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Improving Transfer Capability while Avoiding Series Compensation Challenges

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SUMMARY

Few states in the U.S. have shown leadership as forward-thinking as New York in ensuring the switch to renewable energy sources and electrification. New York has long enhanced the electric grid through governmental measures. The Reforming the Energy Vision policy measures in New York in 2014 were centred on establishing a more resilient and energy-efficient system while embracing new energy technology in the state. This project, together with previous decarbonization regulations, not only highlights the significance of distributed energy resources and smart grid technology but also lays the groundwork for future grid-scale renewables-focused programs. This article explains how Central Hudson Gas & Electric Corp. uses the technology on its grid to speed up the integration of renewable energy sources while avoiding problems associated with conventional approaches.

KEYWORDS

Series Compensation, Sub-synchronous resonance (SSR) Risk, Smart Valve, modular static synchronous series compensator, M-SSSC, Central Hudson, New York CLCPA.

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1. Introduction

New York enacted the Climate Leadership and Community Protection Act (CLCPA) in 2019. This forward-thinking law established extraordinarily challenging targets to combat climate change and achieve net-zero emissions in the state. The act established emissions objectives to quicken the state's transition to net-zero, along with crucial requirements to guarantee that underserved populations profit from the program and the newly established Climate Justice Working Group. While all the goals are ambitious, generating 70% of the nation's electricity from renewable sources by 2030 is probably the most difficult, given the short time left. By 2050, the CLCPA aims to call for a decrease of 85% in greenhouse gas emissions. The CLCPA targets that remain are shown in Figure 1.

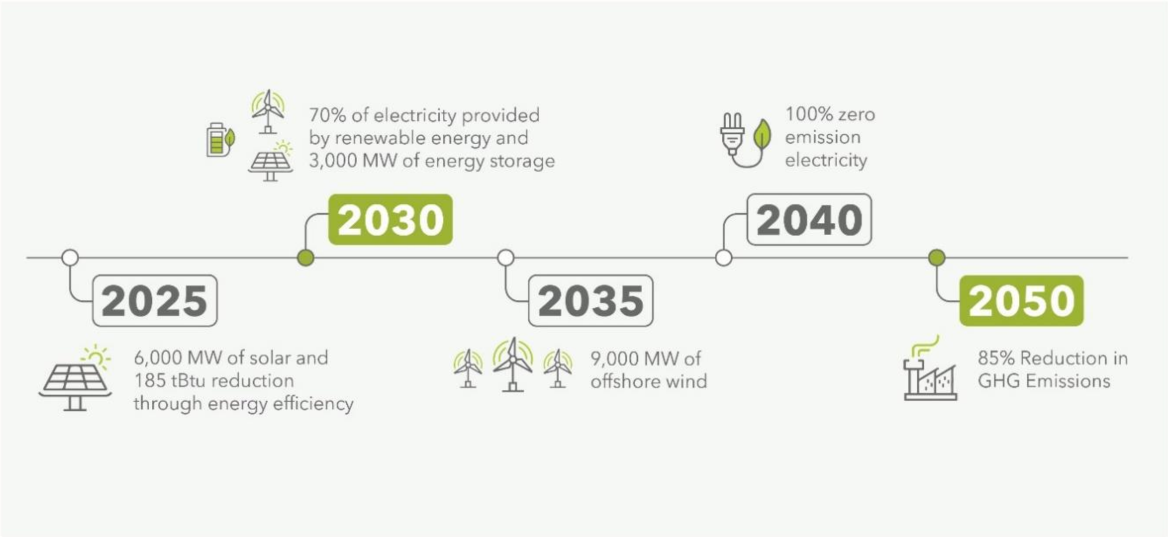

Figure 1. CLCPA climate targets for New York

The state's clean energy and climate targets advanced when New York passed the Accelerated Renewable Energy Growth and Community Benefit Act in 2020. This law established several initiatives to increase the use of renewable energy in the state. One of these was the State Power Grid and Study Program, which aimed to hasten the planning stage for constructing transmission and distribution infrastructure across the state. This analysis highlighted numerous initiatives that would be necessary for the short- and medium-term to meet CLCPA goals. Several of these initiatives use grid-enhancing technologies (GETs), which increase the grid's transfer capacity to hasten the incorporation of renewable electricity.

A future grid depending on GETs has been envisioned by regulators, the New York Independent System Operator (NYISO), and utilities in New York. Several utilities are using GETs to address grid difficulties to take the first steps toward that realization and acquire confidence in the performance and reliability of these technologies.

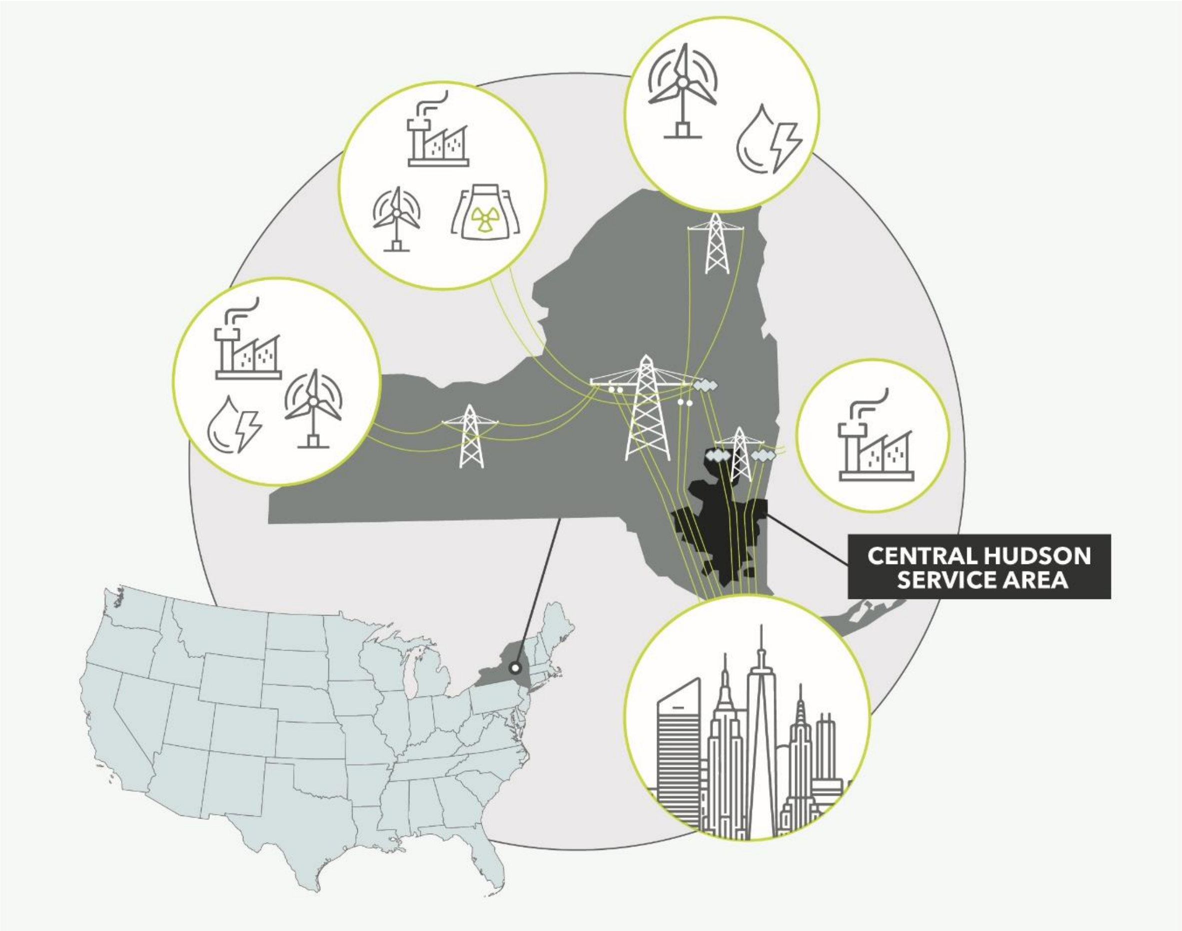

Figure 2: Simplified New York electric transmission grid and central Hudson service area

To supply gas and electricity to the Mid-Hudson River Valley of New York, Central Hudson Gas & Electric was established in 1911. Today, Central Hudson provides electric service to nearly 300,000 customers throughout a service area that stretches from the suburbs of New York City's metropolitan area north to Albany's Capital District. Figure 2 depicts the flow of renewable energy through the state's northern border and into New York City. Central Hudson plays a critical role in reducing congestion along these transmission corridors and enabling increased integration of renewables by increasing the transfer capacity of underutilized lines.

The modular static synchronous series compensator (M-SSSC), a high-impact GET, has been used most frequently by Central Hudson. Within the next few years, the M-SSSC solution will guarantee the full deliverability of several renewable energy projects. Additionally, by evaluating the technology in a pilot project before using it to address grid-related problems, they could gain experience with the solution and contribute to technological breakthroughs that have already helped grids worldwide.

2. Series Compensation Project

The NYISO receives requests for interconnection from generation developers in New York proposing interconnection projects. After receiving the request, the affected transmission owner and the NYISO work together to complete the interconnection process study. The Class Year Facilities Study is what is done in this case. It entails researching how each class year generator affects the system. This study comprises a system deliverability study for capacity resources. If additional capacity resources are needed to ensure system dependability due to the proposed interconnections, NYISO will suggest a system deliverability upgrade project.

The Upstate New York/Southeast New York interface transfer capability is constrained, according to the system deliverability studies conducted for classes 2009, 2010, and 2011. To guarantee the deliverability of class year projects, the transfer capability of the interface needs to be increased by 185 MW. The 345 kV Leeds-Hurley Avenue line would receive a 21% series compensation to do this, according to the NYISO's proposal. This amount of compensation would likely need relay modifications to address reliability and security issues related to distance protection relays.

The Hurley Avenue 345 kV Substation in Central Hudson served as the site of the fixed series capacitor (FSC), which was used in the NYISO's initial concept for series compensation. According to a preliminary protection analysis, Central Hudson would need to address effects on local protection plans; issues with voltage and current reversal would necessitate a substantial and pricey relaying upgrading project. Sub-synchronous resonance (SSR) interactions were also highlighted concerns, which arise from mechanical/electrical interactions between a turbine-shaft generator and the electrical system. The Roseton and Athens natural gas-producing units may interact with SSR, according to a screening study ordered by the NYISO. A more thorough analysis would need to determine the implications and suggested mitigation. Relay upgrades and SSR mitigation would increase project expenses significantly.

FSC installations have recorded problems with deployment and operation despite being widely utilized. The most typical problem is the possibility of sub-synchronous oscillations, or SSOs, where the FSC reverberates at sub-synchronous frequencies (SSO). Sub-synchronous torsional interaction (SSTI) and sub-synchronous control interaction (SCI) are the two types of SSO that occur most frequently (SSCI). The torque forces that oppose one other at the electrical grid and the turbine-generator shaft are known as torsional interaction. Control interactions happen when controls on a doubly-fed induction generator "amplify" sub-synchronous currents (such as wind turbines) coming into the generator. As a result, power electronic control systems become unstable, and generator rotor shafts experience severe torsional stress.

The SSR phenomenon has been seen in locations all around the world. Due to SSR experience, more notably sub-synchronous torsional interactions between the generation facilities and the FSC, an SSR event in Latin America in 2016 resulted in substantial damage to the generation facilities. Four gas-fired power units in Latin America that were close to several FSC installations had to be taken offline as a result of this incident because of fractures and arc-flash damage found at the shafts. A thorough post-mortem investigation identified the incident's underlying cause and produced preventive measures. Several FSC installations in the area are currently out of commission to prevent future SSR occurrences.

Intentionally limiting nearby generation or reducing the impact of the series compensation on power flow control are two examples of expensive SSR mitigations. The quickest and most practical answer is to permanently avoid any FSC installation that may cause SSR due to the numerous operational and financial ramifications of mitigating solutions. However, doing so effectively removes the capacitive reactance's input to the grid and results in stranded multi-million dollar investments. Even if early tests do not reveal SSR problems, future grid topology and generation modifications could create the right circumstances for SSR.

Central Hudson looked into different power flow technologies because of concerns about how they would affect area protection plans, interact with SSRs, and cost. In the end, it was decided to work on this project with an M-SSSC. As the NYISO investigated the effects of capacitive series compensation up to 30% on the 345 kV Leeds-Hurley Avenue line, the device's modular design made it feasible for the application at Hurley Avenue. Future compensation requirements can be rapidly met by installing more modular units.

3. Modular SSSC Solution

3.1. Modular SSSC Technology

Global electric grids have used modular power flow control technologies for the past ten years. SSSC components are assembled into standardized, modular devices to provide these adaptable solutions. While minimizing the difficulties, M-SSSC technology preserves the functionality and advantages of conventional power flow control technology.
To function as an FSC or series reactor, SSSC solutions inject a leading or lagging voltage in quadrature (shifted 90 degrees) with the line current. However, because SSSCs are active, they avoid some technical challenges of passive devices and legacy compensation systems, such as the potential for SSO stimulation and constant reactive power usage.

SSSCs effectively enhance or reduce the reactance of a specific circuit through voltage injection using voltage-source converters, enabling real-time control of power flow. This technique works well in meshed electric grids to address loading violations by utilizing spare system capacity.
The transmission owner network facility and SSSC solutions function together in series. M-SSSCs run at line potential without connecting to the ground and do not require an insertion/coupling transformer, unlike conventional SSSC solutions.

Utilities can build deployments for quicker, more precise system demands because of M-SSSC installations' inherent modularity. Future system needs can be easily accommodated by adding new modules to the deployment. The M-SSSC devices are voltage-agnostic and may be readily redeployed to various lines with varying voltage levels in addition to scaling the current deployment.

Operators can regularly alter the M-SSSC operational settings due to the power electronics' quick response time. This makes it possible to actively manage power flows without affecting the longevity of the devices. Changes to the settings can be made periodically to actively manage power flows while maintaining the device's longevity. M-SSSCs can function in a variety of control modes. By adjusting the injected voltage as a function of line current, operators can program the M-SSSC controls to maintain a fixed reactance or keep the line current within operating limits.

Traditional flexible alternating current transmission systems, such as SSSC or FSC, need significant civil construction to be installed, a sizable footprint, and a unique design to meet the requirements of a specific application and deployment site. The M-modular SSSC's architecture enables quick and inexpensive deployment and re-deployment with a great deal less specific design work, enabling the solution size to be scaled up or down to match the changing needs of the transmission grid. Currently, M-SSSC devices come in modules ranging from 1 MVAr to 10 MVAr. Typically placed as a fleet, they are interconnected across all three phases and provide a continuous range of control up to the deployment's total rating. M-SSSC devices are often deployed by utilities in or near a substation or as a part of a mobile unit for quick deployment.

3.2. Switch from FSC to M-SSSC

Under the summer short-term emergency rating of 3348 A, Central Hudson and Smart Wires, Inc. scaled the M-SSSC deployment to satisfy the 3.5 Ohm (21% series compensation) requirement on the Leeds-Hurley Avenue line. When currents are lower than the STE, M-SSSC technology can provide significantly more compensation because its reactance injection is inversely proportional to the line current. An overview of the M-SSSC solution is presented in Table 1.

Table 1: Summary of Leeds- Hurley M-SSSC solution

Series Compensation Required	3.5 Ω
Max Line Current Post-Injection	3,348 A
Voltage Injection per Phase Required	11.72 kV
Voltage Injection per M-SSSC Device	2,830 V
M-SSSC Devices per Phase	5

At 3348 A, 3.5 Ohm of capacitive reactance minimum is required, which is equivalent to 11.72 kV of capacitive voltage injection. Five M-SSSC devices per phase (15 in total) were used to achieve a voltage injection capability of 14.15 kV at a voltage injection capability of 2,830 V per device. This M-SSSC deployment results in an effective impedance change that is inversely proportional to line current and, for instance, can deliver +/- 7.07 Ohms at 2000 A. The positive or negative values depend on whether the reactance is capacitive or inductive.

The total project cost was comparable to the FSC option when the Hurley Avenue series compensation was switched to an M-SSSC system. It also provided various system effects, design, and installation benefits.

The M-SSSC solution has substantially less affect on protective schemes in terms of system impact. Additionally, the possibility of producing SSR is extremely low because M-SSSC devices inject voltage rather than connecting capacitance. As opposed to the considerable bulk FSC, the modular nature of M-SSSC devices allows for a more imaginative and practical deployment footprint. A ground-mounted M-SSSC solution needed less substation space than the FSC solution, which needed about 25% more space. The decision to move forward with the M-SSSC solution by Central Hudson was further influenced by flexibility in deployment design and the effective utilization of substation space. The fact that there is no single point of failure when using numerous M-SSSC devices is a final enhancement to the risk profile of the deployment.

One of the M-SSSC solution's substantial cost-saving benefits comes from the protective circuitry, which enables Central Hudson to avoid major relay upgrades necessary with the FSC alternative. Schweitzer Engineering Laboratories (SEL) collaborated with Central Hudson and Smart Wires to conduct a relaying study and tests. The testing scope involved creating a reduced power-system model of the line and nearby lines using the RSCAD software to evaluate the effectiveness of the relays protecting the 345 kV Leeds-Hurley line.

To compare the performance of the protective elements in capacitive and inductive modes with and without M-SSSC device adjustment, SEL ran a series of tests on these lines under various loading circumstances. When examining the model, Smart Wires made sure that it provided a comparable portrayal of the M-SSSC device's performance under typical system loading changes and power-system transient circumstances. The group agreed that the model accurately represented how the devices behaved in the real-time simulator (RTS) test environment. The simulation proved that the M-SSSC devices would quickly bypass the Hurley Avenue relays and remove the deployment from the Leeds-Hurley line. Therefore, the 21% series compensation would not need Central Hudson to modify its relays.

SSR and SSCI, which happen when circumstances lead to a generation resource being radially connected to a series compensated line, were another worry for Central Hudson. This circumstance might lead to severe oscillations at frequencies below the fundamental (60 Hz). Nevertheless, numerous system analyses have supported that the SSSC technology risk of SSR is extremely low. Results from a study finished by EnerNex show that SSR should be avoided. In the M-SSSC devices, a phase-locked loop produces a stepped pulse sinusoidal voltage signal independent of the line current and mainly at the fundamental frequency. This plan ensures that SSSCs do not affect SSR/SSCI and has been validated in numerous academic publications and textbooks on flexible alternating current transmission system devices. Figure 3 illustrates how an SSR event at a neighboring generating unit is caused by a simulated series of faults using an FSC solution and an M-SSSC solution. The system reacts to the events as predicted when simulating the response with an M-SSSC solution.

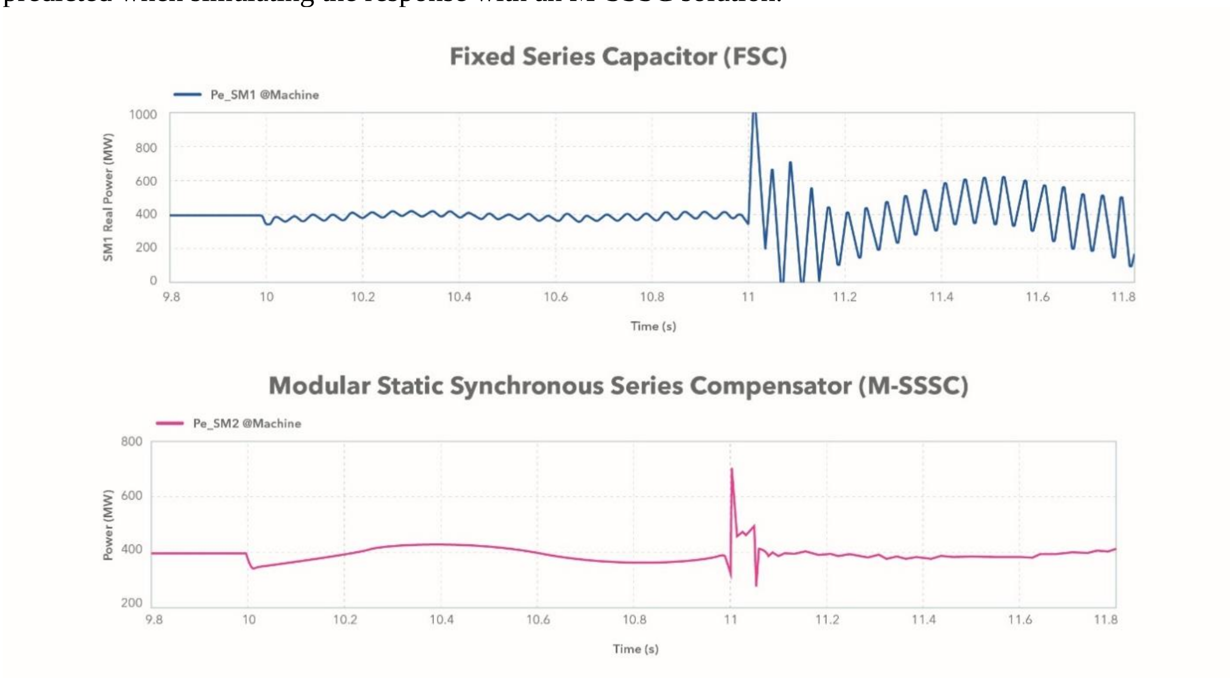

Figure 3: Response Showing FSC SSR Activity and Avoidance Of Such Activity With M-SSSC Device.

Because there is a chance that SSR with FSCs will harm generators and control systems, utilities frequently invest a lot of money in studies and mitigation. The M-SSSC system offers series compensation without SSR risk.

Granular, real-time power flow control is available from M-SSSC solutions. Due to their ability to modify line reactance often without incurring maintenance costs, these devices can change line reactance on a sub-second basis. With this capability, M-SSSC systems can optimize power flows in various system scenarios where raising line reactance may be necessary. With FSCs, this level of control is not achievable. In New York, where solar and wind generations are growing in the northern part of the state, and offshore wind projects are on the horizon in the southern portion, it can be beneficial to integrate renewable generation.

The demand for adaptable and quickly deployable solutions rises as generation and load fluctuate more frequently. Highly effective use of client funds is made possible by the modular design of M-SSSC installations, which guarantees Central Hudson an investment that pays for itself at the Leeds-Hurley site and gives outsized returns with the possibility of use at future locations. M-SSSC devices can be put into operation less than a year after the contract is signed, enabling utilities to realize advantages sooner and raising the cost-benefit analysis. FSCs, on the other hand, are typically not economically advantageous to scale or transfer because they are specifically designed for a given voltage and MVA rating. Additionally, it usually takes longer than a year for them to be installed after purchase.

Greater dependability is provided by the modular design of these M-SSSC solutions, which prevents the unlikely failure of a single device from influencing the deployment as a whole. FSCs have numerous parts, each of which is a potential single point of failure. An FSC failure could have a detrimental impact on reliability and cost by removing all series compensation until an outage is planned and maintenance is finished. After a device failure, the M-SSSC deployment would carry on with little reduced compensation.

3. Central Hudson's Approach to Adopting New Technology

Before implementing the technology at the Hurley Avenue Substation, Central Hudson ordered a trial project to deploy M-SSSC devices close to its Ohioville Substation. Three M-SSSC devices, one for each phase, and three auxiliary bypass units were used in the pilot. Central Hudson carried out the installation design under the direction of Smart Wires on a 115 kV line connecting the Ohioville and Sturgeon Pool Substations, an existing guyed three-pole steel corner dead-end structure was used in the installation design. To link the poles and support the apparatus, new cross arms made of galvanized steel were added to the structure. The inclusion of post insulators gave the poles lateral stability. The cross arms incorporated suspension insulators to support the weight of the apparatus. Due to their close proximity to the devices, Central Hudson added in-line insulators to the down-guys that were already there to keep them sufficiently protected.

The Central Hudson construction manager hired five qualified line workers for the installation job, and standard transmission line trucks were obtained as the main lifting apparatus. The entire installation took place in 2019 and was completed in just over two days of arctic, icy weather. Instead of muddy terrain, which is less stable for line truck work, installation could have been done because the ground was frozen.

Figure 4: Installation of M-SSSC Phase 1 Pilot on Central Hudson's system

Between the line and M-SSSC devices, the initial installation plan called for 795 MCM ACSR jumpers; however, the ACSR jumpers proved difficult to work with during lab testing. Instead, the team chose to use 500 MCM Cu because it offered flexibility for a simpler installation. Since there is a differential potential between the jumpers and the device enclosure, Central Hudson inserted insulating tape on the jumpers and terminals to guard against animals.
Before being shipped to Central Hudson, the communication and control system was pre-configured and tested. An antenna's radio frequency communication to the communication coordinators was tested using a test setup. A spectrum analyzer verified that no interference would negatively affect the system's operation.

Central Hudson installed the system per a collaboratively created specification, integrating the M-SSSC communication and control hardware using tools from SEL. The redundant power sources of the M-SSSC control equipment received 125 VDC power from Central Hudson, which also distributed

electricity via a fuse panel. The LMR-400 cabling connecting the antennas to the M-SSSC communication and control gear was installed by technicians on a mast outside the substation control house.
After a problem with an erroneously entered device identifier was fixed, the communication and control system could connect to all three M-SSSC devices. To test the system, the devices were injected at 500 VAC. On the line, there was a discernible variation in the power flow (Figure 5).

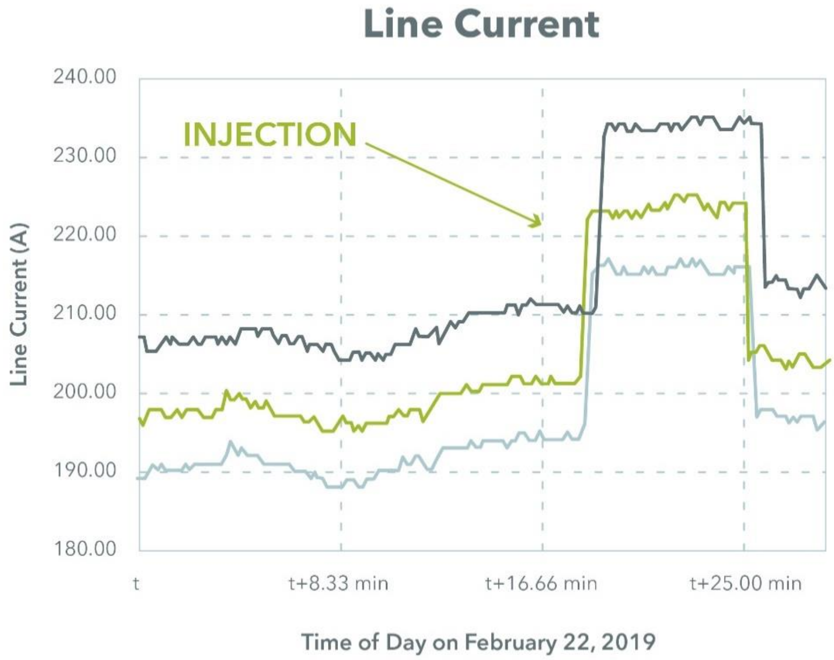

Figure 5: Line Current Measurement for All 3 Phases on Ohioville- Sturgeon Pool Line

Following the first commissioning, integrating the Energy Management System (EMS) with the Central Hudson Remote Terminal Unit (RTU) took about ten person-hours. This effort benefited from exchanging data points and pre-configuring the DNP3 mapping in the M-SSSC communication and control hardware. During the integration process, several configuration errors were found and fixed, including the need to replace an inaccurate identifier in the EMS mapping configuration and modify the station address. Central Hudson hired the Electric Power Research Institute and Smart Wires as third-party assessors to observe the devices' installation and to commission and give a technical report based on its investigation and conclusions. In August 2020, the institution released its final report, which included an assessment of the installation process, communications and controls, cybersecurity, the influence of protection systems, and the impact on the electrical system.

The pilot study successfully identified areas for improvement before the Hurley Avenue project. The user interface of the control software needed to be adjusted, and work and commissioning procedures needed to be clarified. To help with this project and others in the future, Smart Wires put these changes into practice right away. The group discovered further room for improvement. The M-SSSC devices would occasionally recognize system events and bypass them to keep them safe. The units were functioning as intended; however, bypassing events happened more frequently than expected. The incidents often involved traveling waves brought on by system events that should not necessitate disabling the M-SSSC devices (e.g., switching shunt capacitor banks at nearby stations). Although this operation had little effect on the pilot unit, Central Hudson determined that it would be unfavorable for the more critical Hurley Avenue project and would need to be addressed.

According to the study, traveling waves on the system were responsible for the undesired bypass incidents. These waves propagate high-frequency voltage and current surges across the transmission system, which are rapid transients. Voltage and current traveling waves may be created by transmission

line transients, such as lightning surges or capacitor bank switching. To handle these bypass events brought on by traveling waves, Smart Wires introduced two enhancements.
The first involved updating the firmware to allow the M-SSSC to quickly switch back to injection after detecting bypass operation brought on by traveling wave events. This was appropriate to ensure that the capacity to inject was not significantly disrupted for most steady-state applications. The group experimented with the firmware using lab setups, simulations, and Central Hudson's installed M-SSSC devices. Following a traveling wave event, the firmware performed as planned and brought back the devices to injection.

Smart Wires determined that additional modifications were required to guarantee M-SSSC devices wouldn't suffer a bypass operation during traveling wave occurrences for installations crucial to grid functioning and transient applications. The research and development team designed a filter system to reduce the significant voltage differential across the M-SSSC device brought on by these waves. The filter system creates a low-impedance channel between the input terminals so that the high-frequency wave components can travel along the line without passing through the device.
The team assessed the Bypass Filter system's effectiveness using PSCAD electromagnetic transient simulations and in-lab testing. The filter proved successful in effectively managing the impact of traveling waves, as demonstrated by the simulation and laboratory testing.

The year 2020 saw the installation of phase two of the pilot project, which required upgrading the M-SSSC devices to include the filtering system. The knowledge and lessons discovered during the phase one installation were built upon in the installation's design. A device that crews can fully install at ground level, one phase at a time, was created through collaborative design. The assembly was lifted into place as a single unit on the dead-end structure by the boom on the end of a typical digger derrick truck. The installation, which included moving the line out and back in, took a five-person line crew two days to accomplish using bucket trucks and conventional line construction gear and techniques.

Figure 6: M-SSSC Phase Two Pilot Installation on Central Hudson's System

As the communications devices were preprogrammed and the settings were applied before installation on site, the phase two process was sped up by drawing on previous knowledge from the commissioning of the phase one pilot. Sending and receiving orders and data did not encounter problems throughout the DNP point mapping, EMS integration, or testing. Similar effects on line flow were seen during phase one testing and injection testing of the units, as illustrated in Figure 5. The devices' traveling wave capabilities were investigated by switching in and out of service both the nearby 115 kV capacitor bank in Ohioville and a distant 115 kV capacitor bank. In both tests, the units rode through the incidents and kept injecting.

The phase two implementation on Central Hudson's system guaranteed M-SSSC device functioning and validated the changes necessary for the success of the Hurley Avenue project. In addition, utilities have implemented similar upgrades in projects across Europe, Australia, South America, and North America. Most significantly, five M-SSSC deployments were installed on the National Grid United Kingdom transmission system in early 2021. With the help of these installations, flows over a crucial transfer interface are optimized, resulting in a 1.5 GW improvement in transfer capacity for mostly Scottish offshore wind output. One of these installations can be seen in the U.K. in Figure 7.

Figure 7: M-SSSC installation on National Grid's system in the United Kingdom

5. Hurley Avenue Project Execution and Beyond

According to the SEL RTS tests that were previously reported, a small amount of overreach by the line distance relays was occasionally seen when the devices were operating in capacitive injection mode. These situations fell inside the relays' current, programmable reach range. There was no effect on settings or protective devices in inductive injection mode. No relay adjustments are required, as stated. The reach of the line relays must only be configured differently for protection.

The M-SSSC components will be installed in the same spot as the first suggested FSC bank and interconnect. The design and architecture add two new bays—one for the M-SSSC deployment and the other as a maintenance bypass—to the existing Hurley Avenue 345 kV substation. A maintenance bypass bay was unnecessary because of the M-SSSC devices' bypass feature. Central Hudson chose to install one, nevertheless, to shorten the duration of line interruptions required to carry out mandatory M-SSSC device maintenance in the future.

To make room for the installation, the Leeds-Hurley line's incoming segment will be directed to the new bypass bay. Due to this reroute, a new access road for a transmission line needs to be constructed. The new substation bay's layout was carefully considered and created to offer the best solution while incorporating the flexibility to increase deployment size in the future. The engineering team successfully created a layout that satisfies the project's current requirements while also allowing for future extensions that would raise the compensation to 51%. The resources needed for the design and construction of this expansion would be negligible. Additionally, it might be finished more quickly. The design created for the M-SSSC deployment required 70% less footprint compared to the layout and area needs of an FSC bank. With a few minor adjustments owing to site-specific needs, the support structure and layout will be comparable to those of the units on National Grid's system, as shown in Figure 7.

After the design work was finished, construction began in September 2021. Construction on the site will continue until the end of the year. For the project to meet the projected in-service date, Central Hudson is moving the project along and managing the numerous substation workforces in a safe, effective, and efficient manner.

6. Conclusions

To satisfy future renewable energy targets and address urgent grid needs, Central Hudson realized the advantages of installing GETs. Validating M-SSSC as a dependable solution to address essential grid constraints required an aggressive strategy. The value of Central Hudson's work has greatly increased as a result of the incorporation of comments and lessons learned in the completion of projects around the world.

The Hurley Avenue project will have an immediate impact since it represents a significant advancement in New York's efforts to integrate renewable energy sources. When this project is implemented in Q4 2022, it will enhance transfer capacity by about 185 MW. The potential growth of the project's impact and value in the future is made possible by the projected capacity for more M-SSSC devices. The implementation at Hurley Avenue may scale as renewable generation increases, including hydro imports from Canada, improving transfer capacity, and enabling more renewable generation to reach the downstate load centers.

The CLCPA in New York is a challenging piece of legislation intended to boost the integration of renewables in the state. Utilities across the state have suggested power flow control to deal with the challenges posed by the first and second phases of the plan's execution. To achieve 70% renewable electricity by 2030 and an 85% decrease in greenhouse gas emissions by 2050, utilities must be able to reduce project costs and shorten project lead times. M-SSSC technologies help utilities achieve these goals.

For Further Reading

- The Brattle Group; Pterra Consulting; New York Department of Public Service Staff; NYSERDA Staff, "Initial Report on the New York Power Grid Study", January 19, 2021 https://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId=%7BE41D6A17-1EA5-47D3-90E8-A4E981705FE3%7D
- Kovalsky, Len; H. Khalilinia, G. Chavan, S. Natti, M.Y. Xue, A. Brahman. "Study Results of the Impact of a Modular SSSC to Transmission Line Protections Schemes." CIGRE US National Committee. 2018 Grid of the Future Symposium.
- Zavadil, RM. "Comparative Performance of Smart Wires SmartValve with EHV Series Capacitor: Implications for Sub-Synchronous Resonance (SSR)" April 20, 2017. https://www.smartwires.com/download/8319/
- "Evaluation of SmartValve Devices Installation at Central Hudson" EPRI, Palo Alto, CA: 2020. 3002019771. https://www.epri.com/research/products/000000003002019771
- "National Grid U.K. Announces World's First Large-Scale Use of Power Flow Technology," T&D World, 10-May-2021. [Online]. https://www.tdworld.com/overhead-transmission/article/21163434/national-grid-uk-announces-worlds-first-largescale-use-of-power-flow-technology