Stabilizing the Power System in the US by Using FACTS Devices

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1. Introduction

Since the mid 1990s, electric power companies in the US have been concerned about voltage stability and restrictions on reactive power as a result of the deregulation on electric power systems and the separation of electrical power production from power distribution and transmission.

Figure 1 shows the retirement of power supplies by energy type from 2008 to 2020 in the US. In recent years, to reduce carbon emissions, aged thermal coal generation plants have been retired successively and the use of renewable energy resources as an alternative energy has been increasing.(1) Due to these changes, inverter-connected renewable energy resources are being interconnected to systems that have already been weakened by the decrease of thermal power plants that use synchronous generators, thus worsening the voltage stability of the electric power systems.

Constructing new grid systems to stabilize the voltage of such electric power systems is very expensive. In addition, mechanically-switched capacitor banks are not effective for problems with dynamic system stability including system faults due to operation delays, discrete control levels, and restrictions on the service life based on the number of opening and closing times. Therefore, static var compensators (SVCs) and static synchronous compensators (STATCOMs), which are the main types of flexible AC transmission systems (FACTSs), have been widely applied to improve the voltage stability of electric power systems because they can control reactive power in both the steady and dynamic states at high speed. This paper introduces the characteristics of SVCs and STATCOMs along with case examples.

2. Characteristics of SVCs and STATCOMs

Adopting SVCs and STATCOMs (FACTS devices) increases the power transmission capacity of existing systems and contributes to stabilizing the system voltage. Therefore, for electric power companies, they are highly cost-effective solutions for a wide variety of requirements of electric power systems. Table 1 compares the characteristics of a general SVC and STATCOM.

SVCs have thyristors as switching elements. Thyristors are line-commutated and currents are commuted by the system voltage. An SVC mainly consists of a thyristor-controlled reactor (TCR), thyristor-switched capacitor (TSC), and harmonic filter. Because the currents output from TCRs contain harmonics, harmonic filters are required. The current that an SVC can output decreases in proportion to the decrease in the system voltage because the inductance and capacitance of the TCR, TSC, and harmonic filter are fixed values.

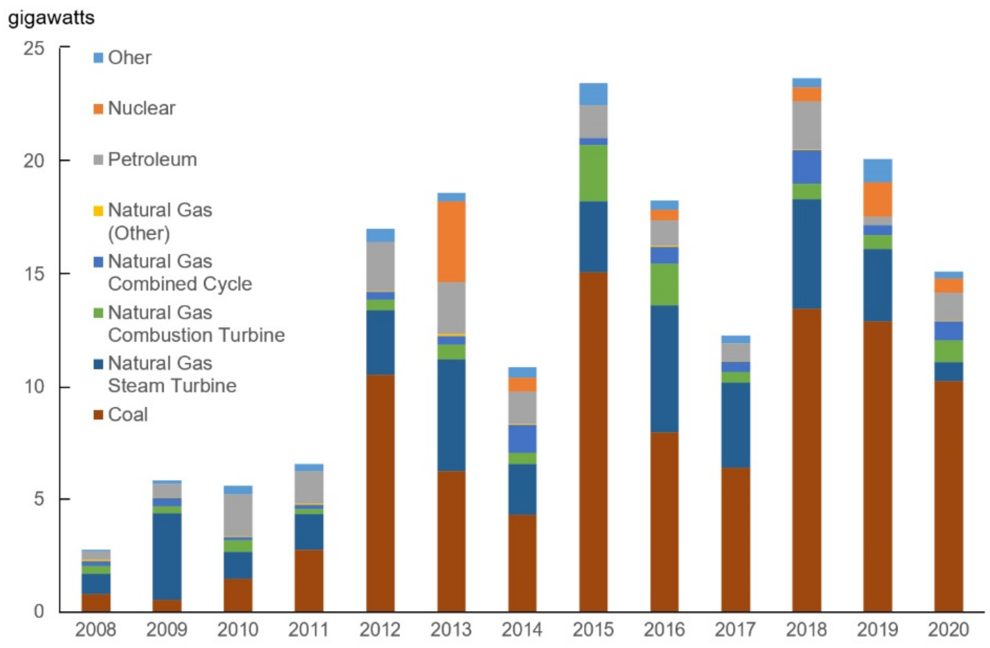
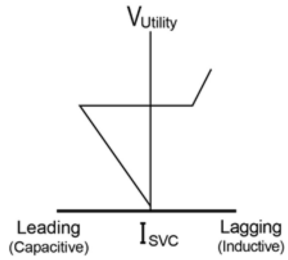
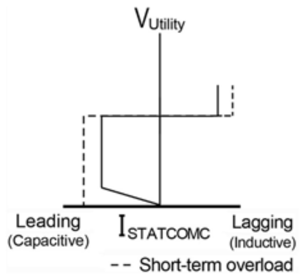
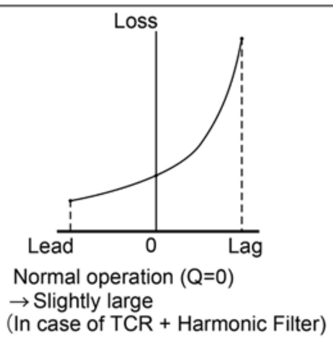
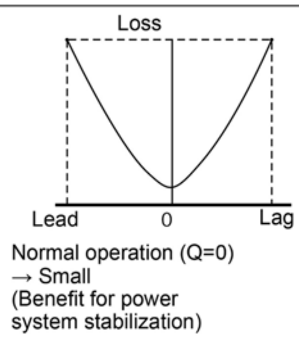


Fig. 1 Retirement of utility-scale electric generating capacity in the US(1)

*Transmission & Distribution Systems Center

Table 1 Characteristics of SVC and STATCOM

<table>
<tr><th></th><th>SVC</th><th>STATCOM</th></tr>
<tr><td>Output current characteristics</td><td>
</td><td>
</td></tr>
<tr><td>Harmonics</td><td>Large
(As a result of TCR firing control)</td><td>Small
(As a result of multiple converters)</td></tr>
<tr><td>Loss characteristics</td><td>
</td><td>
</td></tr>
<tr><td>Footprint</td><td>Large
(Harmonic filter is necessary)</td><td>Small</td></tr>
</table>

On the other hand, for STATCOMs, gate commutated turn-off (GCT) thyristors and insulated gate bipolar transistors (IGBTs) are used as switching elements. These self-commutated switching elements can be turned on and off independently from the power system voltage. The harmonics generated by STATCOMs are small in general and no harmonic filter is required; therefore, the footprints of STATCOMs are smaller than those of SVCs. In addition, currents that STATCOMs can output are steady regardless of a decrease in system voltage. Therefore, the STATCOMs' reactive power compensation characteristics when the voltage drops are superior to those of SVCs.

Mitsubishi Electric Corporation and Mitsubishi Electric Power Product Inc. (MEPPI) have installed many SVCs and STATCOMs in electric power systems in North America. The following section describes case examples.

3. Case examples of FACTS

3.1 SVC

In May 2016, Indianapolis Power & Light Company (IPL) started operation of our SVC (+300/−100 MVar) at the Southwest S/S.

The SVC was installed to solve fault induced delayed voltage recovery (FIDVR) due to faults on the 138-kV system. The US Environmental Protection Agency (EPA) ordered IPL to retire most of its thermal coal generation plants on the 138-kV system or replace them with natural gas power plants by 2016. As a result, many thermal coal generation plants were retired in 2016 and 2017 and the operation of new combined cycle natural gas power plants began in 2017. However, system analysis revealed that the voltage behavior after system faults would not be within design criteria and system loads would drop by FIDVR. Although application of a switched shunt capacitor (300 MVA) was first considered as a countermeasure, it could not be confirmed that it would meet the criteria for FIDVR. Therefore, application of quick-response FACTS was considered. It was confirmed that applying an SVC (+300/−100 MVar) or STATCOM (+250/−100 MVar, short-term overload: 125%) would meet the system contingency criteria as a countermeasure against FIDVR; an SVC was selected because there was plenty of space, there was a margin on the system side for harmonics, and an SVC cost less.

Figure 2 is a one-line diagram of the Southwest SVC delivered by Mitsubishi Electric. It consists of a TCR (0 to −200 MVA), TSC (+200 MVA), and harmonic filter (5th and 7th, 100 MVA).(2)

3.2 STATCOM

In June 2017, Dominion Energy (DE) started operation of our STATCOM (+/−125 MVar) at the Colington Substation (S/S).

This STATCOM was installed to solve FIDVR due to faults on the 115-kV system. The Colington S/S is located in an area consisting of a string of barrier islands of more than 200 miles (approximately 320 km) and it is on the end system side. The climate of the area is subtropical and the population increases approximately three- or five-fold in summer because it is a popular tourist destination. Therefore, FIDVR may occur due to the increase in air-conditioning loads in summer.

According to the guidelines of the Potomac-Jersey-Maryland (PJM) system, the electric power system must recover the system voltage to 70% within 2.5 seconds after a system fault of N-1-1 (when one line is out of service, another one transmission line fault occurs).

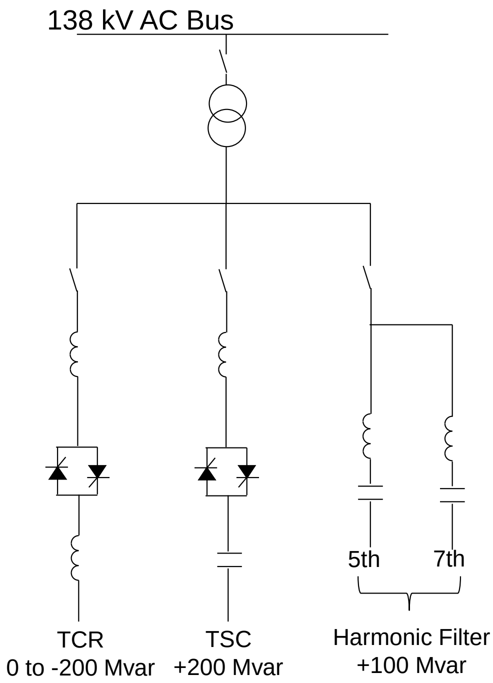


Fig. 2 Southwest SVC one-line diagram

At the Colington S/S, as a countermeasure against FIDVR, an SVC (+167/−30 MVar) manufactured by another company had been used since 1997. Because it had been operating for approximately 20 years, replacement was planned in view of the following factors: operational reliability considering replacement parts, salt damage to the outdoor equipment, and restrictions on the stabilization performance. Because the power system was particularly weak, importance was placed on reducing the influence of harmonics on the system and so a STATCOM was selected. The rating was +/−125 MVar (short-term overload: 125%).

The Colington STATCOM is a modular multilevel converter (MMC) type STATCOM, which is our first model. Figure 3 illustrates the configuration of the STATCOM. Figure 4 is a photograph of the outdoor equipment. Figure 5 shows a photograph of the valves. In the MMC type, small converters called sub-modules (SMs) are connected in series as shown in Fig. 3. As switching elements, IGBTs (manufactured by Mitsubishi Electric) are used. In addition, each SM has a bypass switch (manufactured by Mitsubishi Electric) that is closed when the SM fails and therefore each SM has redundancy.[(3)]

Before shipping the product, the control system of the STATCOM was connected to a real-time simulator to test its control performance as factory testing.

Figure 6 shows part of the waveforms obtained in

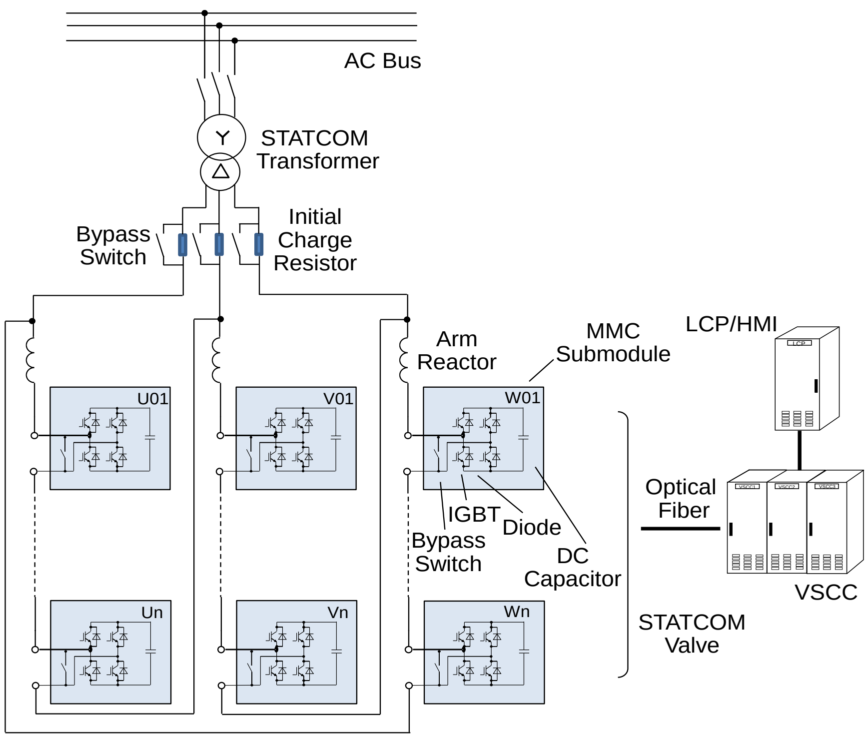


Fig. 3 Colington STATCOM system configuration

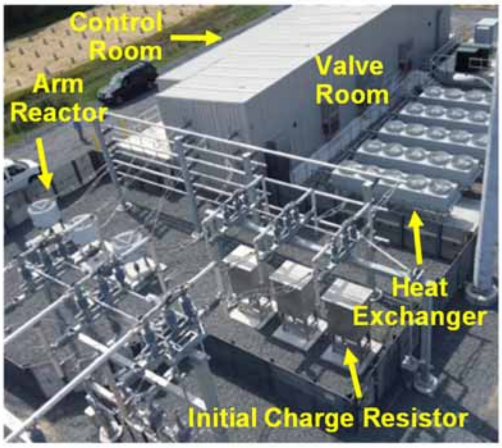


Fig. 4 STATCOM outdoor equipment

Fig. 5 STATCOM valve

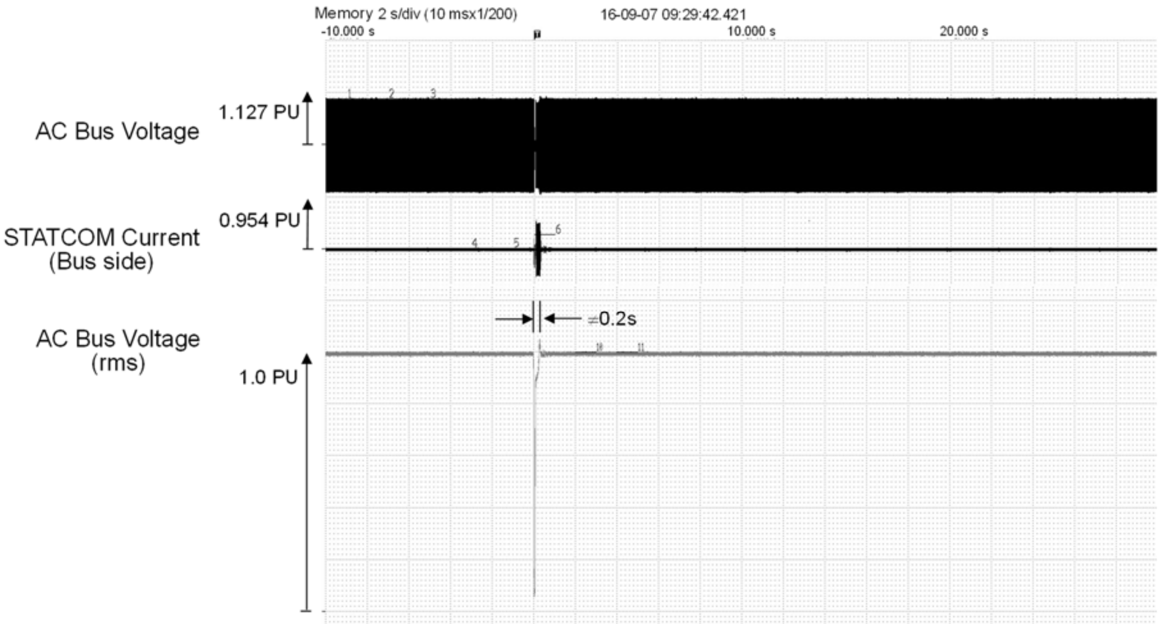


Fig. 6 An example waveform of the real-time simulator test

the test when a three-line ground fault was simulated. The test conditions were as follows: an induction motor with 0.6 pu (STATCOM's capacity) was connected as a load; and without the STATCOM, approximately 20-second FIDVR would occur under the test conditions. On the other hand, as shown in Fig. 6, with the STATCOM, the system voltage returns to 1.0 pu in approximately 0.2 second due to its reactive power control. This result shows that the STATCOM has the required performance.

4. Conclusion

FACTS devices such as SVCs and STATCOMs have been introduced to stabilize electric power systems. Mitsubishi Electric and MEPPI have installed many SVCs and STATCOMs in power systems in North America. This paper introduced some case examples. We will promote the FACTS business in the world including Japan, Europe, the Middle East, and Asia in the future as well.

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