Development of a 20-MVA STATCOM for Flicker Suppression

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OVERVIEW: Power system-connected trials of a 20-MVA STATCOM with self-commuted conversion have been completed at Hokuriku Electric Power Company's Fushiki Substation, and the system has now been put into service. In addition to reactive power compensation, the STATCOM provides flicker suppression capability that is now in great demand, features a novel new control scheme developed by Hitachi, and easily satisfies its prescribed performance criteria. Hokuriku Electric's Fushiki Substation supplies power to an industrial customer that operates electric arc furnaces that, because of the rapidly varying and largely unbalanced nature of the furnace load, were major source of system flicker. The STATCOM provides complete reactive power compensation, and is thus able to mitigate the adverse effects of flicker on the lines of other utility customers. With the objective of developing a STATCOM that is highly effective at mitigating flicker based on a relatively modest output 20-MVA converter as opposed to a 60-MVA system, we have now verified that the system easily satisfies the prescribed flicker suppression performance criteria, and the system has now been put into actual service.

INTRODUCTION

WITH increasing diversity of customers with widely varying load requirements ranging from industrial customers to general residential utility end-users, we have seen growing interest in compensation devices that can provide improved system voltage stability and electric power quality. One solution that is seeing a growing number of installations is the STATCOM (static synchronous compensator), a reactive power compensator employing a very fast responding self-commuted converter for flicker suppression. Hitachi has many installations of large-capacity thyristor-controlled SVC (static var compensator) and has contributed to improved power system stability in other

Fig. 1—Overview of the 20-MVA STATCOM.
The STATCOM (static synchronous compensator) system consists of two 10-MVA units comprised of six three-phase transformers for converters that are connected to the power system, a self-commuted converter, and a circulating water cooling scheme. Converters are housed in a special enclosure, while transformers for converters and cooling equipment are installed outside the enclosure.

TABLE 1. System Specifications
System specifications of the STATCOM developed in this work are shown.

Item	Specification
Rated capacity	20 MVA (10 MVA × 2 connected in parallel)
Rated voltage	66 kV (3-phase)
Rated frequency	60 Hz
Converter configuration	Six 3-phase bridge converters connected in parallel at DC side
Rated DC voltage	1,600 V
Main device	3,300 V, 1,200 A, IGBT
Modulation scheme	Multi-connected with 9-pulse PWM
Cooling scheme	Circulating water cooling
Harmonic filter	Not implemented

DC: direct current
IGBT: insulated gate bipolar transistor
PWM: pulse width modulation

ways, but the emphasis in this work was to develop a 20-MVA STATCOM for the purpose of mitigating flicker caused by the large industrial load of arc furnaces that are installed with harmonic filters.

Hokuriku Electric Power Company's Fushiki Substation supplies power to an industrial customer that operates electric arc furnaces, and because of the unbalanced and rapidly fluctuating nature of the furnace's load, the arc furnace is a major source of flicker on the power system. There was concern that this flicker would be transmitted over the substation's bus line to adversely affect all the other connected customers. This led us to develop and deploy this STATCOM that was specifically designed to suppress flicker, which has now proved itself in system-connected trials and been put into service (see Fig. 1). This paper describes the structure of STATCOM and highlights its flicker suppression capabilities.

STATCOM SPECIFICATIONS

System Specifications

The system is comprised of two parallelly connected 10-MVA units, each of which consists of six 3-phase bridge converters, for a total output of 20 MVA. Table 1 summarizes the main system specifications.

Main Circuit Configuration

Fig. 2 is a circuit diagram of the STATCOM, Fig. 3 shows the configuration of one of the 10-MVA units making up the STATCOM, and Fig. 4 is a photograph of the 10-MVA IGBT (insulted gate bipolar transistor)

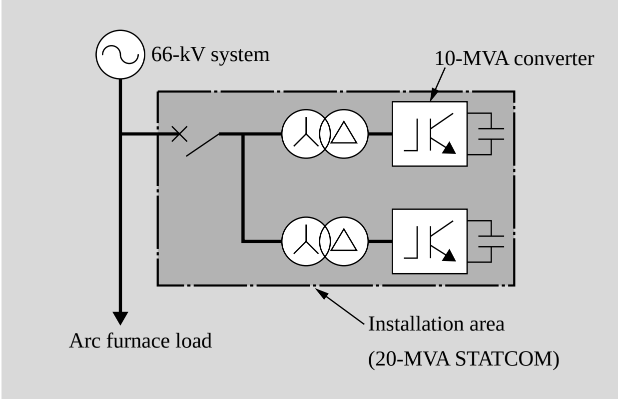

Fig. 2—STATCOM Circuit Diagram.
System is comprised of two 10-MVA units serially connected.

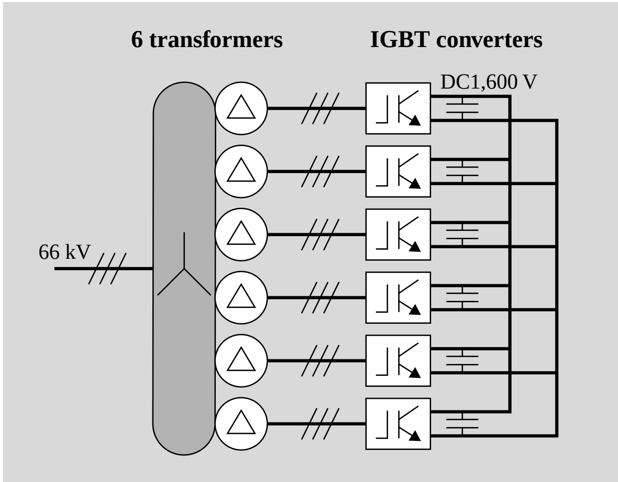

Fig. 3—Configuration of a 10-MVA STATCOM Unit.
10-MVA converter is configured of six three-phase transformers connected in series on the AC (alternating current) side, and six three-phase bridge converters connected in parallel on the DC side.

Fig. 4—Appearance of the 10-MVA IGBT Converter.
The converter consists of a single bank deployment with converter control panel (on the left) and main circuitry housed in a compact enclosure.

converter. A single 10-MVA converter is configured of six 1.67-MVA three-phase transformers connected in series on the AC (alternating current) side, and six three-phase bridge converters connected in parallel on the DC (direct current) side. The IGBT switching pulse timing of the six transformers is shifted one-sixth of a 540-Hz (60 Hz × 9 pulses) cycle to implement multiple PWM (pulse width modulation), which effectively suppresses the harmonic current on the AC side so a harmonic filter is not needed.

IGBTs are employed as the primary conversion devices in the converters. The IGBT units use a low-inductance laminate bus, and the DC condensers are dispersed in close proximity to the IGBTs without snubber circuits for very low losses. A circulating water cooling scheme carries heat from the IGBTs to a forced-air cooler installed outside the equipment, an arrangement that allows us to use larger capacity converters.

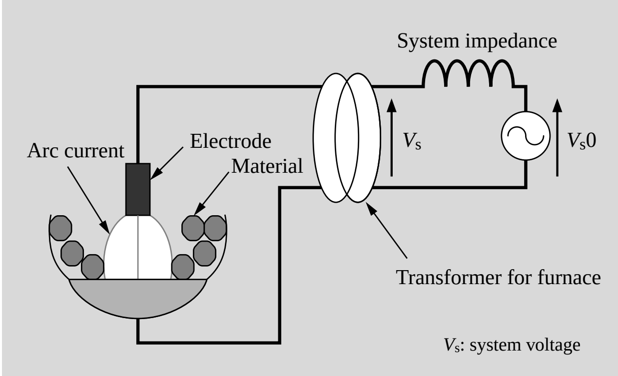

Fig. 5—Arc Furnace Schematic.
Impedance between electrodes constantly changes as the material melts.

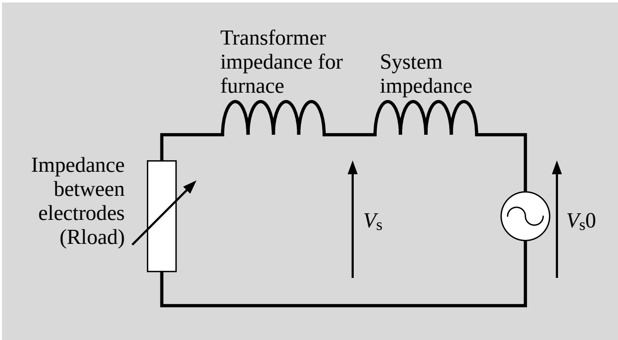

Fig. 6—Arc Furnace Equivalent Circuit.
Change in impedance between arc furnace electrodes (Rload) simulates variable resistance.

FLICKER SUPPRESSION CONTROL

Principle Cause of Flicker

We observed earlier that electric arc furnaces operated by commercial-scale utility customers are a major source of flicker. Arc furnaces are a common type of industrial furnace that use electric power to melt raw material to manufacture target products. They are also commonly used to melt pig iron, burned ash, and other materials. Fig. 5 shows a schematic of an arc furnace, and Fig. 6 shows the equivalent circuit. AC voltage is stepped down by the furnace transformers, and the material is melted by arc current.

When the metal is melted, the molten material flows down to an electrode which is then short-circuited by the material. When this happens, the impedance between furnace electrodes (Rload) shown in Fig. 6 falls off precipitously, causing a large reactive current to flow in from the power system. It is this surge of reactive current that causes the system voltage, Vs, fluctuations we know as flicker.

Our SATCOM system was specifically developed to mitigate flicker by detecting reactive current fluctuation components flowing to utility customers, then rapidly outputting reactive current to the power system to cancel those components.

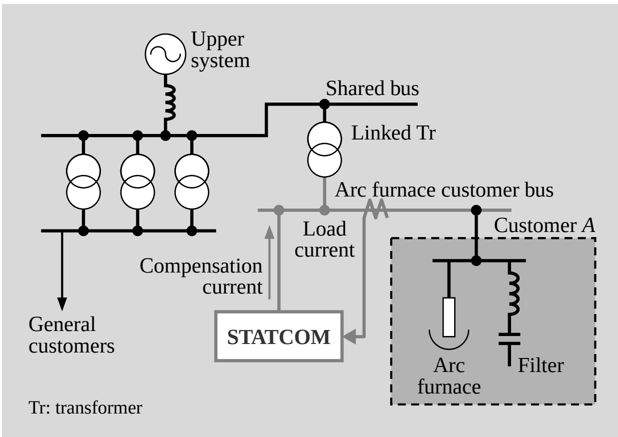

Fig. 7—Power System Circuit Configuration.
By connecting STATCOM to a bus shared with Customer A operating an arc furnace, flicker is suppressed.

System Configuration

Fig. 7 shows a circuit configuration of a power system equipped with the flicker suppression STATCOM. STATCOM is connected to Customer *A* who operates arc furnaces over the arc furnace customer bus. If the STATCOM is not connected, then the large fluctuating reactive power produced by Customer *A* causes flicker on the shared bus line and

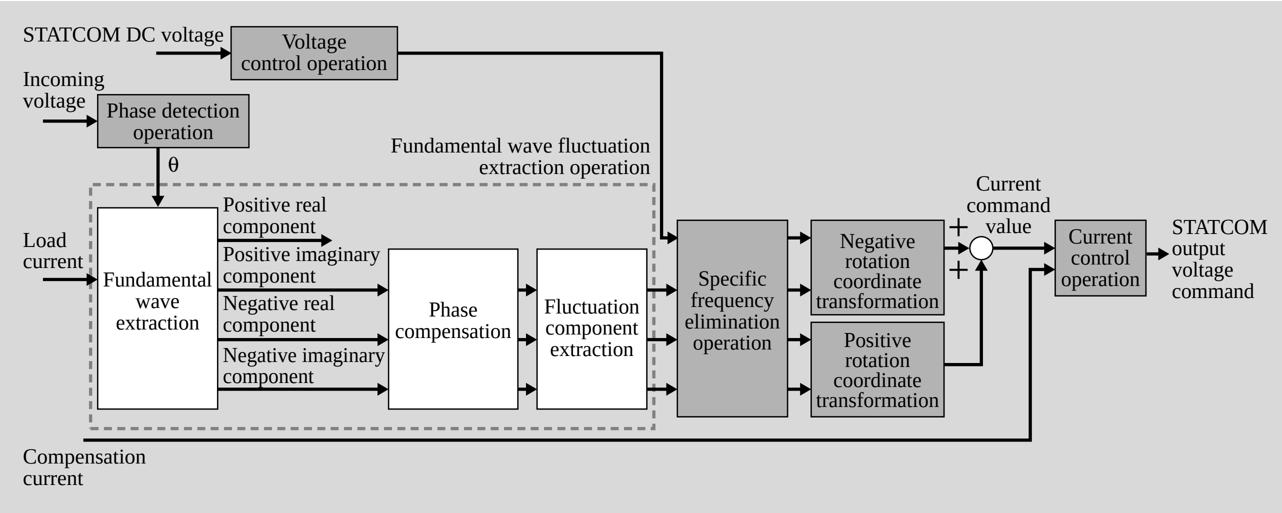

Fig. 8—STATCOM Control Block.
Fundamental wave in detected load current is extracted, subjected to phase compensation, and the fundamental wave fluctuation components are extracted using a fluctuation component extraction operation. The value with resonance component eliminated by the specific frequency elimination operation is used as the current command value to control the current.

voltage fluctuations that are transmitted to the other general utility users.

Although there is no legal restriction on flicker, "Electrical Cooperative Research"(1) defined $\Delta V_{10\text{-}4}$* ≤ 0.45 V as the value eliminating perceptible flicker, which means that the flicker produced by Company *A* must be reduced by at least 67% in order to supply voltage to other utility customers that meets the above flicker-free criterion.

Flicker Suppression Control

The STATCOM mitigates flicker by first detecting load current flowing to Customer *A*, then outputting the reactive current that cancels out the reactive current of the fluctuation component. The only problem is that the load current flowing to Customer *A* includes not only current flowing to the arc furnace but also current flowing to the harmonic filter. When the current flows into the filter and the STATCOM produces an output current reference signal with the sensed value of the filter current, that causes a resonance current between the filters and the STATCOM. To prevent this, we had to develop a resonance suppression technology to work in conjunction with the filter.

To hold the resonance in check, we developed the following methods that we subsequently verified are effective at suppressing both flicker and resonance.

(1) A fundamental wave fluctuation extraction operation that first isolates the fundamental wave component of the load current, then extracts the fluctuation component

(2) A specific frequency elimination operation that eliminates the frequency component which causes resonance with the filter from the current command value

(3) A current control operation that tracks the fluctuating current command value

Fig. 8 shows the STATCOM control block that

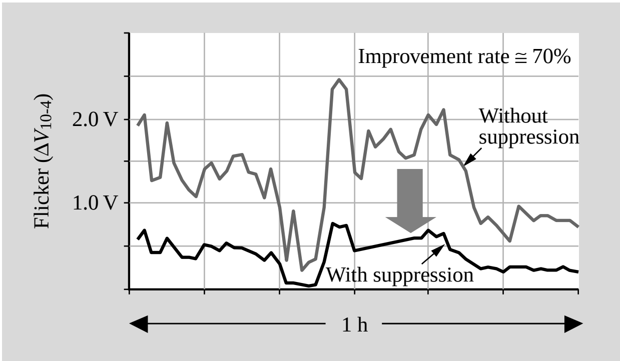

Fig. 9—Arc Furnace Customer Bus $\Delta V_{10\text{-}4}$.
Compared to when no compensation device is used, the measured flicker value is reduced by approximately 70% by connecting STATCOM to the power system.

*$\Delta V_{10\text{-}4}$ is a criterion developed by the Arc Furnace Committee of the Japanese Committee for Electro-Heat (antecedent of Japan Electro-Heat Center) for measuring flicker. It defines flicker as the visual coefficient reflecting the actual value of voltage fluctuation occurring each minute in a 100-V system.

incorporates these operations.

Flicker Suppression Effects

Fig. 9 shows how effectively flicker is suppressed by connecting STATCOM to the power system. One can see from the figure that, by installing STATCOM, the flicker produced by Customer *A* is suppressed by more than 67%.

CONCLUSIONS

This paper described the configuration and performance of a 20-MVA STATCOM with self-commuted conversion developed specifically to mitigate flicker that was recently connected to Hokuriku Electric's Fushiki Substation. We remain committed to the safe and stable operation of power systems through development and deployment of power electronics system solutions.

ACKNOWLEDGMENTS

Finally, we express our great appreciation to the Hokuriku Electric Power Company for its support and many useful suggestions in the development of the STATCOM.

REFERENCE

(1) "Permissible Value of Light Flicker from Arc Furnaces," Electrical Cooperative Research 20, No. 8 (1964) in Japanese.

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