for safer operation.
- Low potential for iron damage as clean metal disperses the laser beam.
- Fast overall cleaning process using less personnel with little-to-no fatigue due to the automated system



*Figure 7: Laser Cleaning System*

### **5.3 Core Requalification using SMCAS and HF Loop Testing**

Stator core integrity inspections are typically done during a rewind. This is done with either SMCAS (Siemens Multi Frequency Core Assessment System) or by ring flux (loop testing) or in some cases a combination of both methods. Typically, a baseline is done prior to the start of rewind work, one is performed after stripping, and one is performed at the conclusion of winding to establish a new baseline prior to operation. Due to the availability of the Elevated Frequency Loop Test System and the fact that this is a Siemens ungrounded stator core, the Elevated Loop testing process was used.

#### **5.3.1 Stator Core Inspection by Elevated Frequency Loop Testing**

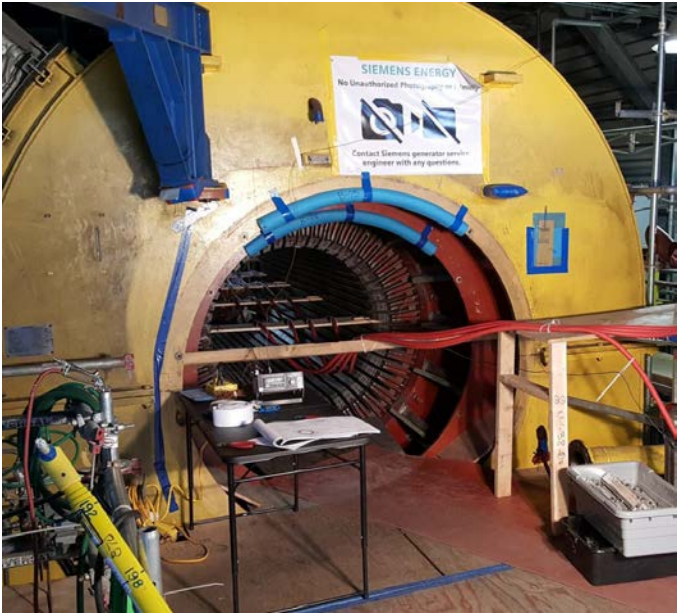
The patented Siemens Elevated Frequency Loop Test was used to inspect the stator cores a total of six times at this site. This testing is performed to determine the condition of the stator



core insulation to indicate thermo-mechanical fatigue and aging phenomena as well as mechanical damage due to foreign objects.

The measurement is performed at a frequency between 400 and 600Hz, as significantly lower power is required at high frequency than at grid frequency (50 or 60 Hz) to generate equivalent magnetization losses in the stator core. Since the stress on the insulation between the laminations is comparable, the integrity of the core can be evaluated just as effectively. This patented process has many beneficial attributes including allowing testing at lower voltage, less required customer intervention and faster setup time than ordinary testing at grid frequency.

The requisite cabling is also considerably smaller and lighter in comparison with that needed for ordinary testing at grid frequency. This shortens the overall duration of the test program and assembly of the test setup. The system is more transportable and simpler to implement.



*Figure 8: Elevated Frequency Loop Test Setup*

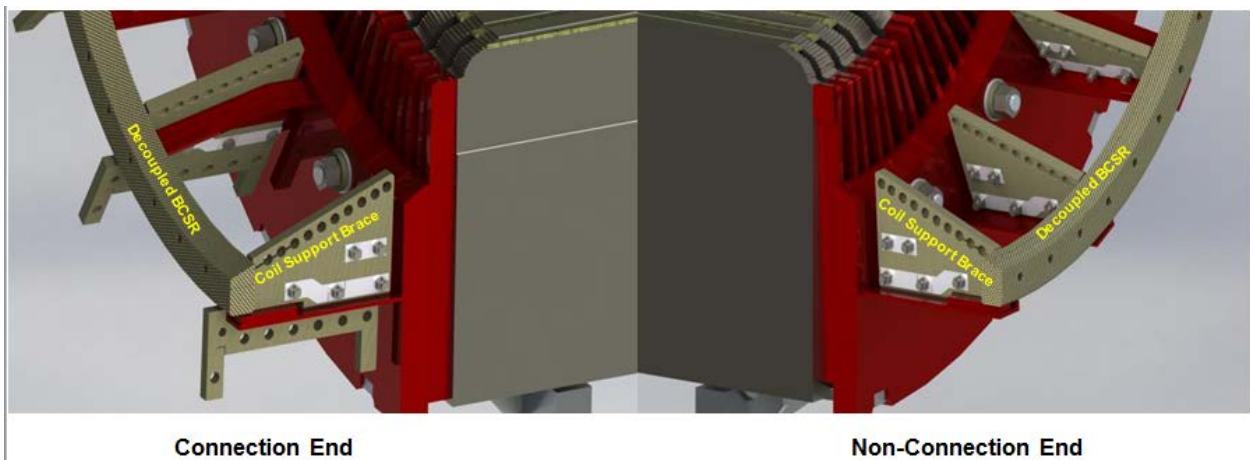




*Figure 9: Easy transportable elevated frequency power supply inside shipping container*

#### **5.4 Fast Stator Rewinding**

With the stator winding removed, brackets inspected, and the core cleaned the new end winding structural components could be installed. In addition to using the laser cleaning technology for the stator core slots, the laser was used to rapidly remove the paint from the winding support brackets for visual inspection of the welds. Following inspection of the support brackets, the glass winding support braces were installed. These support braces were specially tuned during manufacturing with the final modal analysis in mind. A new bottom coil support ring (BCSR) was installed on each end of the generator at this time. The bottom coil support ring was a two piece design that could be installed with no modification to the frame opening. Alignment/positioning of the support rings with respect to the core and braces was confirmed prior to installing bottom coils.



*Figure 10: Rewind Design – Coil Support Structure*

After the installation of the new structural components, the project transitioned to a typical SVPI conventional rewind. Standard fast rewind processes were utilized including pre-staged material kitting, 24/7 work schedule, and specially designed tooling for rapid installation. A Siemens generator engineer was onsite to provide rapid assessment and resolution of issues encountered. Given this was a dual rewind in a staggered-parallel arrangement, any lessons learned could be immediately applied to the second unit.

Due to the original design of the machine, the only major components to be re-used were the parallel rings. The parallel ring segments were inspected for re-use and the tabs were cleaned and checked for flatness. The insulation of the parallel rings was inspected, and the ring segments were individually DC hi pot tested to verify the integrity of the insulation.

The bottom coils were installed and then secured in the slot using rippled side filler. While the side filler was installed, the end windings were consolidated using typical SVPI rewind materials. The same installation practices were utilized for the top coils and then the mid-basket support hoses were installed.

The stator was wedged, and the slot wedge profile was refined using 3D printed wedges that could be test installed in the stator prior to final manufacture of the full set.

The design of the SVPI hard coil incorporated double bar series and phase connections between the top and bottom half coils. To increase the speed of the brazing operation, dual induction brazing heads were designed to allow brazing both sides of the connection simultaneously. Following brazing of the series and phase leads, the integrity of all connections was verified by ultrasonic inspection.

After brazing and wedging were completed insulation was applied on the series and phase connections and series blocking was installed.

## **5.5 Winding complete**

At the completion of winding, final electrical and mechanical testing was performed. A typical battery of testing during the winding process and at the end of the rewind insured that the machine would be ready for operation.

The final electrical testing consisted of an elevated frequency loop test, winding insulation resistance, winding resistance, and over potential testing.

A Fast Fourier Analysis Techniques test was administered to the stator end windings to verify the resonant frequencies of the stator phase leads and end windings were away from the electromechanical operating frequency. All test points were satisfactory at the conclusion of the testing.

After all final testing was complete and satisfactory the unit was painted with insulating enamel for uniformity and to aid in future inspections.

## **6 Summary**

After a forced outage of one unit in 2017 that was reportedly caused by a winding fault, significant coil damage was reported. Siemens was contacted and inspected the second GT unit at the same site. Due to significant reduction of outage duration versus previous industry-wide GVPI rewinds, both units could be released for commercial operation two months later. Siemens has demonstrated the viability of performing an innovative fast GVPI to SVPI stator rewind to meet its customers' needs and that Siemens has a proven track record for forced outage response. In the unlikely event and depending on the site parameters and customer needs, Siemens can offer the Footprint replacement, repair, or rewind solutions on the GVPI fleet.

## **7 Disclaimer**

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