CIGRE-540

2022 CIGRE Canada Conference & Expo
Calgary, Alberta, Oct.31 – Nov. 3, 2022

Installation and Energization of the World's First EHV Rapid Response Multi-Voltage Transformer Lease

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SUMMARY

Society depends on reliable electricity – long-term power interruptions can have disastrous consequences. Grid resiliency can be improved by mobile plug-and-play transformers that can quickly restore power (after a failure at either a substation or generating facility) or avoid disruptions during grid maintenance and upgrades. Recently an Extra High Voltage (EHV) Large Generation Step Up (GSU) power transformer failed at a combined cycle power plant. This unforeseeable event forced the steam turbine generator to be shut down. While the energy supply to thousands of households was not directly affected, a sustained outage could have caused severe disruption to the grid and financial hardship to the facility owners.

Three EHV modular multi-voltage single phase power transformers were delivered to the power plant, and were fully assembled, oil filled and tested in less than two weeks. Usually, it takes 9-12 months to replace conventional transformers with a suitable new unit.

The power transformers were leased to the facility, making it possible for the steam turbine generator to return to service in less than two months from the forced outage caused by the failed GSU transformer. This was the first time an EHV multi-voltage Large GSU has been leased to customers as a flexible transformer replacement option. Being able to rapidly deploy innovative replacement equipment is key to enhancing grid resiliency.

This paper presents the solution which allowed the power plant owner to mitigate the impact of the outage. Aspects associated with the importance of appropriate planning as well as transportation and storage will be discussed.

The paper will also dive deeper into the required installation and energization activities that were needed to get the steam turbine generator back online in a quick, flexible, and resilient manner.

KEYWORDS

Resilience, reliability, GSU, Pretact, transformers, plug-in-bushings, plug & play transformers, ester, environmentally friendly, mobile, rapid response, bypassing

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INTRODUCTION

A forced outage of a Generator-Step-Up (GSU) transformer in any power plant is a nightmare for everyone involved, not only due to the consequences of power outages on industry and communities but also because they can quickly evolve into financially critical situations that could have deep long term impacts on different stakeholders, including producers, consumers and retailers of electricity.
Beside the conventional practice of having spare transformers, more advanced solutions are now available for conventional generating power plants as well as for renewable generating facilities which will be presented in this paper.

Resiliency GSUs are designed and constructed to be mobile, meaning they can easily be transported to anywhere in North America. They can also be installed and energized in industry-benchmark short time frames. Applying state of the art designs the most compact transformers can be manufactured. High temperature materials like aramids in combination with the use of synthetic ester insulating fluid Midel 7131 consequently reduce weight, size and enable higher power ratings compared with a conventional design. Through the incorporation of plug-in bushings and cables in the design, the installation and commissioning time is reduced dramatically.

While the resilience transformer concept is a known solution used in step-down substations, newest developments in the area of Mobile Resilience GSU transformers are significant and have proven versatile and able to replace many different types of units in a wide variety of configurations. The coverage of various generator and transmission voltages guarantee the most flexibility in operation.
Mobile resilience GSU transformers contribute in a new way to enhance grid resilience. The new concept provides additional reliability and peace of mind to the owners and operators of generating plants.

In this paper we present details of a deployment to a power plant. The power transformers were leased to the facility, making it possible for the steam turbine generator to return to service in less than two months from the forced outage caused by the failed GSU transformer. Being able to rapidly deploy innovative replacement equipment is key to enhancing grid resiliency.
The paper also dives deeper into the required installation and energization activities that were needed to get the steam turbine generator back online in a quick, flexible, and resilient manner.

CAPABILITIES OF A MOBILE RESILIENCY GSU TRANSFORMER

Despite having prevention measures in place, the unexpected may still happen and it is recommended to have a contingency plan prepared and ready. Such a detailed plan should include the steps which need to be taken, such as detailed transportation plans, layout and work plans.
Mobile Resilience GSU power transformers play a significant role to increase the ability to respond to emergencies.

In order to facilitate a very rapid deployment, a reduced transport weight and physical size are crucial. Innovative solutions, like highly flexible cables and plug-in bushings are supporting a reduction in installation time. Finally, by applying the recommended commissioning procedure, a transformer bank could be brought online within an extremely short period of time [2].

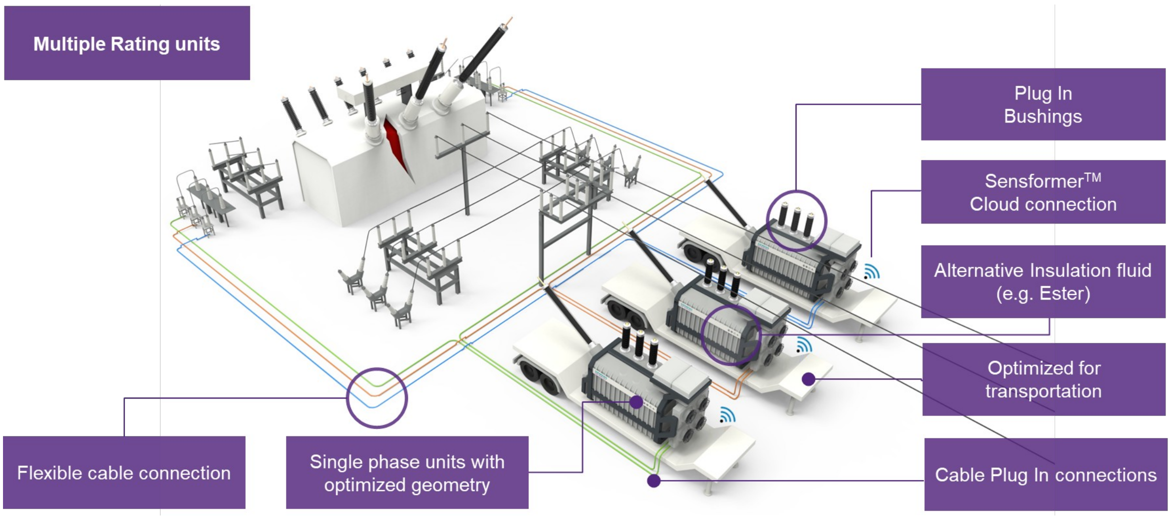

Figure 1 - Schematic arrangement of Siemens Energy's resilience concept [2]

Especially in case of a failure at a generation site, it is essential to move on as fast as possible and replace such transformers within the shortest possible time. In case no spare transformers are in stock, leased models specifically for GSU resilience transformers have been introduced.

TECHNICAL CHALLENGES FOR GSU RESILIENCY TRANSFORMER

The resilience GSU (Figure 2,4,5) was designed to be flexible to cover most specifications of the existing generating facilities fleet in North America (US, Canada and Mexico) up to 400 kV considering as well:

- **Vector group**: **YNd and YNyn(d).** For GSU applications, the high voltage is most commonly a grounded wye connection. A low voltage wye connection is in some special cases used as well. For those (special) wye-wye applications a buried tertiary to handle asymmetrical loading currents is available. Low voltage connection chambers enable interconnection of single-phase units as a bank and provide connection points to the Generator (Figure 2, 3).

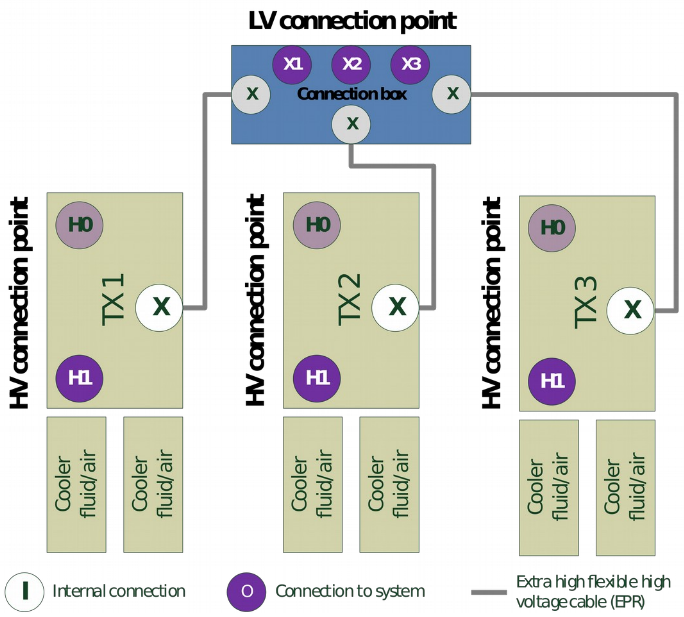

Figure 2 - Connection diagramm
Combination of single phase transformers to bank for GSU application [3]

Figure 3- External connection box
to connect the single phase transformers to bank configuration

- **Power rating. From 50 to 250 MVA for one bank**: The large variety of power plants with ratings from a few MVA up to GVA must be divided in several groups. To address the majority of medium size power plants a focus on a range of 50-250MVA was defined. The solution was to concentrate on the top rating with enhanced cooling and the usage of upgraded insulation system materials (e.g. aramids) in the most stressed areas. It is always a balance of size and weight, top rating and flexibility in voltages classes, which define the applicable solutions. In case of an emergency the positioning of coolers and transformers is very important, thus a simple solution for connection of transformers to the cooling equipment and the interconnection of transformers to the bank is a requirement. Flexibility was achieved by interconnection with flexible cables with quick connect plugs.
- **HV from 115kV up to 400kV:** Based on optimized winding arrangement on the core and a smart state of the art winding arrangement, the time and effort for reconnection could be kept to a minimum. Plug-in bushings are used for voltages up to 345kV, and RIS bushings with adapters are used for the 400kV application.
- **LV from 12kV delta up to 34kV wye:** Via a combination of a clever regulation principle and an optimized winding arrangement the time and effort to match the low voltage level to the generator specific voltage was achieved.
- **Transport:** The transformer(s) shall be able to be transported and be ready for service in a short period of time. Weight restrictions for transport was considered to optimize transport permitting and logistics. To guarantee a fast transport to the power plant, a low weight and minimized size is key. With the application of state-of-the-art technologies, like aramid high temperature insulation materials, in combination with thermally upgraded material and a high efficiency cooling system, this was achieved.
- **Safety:** Use of synthetic ester Midel 7131 as insulating fluid, increased fire safety significantly. Synthetic esters have a much higher fire point (>316°C) and flash point (275°C) than mineral oil (fire: 170°C, flash: 160°C), reducing fire risks [4].
- **Insulating fluid stability:** Use of synthetic ester increases the stability and flexibility of operation. Natural esters rapidly oxidize (becoming solid) when in contact with oxygen, but synthetic esters are highly stable. Synthetic esters have higher oxidation stability performance as traditional mineral oil.
- **Low ambient temperature:** Synthetic esters have extremely good behavior at very low temperatures. While the pour point of natural esters is in the range of -21°C [6], Midel 7131 synthetic ester has a pour point of -56°C [4, 5] making it adequate for utilization in regions with extremely low ambient temperatures.
- **Environmentally friendly:** By using Midel 7131 as insulating fluid the sustainability of the environment is safeguarded. While after a 28-day test, biodegradation of synthetic ester reaches

89%, traditional mineral oil only has degraded 9.7%. Ester insulating fluids are fully biodegradable (according to IEC 61039) [7].

TRANSFORMER DESIGN PARAMETERS OVERVIEW

- Three units of 83.3 MVA each – single phase – 60 Hz (250 MVA bank)
- 41 operation modes:

	Vector Group	d	d	y	d	y	d	y	d	y	d	y
	Low Voltage [kV]	34.5	20	34.6	18	31.2	16	27.7	14	24.3	12	20.8
High Voltage [kV]	400*)	•	-	-	-	-	-	-	-	-	-	-
	345	-	•	•	•	•	•	•	•	•	•	•
	230	-	•	•	•	•	•	•	•	•	•	•
	138	-	•	•	•	•	•	•	•	•	•	•
	115	-	•	•	•	•	•	•	•	•	•	•

Tertiary 13.6kV, operating voltages (@ three phase rating)
*) 400kV via adapter and Basic Impulse Level (BIL) 900kV

Figure 4 - Possible operation voltage of the resilience GSU

- Tertiary 13.6 kV (for stabilizing).
- Switching links utilized to change between operating voltages.
- HV Plug-In bushings up to 345kV.
- LV customer connection via oil/air GSU bushing,
  LV interconnection with alternative plug-in Cable connection (60m ~200ft).
- Neutral with plug-in cable.
- Tertiary with plug-in cable.
- Noise level 70 dB(A) no-load, sound pressure level.
- Hybrid insulation using NOMEX® and TUP (Thermally Upgraded Paper).
- KDAF – Synthetic Ester – Midel 7131.

Low transport weights:

- Total weight (assembled and oil filled): 214,000 lb, 97 t.
- Transport weight (transformer) w/o oil: ~114,600 lb, 52 t.

DEPOYMENT

A customer contacted Siemens Energy regarding a Generator Step Up (GSU) transformer failure at one of their combined cycle power plants in Western Ohio. The GSU transformer for the steam turbine generator experienced a catastrophic bushing failure that resulted in a fire, destroying the unit. Siemens Energy immediately evaluated if the Pretact™ Resilience transformer, that was stored in a warehouse would be a fit for this application. The available voltages on the Pretact Resilience unit were a fit and the customer evaluated whether the higher impedance of the multi-voltage unit will be a problem. It was determined that the Pretact Resilience transformer can be used as a replacement unit for the failed unit and Siemens Energy immediately started working on a lease agreement with the customer and started aligning transportation contractors, cranes and other equipment suppliers to facilitate a speedy deployment.

When agreement on lease terms and conditions were reached between all involved parties (Siemens Energy, the customer and their insurance agency), the customer issued a Notice to Proceed, and arrangements were immediately made to prepare the unit for shipment. A team was mobilized to the storage warehouse and the preparations were under way within 6 days after receiving verbal notice to proceed. The team worked for the following 4 days to prepare the three single phase transformers for shipment, by draining the tanks, removing conservators and coolers and packaging everything for transport to Ohio. Transport permits were being fast tracked and trucks started loading the equipment prior to having the transport permits issued. Time was of the essence and the trucks left the storage facility when the transport permits for most of the route was obtained – only the last section in Ohio was still outstanding, but Siemens Energy had assurances that the permits would be approved and issued by the time the trucks made their way to the Ohio state line. The permitting was received prior to arriving at the state line and the main tanks were delivered to the customer's facilities 6 days later.

The failed GSU transformer and a section of isophase busbar were removed, and Siemens Energy and its subcontractors immediately set up a large crane and placed the transformers inside temporary oil containment berms in front of the foundation of the failed unit. The LV connection chamber (that is used to connect the three single phase transformers with power cables on the LV side) was installed underneath the isophase busbar on the GSU transformer foundation to facilitate easy connection to the isophase busbar. Coolers and conservator tanks were staged for assembly and the transformers were then reassembled – all associated piping, protective devices and accessories were installed to facilitate processing and oil filling the units.

A temporary section of custom-built isophase busbar was installed to connect the LV connections chamber to the generator. While this work was ongoing, Siemens Energy's Technical Field Assistants (TFAs) started reconfiguring the internal voltage connections of the three single phase units and the subcontractors assisted another Siemens Energy team in installing the power cables. Once the voltage reconfiguration on the first unit was completed the TFAs moved to the next unit and the Transformer Services crew started processing and oil filling the unit. When oil filling was completed, each unit was tested per industry standard and test results, which included testing and installation of the HV plug-and-play bushings and HV and LV surge arresters, were reviewed to ensure the individual units were fit for energization. After satisfactory test results the TFAs started working on terminating all the power cables for the tested transformer, including connections to the LV connection chamber. This process was repeated for all three phases. When all three transformers were completed and connected, additional three-phase testing was performed to ensure proper winding configuration.

In parallel to these activities, Siemens Energy installed and connected the main control cabinet (which is the common connection point for the three single phase transformer controls and monitoring) and installed all the interconnection cables from this cabinet to the individual cabinets on each single-phase transformer. The customer then connected the main control cabinet to their control and monitoring system. The complete installation process at the customer's power station took 13 days from when the first transformer was unloaded to when it was ready for energization.

The Pretact Resilience GSU remained in service for 9 months while a replacement GSU was manufactured and shipped to the site. Upon arrival, the replacement transformer was fully assembled, processed, oil filled and tested adjacent to the foundation in order to facilitate a short duration outage. The transformer was placed in a convenient location to enable a short jack and slide from the assembly location to the final location. In parallel, the Pretact Resilience GSU was being drained and dismantled to be removed and relocated to the next deployment location. Another customer with a GSU transformer failure was already waiting for the Pretact Resilience unit to become available for immediate deployment at their combined cycle power plant.

The complete disassembly and decommissioning process took 7 days to complete, which included the following activities:

- As left testing of the transformers
- Removing isophase connections for the LV connection chamber
- Draining the fluid directly into road tanker trucks
- Disconnecting and spooling up all control and power cables
- Dielectric (Partial Discharge) testing of all used power cables
- Removal and packaging of conservator tanks, bushings, surge arresters and coolers
- Loading all loose equipment, power cables and accessories in shipping containers
- Loading the three single phase transformers on trucks
- Loading all containers, coolers and conservator tanks onto trucks

The replacement transformer was moved into its final location on the final day (day 7) of removal/decommissioning activities of the Pretact Resilience GSU. Activities to get the replacement unit ready for service immediately commenced and the unit was placed back in service as soon as the installation, testing and final commissioning activities were completed.

Figure 5 – 250 MVA bank – 345 kV Pretact™ Resilience Generator Step-Up Transformers
On site – Completely installed and energized

THINGS TO CONSIDER

When deploying the Pretact Resilience GSU, a few items need to be evaluated to avoid potential delays or issues:

1. Avoid ground loops around power cables at all costs – this includes any ground wires that run over top of any power cables, large loops like H-frame structures or any other path that can create a loop for induced currents. Failure to do so will result in unacceptable induced/circulating currents in the grounding system.
2. Ensure that protective relay settings are adjusted for the increased inrush current that these units will experience during energization. These are single phase units and will have a significantly larger inrush current as compared to traditional three phase units due to the much larger volume of core steel that needs to be energized.
3. Evaluate if the increased impedance of the Pretact Resilience GSU is something that will cause operational concerns or restrictions. Most GSUs have an impedance of around 11 to 19% @250MVA base, while the Pretact Resilience GSU have an impedance of 20.4 to 29.6% @250MVA, depending on which voltage combination is chosen. This increased impedance may require some special operation restrictions, depending on type of generator and how the system is configured.
4. Evaluate the station service requirements for cooling fans and fluid pumps. The Pretact Resilience GSU has a total of 6 fluid pumps and 18 cooling fans, which are powered of a 208V three phase power supply with a total load of around 68kVA. Also ensure that the system has the capability to start all these motor loads at once following a short station service outage.
5. The power cables for this specific solution are roughly 200 feet in length and the slack needs to be absorbed throughout the substation yard when the transformers are close to the LV connection chamber. Care shall be taken to ensure a minimum spacing of three feet between cable bundles (one bundle for each LV winding terminal, with a total of six multicable bundles) to reduce short circuit forces on these cables during single or three phase fault conditions.

CONCLUSION

Reducing risk, however, does not mean that catastrophic or unexpected events will not happen. This will require contingency plans to allow for better response to such events on short notice to restore power to the customers. These contingency plans typically require the rapid deployment of spare or mobile equipment that can be installed and commissioned quickly and with enough flexibility to bypass the failed equipment.

State of the are solutions are currently available to address both step-down transformer as well as generator step-up transformer replacement or bypassing needs. A single resiliency transformer can be designed to be extremely flexible and be able to operate at a wide range of different conditions including different voltage levels or vector group connection requirements, as well as to be able to be installed using plug-in bushings or cables as alternatives in otherwise normally non-accessible places. Using state of the are design tools and materials a resiliency transformer can be made extremely compact and lightweight allowing manageable transportation, installation and commissioning. Use of environmentally friendly insulating fluids reduces risks during transport and operation.

Keeping purpose in mind, units can be designed so the total installation and commissioning time is reduced from several weeks, which is common on standard power transformers, to only a few days becoming so a valuable and proven option in the industry.

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