Technical Comparative Study Between STATCOM and SSSC Devices for Steady State and Transient Stability of Power System

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ABSTRACT

The aim of this paper is to give a comparison study between two very important and recent shunt /series FACTS devices, which are, Static Synchronous Compensator STATCOM and Static Synchronous Series Compensator SSSC. The study discuses and compares the location of both devices in power network, and their applications to solving power system problems, such as, power flow control, increase of transmission capability, voltage control, as well as the impact of these devices to improve system stability when a three-phase fault is applied. The capability of the system to operate when one element is out of service was tested in the presence of these devices.
In addition, the Critical Clearing Time CCT of the system with and without FACTS devices was determined, the IEEE 14 bus was selected to performed this study by using (PSAT software). The results showed that the STATCOM is better than SSSC for voltage regulation, while the SSSC is best in core of controlling the flow of power and damping out the oscillation.

Keywords - FACTS devices, STATCOM, SSSC, power flow control, voltage control, system stability improvement.

1. Introduction

The highly complex and interconnected power systems need to improve electric power utilization while still maintaining reliability and security, Power demand has increased substantially while the expansion of power generation and transmission has been severely limited due to limited resources and environmental restrictions. As a consequence, some transmission lines are heavily loaded and the system stability becomes a power transfer-limiting factor [1,3].
In the late 1980, the Electric Power Research Institute (EPRI) formulated the vision of the Flexible Alternating Current Transmission System (FACTS), in which various power electrics based controllers regulate power flow, transmission voltage, enhancing system stability and mitigate dynamic disturbances …etc . Many of FACTS devices are connected in shunt or in series either with or without storage element for effective compensation [1,2].
The STATCOM is a static synchronous generator operated as a shunt-connected static var compensator whose capacitive or inductive output current can be controlled independent of the AC system voltage. It provides voltage support by generating or absorbing reactive power at the point of common coupling without the need of large external reactors or capacitor banks. [3,4]
The SSSC is a solid-state Voltage Sourced Converter (VSC), which generates a controllable AC voltage, and connected in series to power transmission lines in a power system. SSSC virtual compensates virtually a transmission line impedance by injecting controllable voltage (VS) in series with the transmission line. VS are in quadrature with the line current, and emulate an

inductive or a capacitive reactance so as to influence the power flow in the transmission lines. The virtual reactance inserted by VS influences electric power flow in the transmission lines independent of the magnitude of the line current. [3,4,5]

Many researches have been conducted the application of FACTS Controllers on power grid. Among them are: D. Murali and Dr. M. Rajaram [5] have studied the control of active and reactive power flow using FACTS Devices, where the power flow control performance of the UPFC is compared with that of SSSC. N. Mithulanathan, and others [6] have compared of PSS, SVC and STATCOM controllers for damping power systems oscillations. Sadek M. Alkiesh, and others [7] uses the UPFC to Control the flow of Power in a Part of Libyan. [8] Omar G. Mrehel, and others have studied and compared the effect of TCSC and SSSC to Control the Power Flow and Oscillation Damping.

This paper focuses on a technical comparative study between STATCOM & SSSC in terms of steady state and dynamic performance for IEEE 14 bus electrical network.

1.1 **Static Synchronous Compensator STATCOM**

In its simplest form, the STATCOM is made up of a coupling transformer, a VSC, and a dc energy storage device. The energy storage device is a relatively small DC capacitor, and hence the STATCOM is capable of only reactive power exchange with the transmission system. If a dc storage battery or other dc voltage source were used to replace the dc capacitor, the controller can exchange real and reactive power with the transmission system, extending its region of operation from two to four quadrants. A functional model of a STATCOM is shown in Figure 1 [6,7,8].

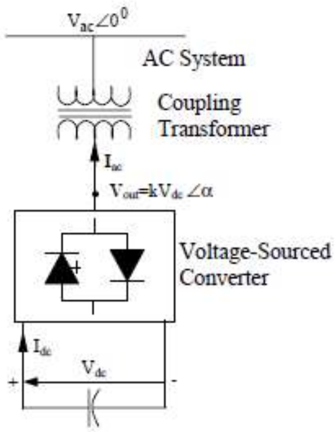


Figure 1. Functional model of a STATCOM

The STATCOM's output voltage magnitude and phase angle can be varied. By changing the phase angle α of the operation of the converter switches relative to the phase of the ac system bus voltage, the voltage across the dc capacitor can be controlled, thus controlling the magnitude of the fundamental component of the converter ac output voltage, as Vout = kVdc. Note that the coefficient k in this equation depends on the converter configuration, number of switching pulses and the converter controls. The difference between the converter output voltage and the ac system bus voltage basically determines the flow of reactive power through the coupling transformer to or from the system [1,2,3,9].

1.2 Static Synchronous Series Compensator SSSC

Figure 2 shows a functional model of the SSSC where the dc capacitor has been replaced by an energy storage device such as a high energy battery installation to allow active as well as reactive power exchanges with the ac system. The SSSC's output voltage magnitude and phase angle can be varied in a controlled manner to influence power flows in a transmission line. The phase displacement of the inserted voltage Vpq, with respect to the transmission line current, determines the exchange of real and reactive power with the ac system [1,2,3,9].

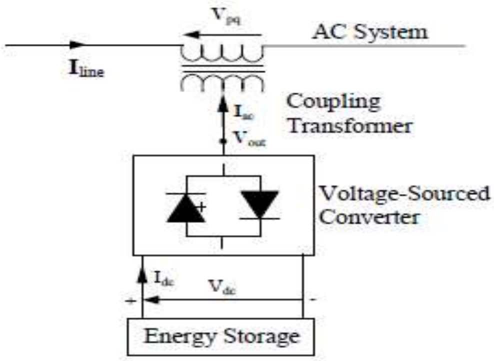


Figure 2. Functional model of SSSC

2. Power system modeling

The network under study IEEE14 bus system (standard) was selected, it consists of five synchronous machines with IEEE type-1 exciters, three of which are synchronous compensators

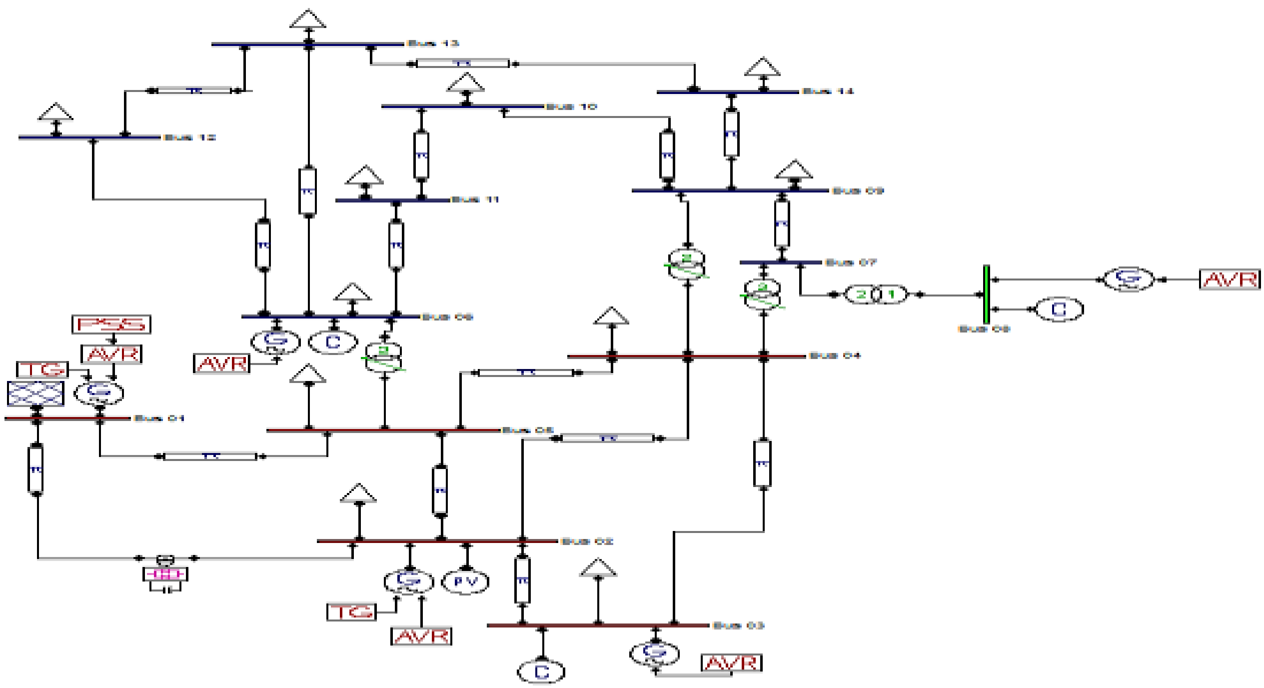


Figure 3. IEEE 14-bus system with (SSSC) Simulation model in PSAT/Simulink.

used only for reactive power support, there are 11 loads in the system, in this system, manufacturing units as standard PV buses, are modeled by the limit of P,Q and loads are assumed as constant PQ loads, the location of STATCOM and SSSC in the network under study is selected based the load ability of transmission line. From the of load flow presented results, it is clear that the loadest line in the network is the line connected between bus1 and bus2 there for the SSSC is installed on line 1-2 as shown in Figure 3, and the STATCOM is connected to bus 2, the study will be performed based in these locations of FACTS separately.

3. Simulation and results

The effect of both **SSSC** & STATCOM on voltage control, power flow control, and transient stability are simulated, and compared with the case of without FACTS devices.

3.1 Voltage control

The SSSC of 100 MVA rating was installed in the end of line 1-2 at bus 2, the injected voltage of a variable magnitude in quadrature with the line current is -0.188 pu and 0.03213, there by emulation an capacitive and inductive reactance respectively, as follows: Initially Vqref is set to 0 p.u; at t=2 s, Vqref is set to -0.188pu (SSSC capacitive); then at t=6 s, Vqref is set to 0.03213 pu (inductive).

A 100 MVA, STATCOM was placed at bus 2 the STATCOM is in Var control mode. A positive value of reactive power injection reference implies capacitive shunt reactive power compensation, while a negative value implies inductive compensation, the reference current as follows: Initially Iqref is set to 0 p.u; at t=2 s, Iqref set to 1pu (STATCOM capacitive mode); then at t=6 s, Iqref is set to -1pu (STATCOM inductive mode) where main function is to control the compensation of STATCOM controller.

The voltage magnitude at bus 2, bus 4 and bus 13 and the flow of power are presented in Table 1, voltage wave forms are shown in Figures 4 and 5, the total generation and loses are in Table 2.

Table 1: *Voltage magnitude with and without FACTS controllers*

	without		With SSSC		With STATCOM	
	Total generation p.u	Total loses p.u	Total generation p.u	Total loses p.u	Total generation p.u	Total loses p.u
Active power	2.725	0.1358	2.6804	0.0904	2.7258	0.1358
Reactive power	1.088	0.2749	1.1122	0.2982	1.0889	0.2749

Table 2: *total generation and loses without and with FACTS*

		Without	With SSSC		With STATCOM	
			capacitive	inductive	capacitive	inductive
Bus Voltage (p.u)	bus 2	1.045	1.095	0.99303	1.095	1.0234
	bus 4	1.012	1.0401	0.98059	1.0403	0.99972
	bus13	1.047	1.0645	1.0271	1.0644	1.0395

From the results obtained above, it is clear that the SSSC can control the voltage at buses when it installed at line between bus 1 and 2, as shown in Table 1, the SSSC changes the voltage from 1.095 p.u (capacitive mode) to 0.993 p.u (inductive mode) depending upon the set point of (Vq reference) either the SSSC does not changes only the adjacent bus when it installed but can change even the other buses voltage for example bus 4 and bus 13 as shown in Table 1. Table 2 illustrates the total generation and losses in case with and without FACTS, it noted that the SSSC can reduce the total power losses to about 33.4%.

The STATCOM can control the voltage, as shown in Table 1, the STATCOM changes the voltage from 1.095 p.u (capacitive mode) to 1.0234 p.u (inductive mode) depending upon the set point of (Iq reference). Table 2, illustrates the total generation and losses in case with and without FACTS, it noted that the STATCOM does not has any effect on the total power losses.

Figures 4 and 5 show the wave forms of voltage at bus 2 in presence of SSSC and STATCOM respectively, it is clear that the SSSC & STATCOM can change the voltage on bus by changing their set point

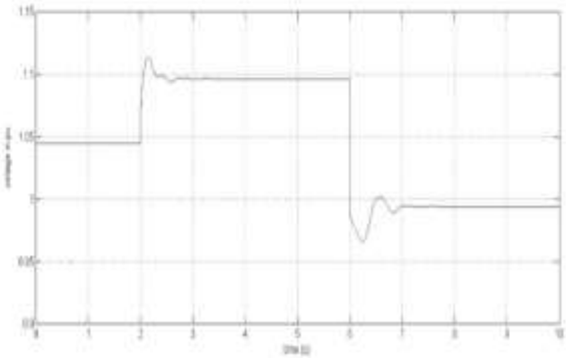


Figure 4. Voltage at bus 2 in presence of SSSC

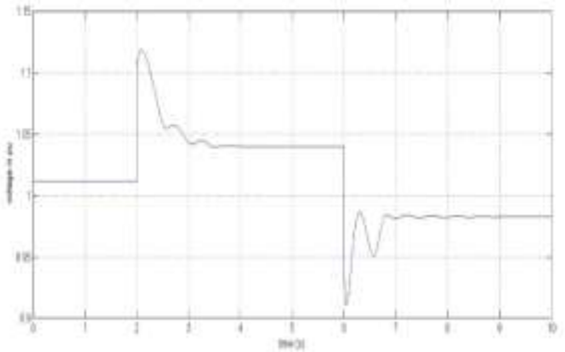


Figure 5. Voltage at bus 2 at presence of STATCOM

. In the next step the SSSC and STATCOM will used to maintain the voltage on bus 2 at 1 p.u and the results are given in Table 3, and Figures 6 and 7, the SSSC can fix the voltage on bus 2 at 1 p.u,

with the changing in power flow in line 1-2 from 1.5712 p.u to 1.3139 p.u, which reduces the power on this line to about 16.3%, while the STATCOM can fix the voltage on bus 2 at 1 p.u, the STATCOM can control the voltage magnitude on the bus without changing the flow of power on the line 1-2.

Table 3: *power flow and voltage with and without FACTS controllers*

	Without	With SSSC	With STATCOM
Voltage bus 2 (p.u)	1.045	1	1
Line power 1-2 (p.u)	1.5712	1.3139	1.5754

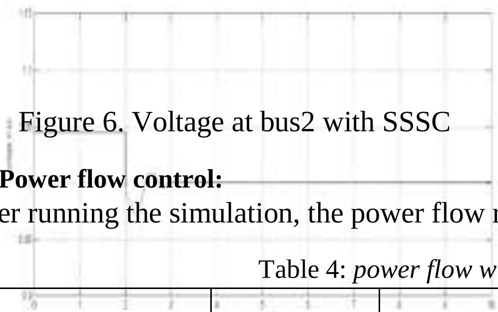


Figure 6. Voltage at bus2 with SSSC

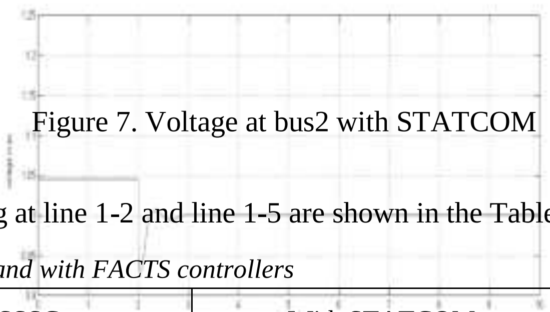


Figure 7. Voltage at bus2 with STATCOM

3.2 Power flow control:

After running the simulation, the power flow reading at line 1-2 and line 1-5 are shown in the Table 4.

Table 4: *power flow without and with FACTS controllers*

	Without	With SSSC		With STATCOM	
		Capacitive	Inductive	Capacitive	Inductive
Line power 1-2 (p.u)	1.5712	1.5823	1.5924	1.4234	1.5643
Line power 1-5 (p.u)	0.7546	0.541	0.7462	0.7462	0.76

From the results given in Table 4, the SSSC can control the flow in the line from 1.5823 p.u to 1.4234 p.u depending on the injected voltage, also the STATCOM has a capability to control the flow of power on line 1-2 for a small range from 1.5924 p.u to 1.5643 p.u.

The next Table 5 shows the voltage magnitude at bus 2 when the SSSC maintain the power on line 1-2 at 1.7299 p.u, it clear that the SSSC can change the power while the voltage at bus 2 remain as the previous value and the wave form of the real power at line 1-2 is presented in Figure 8. When the STATCOM requested to rise the power on line 1-2 to 1.7259 p.u, it can reach this value but the voltage on bus 2 will increased to 1.1944 p.u, i.e which is about 19% above the previous value, and the waveform of the line 1-2 is depicted in Figure 9, the figure shows the oscillation of power.

Table 5: *power flow and voltage with and without FACTS controllers*

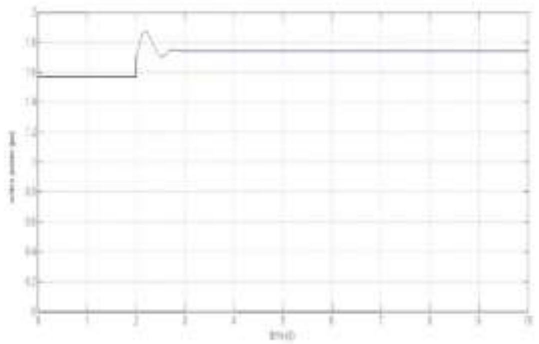
	Without	With SSSC	With STATCOM
Voltage bus 2 (p.u)	1.045	1.045	1.1944
Line power 1-2 (p.u)	1.5712	1.729	1.7259

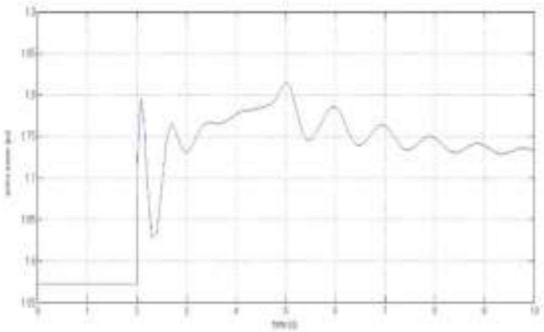
Figure 8. Active power in line 1-2 with SSSC

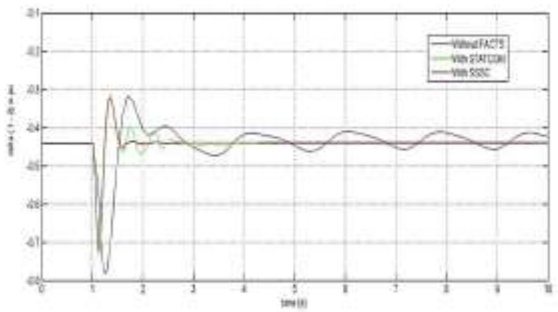
Figure 9. Active power in line 1-2 with STATCOM

3.3 **Transient stability improvement**

In this case the effect of SSSC & STATCOM to damp out the oscillation during three phase fault is presented and analyzed. The simulation of network is performed when a three phase to ground fault is applied on bus 2 at t=1s with fault duration of 0.15s. The network is equipped with SSSC and STATCOM, the results are shown in figures 10 to 13.







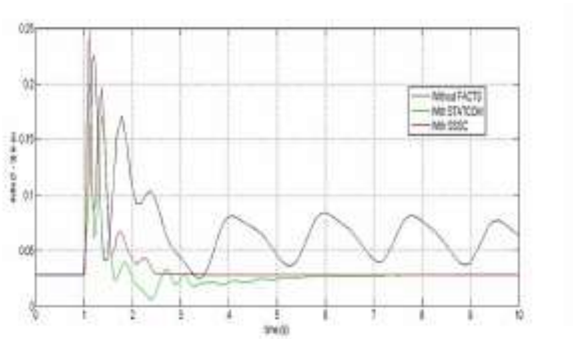
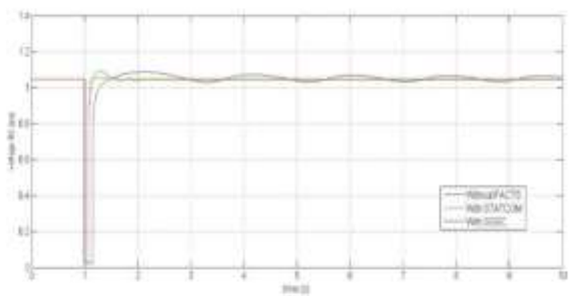


Figure 10. Delta between generator 1 and 2

Figure 11. Delta between generator 1 and
3



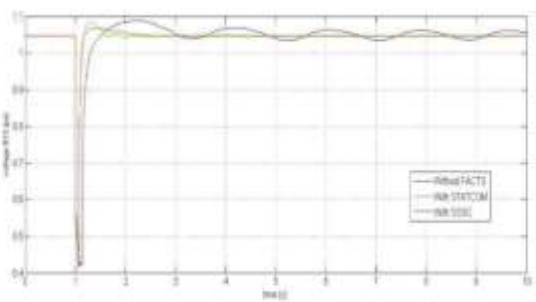


Figure 12. Voltage waveforms of bus 2

Figure 13. Voltage waveforms of bus 13

From the above figures, it is seen that, the simulation results reveal that both the SSSC and the STATCOM can significantly enhance the damping of oscillation and guarantee the stability of the system, it's clear that the SSSC is more effective than the STATCOM in damping out the oscillation.

3.4 N-1 condition

After t=1s of run the simulation the line connected, between bus 2 and bus 4 is disconnected by the circuit breaker until the simulation ended, the results of change in the angular speed between the generator 1 and 2 shown in Figure 14, and the voltage waveform of the bus 5 represented in Figure 15.

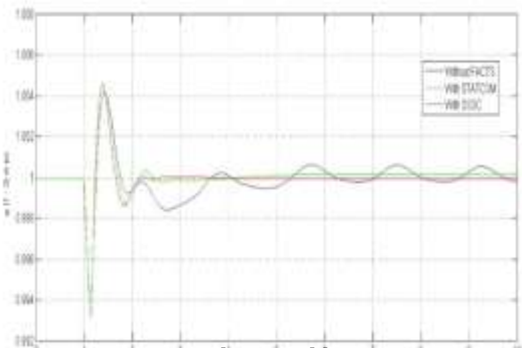


Figure 14. Angular speed between generator 1 and 2

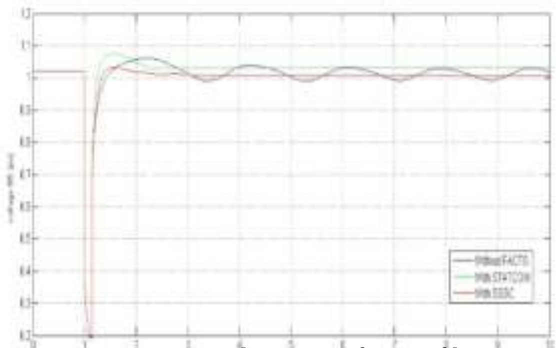


Figure 15. Voltage waveforms of bus 5

From the above Figures, it seen that both of the SSSC and the STATCOM can effectively enhance the damping of oscillation and guarantee the stability of the system, but the SSSC is more effective than of the STATCOM in damping the oscillation.

3.5 Critical Clearing Time

To calculate the CCT of power system, a three-phase fault under deferent fault locations is subjected to the network under study. The effect of FACTS devices SSSC & STATCOM on Critical Clearing Time is outlined in Table 6.

Table 6: *Critical Clearing Time (s)*

Faulted bus	CCT of system		
	Without FACTS	With STATCOM	With SSSC
1	0.38 sec	0.43 sec	0.46 sec
2	0.43 sec	0.49 sec	0.54 sec
6	0.70 sec	0.75 sec	0.78 sec
8	0.79 sec	0.85 sec	0.88 sec

It’s clear that the performance of SSSC is more effective than of the STATCOM’s on critical cleaning time.

4. Conclusion

From the assessment of the results the conclusion can be
The SSSC can control the voltage on bus 2 at 1p.u, but will reduces the power on the line to about 16%. While the STATCOM can fix the voltage on buses where it installed to 1p.u without any changing of the power, so the STATCOM is better than SSSC for regulating the voltage of the system.
The SSSC can control power flow on the line without changing the bus voltage, Whereas the STATCOM can change the power with increasing the voltage of buses to impermissible limit.

In case of system stability, both STATCOM & SSSC can improve the transient stability. But the SSSC has more rapid damping out the oscillation than STATCOM. For the CCT of the entire system, both SSSC & STATCOM can improve it, and the SSSC has best CCT rather than STATCOM.

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