

OVERVIEW OF STATCOM TECHNOLOGY

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Abstract- This paper introduces the development of STATCOM in world. Topologies of STATCOM are discussed, and the cascade multilevel configuration is given in details. Power valves such as GTO, IGBT, IGCT, IEGT used in STATCOM are also mentioned for competence.

Keywords: Flexible AC Transmission System (FACTS), Static Var Compensator (STATCOM), Cascade Multilevel Converter, Integrated Gate-Commutated Thyristor (IGCT).

I. INTRODUCTION

A Flexible AC Transmission System (FACTS) is an AC transmission system incorporating power electronic-based or other static controllers which provide better power flow control and enhanced dynamic stability by control of one or more ac transmission system parameters (voltage, phase angle, and impedance) [1]. Two of the most important FACTS devices, which have broad application in electric utility industry, are SVC (Static Var Compensator) and STATCOM (Static Synchronous Compensator). STATCOM, also named ASVG (Advanced Static Var Generator) is one of the new-generation FACTS devices, and recognized to be one of the key technologies in feature power system.

For example, a steady state application of STATCOM is illustrated in Table 1 with other devices of FACTS. STATCOM has played an important role in power Industry since 1980s. Kansai Electric Power Co., Inc. (KEPCO) and Mitsubishi Motors, Inc. developed the first STATCOM in the world, 20 MVar STATCOM using force-commutated Thyristor inverters, and put it into operation in January 1980 [2]. In October 1986, a ± 1 MVar STATCOM was put into operation, which was developed by EPRI and Westinghouse Electric Company, and was the first static compensator employing high-power GTO inverters [3].

In 1991, a ± 80 MVar STATCOM developed by KEPCO and Mitsubishi Motors was installed at Inuyama Switching Station to improve stability of a 154 kV system [4]. Tennessee valley authority (TVA), together with EPRI

and Westinghouse, installed a ± 100 MVar STATCOM [5, 6] Sullivan 500 kV Transformer Substation in October 1996 and it kept in good operation since then.

In 1997, Siemens installed an 8 MVA STATCOM at Rejsby Hede wind farm to provide dynamic control of wind generators [7]. In July 1997, American Electric Power (AEP), cooperating with Westinghouse Electric Company, developed a ± 160 MVA STATCOM and EPRI, as the parallel part of first Unified Power Flow Controller (UPFC) installed at Inez Station in eastern Kentucky [8]. EPRI and Siemens also developed a ± 200 MVar STATCOM, which was installed at Marcy 345 kV substation in February 2001 [9].

In early 2001, a 175 MVar STATCOM developed by ALSTOM, the first cascade multilevel-inverter-based STATCOM in the world, entered commercial service at NGC (National Grid Company) East Claydon, England [10]. A $+ 133/-41$ MVar STATCOM system has been installed at the Vermont Electric Power Company's Essex 115 kV substation since May 2001, to compensate for heavy increases in summertime electric usage [11]. A three-level ± 100 MVar STATCOM is installed by San Diego Gas & Electric (SDG&E) at Talega substation, California in October 2002, and is to be extended to a Back-To-Back system [12]. An 80 MVar UPFC developed by Korea Electric Power Corporation is under installation and ready for commercial operation from year 2003 [13].

Now a STATCOM, consisting of two halves, each rated ± 75 MVar, is under development by Alstom and is due to be installed at Northeast Utilities' Glenbrook substation by the end of December 2003 [14]. ABB has installed six STATCOM (also named SVC Light) since 1997, listed in Table 1, and ABB has won a US\$ 14 million order from Austin Energy, Austin, Texas, to design, manufacture and install another STATCOM based on SVC Light technologies at Pedemales Substation by October 2004. Improving stability of power systems has received significant attention since August 14, 2003 blackout that affected the Northeast and Midwest of USA, and parts of Canada, so it can be expected that more STATCOMs and other FACTS devices will be installed in a few years.

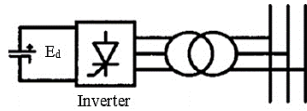


Figure 1. Schematic configuration of STATCOM

II. THEORY OF STATCOM

The STATCOM is basically a DC-AC voltage source converter with an energy storage unit, usually a DC

capacitor. It operates as a controlled Synchronous Voltage Source (SVS) connected to the line through a coupling transformer. Figure 1 shows the schematic configuration of STATCOM. The controlled output voltage is maintained in phase with the line voltage, and can be controlled to draw either capacitive or inductive current from the line in a similar manner of a synchronous condenser, but much more rapidly.

Table 1. Steady state application of STATCOM [29]

Issue	Problem	Corrective Action	Conventional solution	FACTS device
Voltage limits	Low voltage at heavy load	Supply reactive power	Shunt capacitor, Series capacitor	SVC, TCSC, STATCOM
-	High voltage at light load	Remove reactive power Supply & Absorb reactive power	Switch EHV line and/or Shunt capacitor & Switch shunt capacitor, shunt reactor	SVC, TCSC, STATCOM
-	High voltage following Outage Low voltage following	Absorb reactive power & Supply reactive power	Add shunt reactor & Switch shunt capacitor, reactor, series capacitor	SVC, STATCOM
-	Low voltage and overload	Supply reactive power and limit overload	Combination of two or more devices	TCSC, UPFC, STATCOM, SVC

Compared to SVC and other conventional reactive power compensators, STATCOM has several advantages listed below:

- 1- STATCOM has a dynamic performance far exceeding the other Var compensators.
- 2- The overall system response time of STATCOM can reach 10 ms or less [16].
- 3- STATCOM has the ability to maintain full capacitive output current at low system voltage, which also makes it more effective than SVC in improving transient stability.

Simulations indicate that 1.3 MVar SVC and 1 MVar STATCOM have similar effects in maintaining dynamic voltage stability. Figure 2 shows a much larger operating range of STATCOM compared with the SVC.

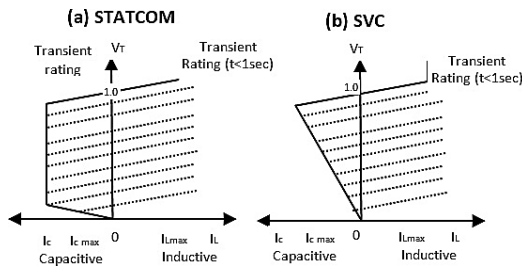


Figure 2. V-I characteristic of the STATCOM and the SVC

Table 2. ABB STATCOM (SVC Light) projects [15]

Project	Rating	Application	Order	Country
Hagfors	0-44 MVar	Flicker mitigation EAF steel plant	1997	Sweden
Moselstahlwerk	0-38 MVar	Flicker mitigation EAF steel plant	1999	Germany
Eagle Pass	36 MW	Asynchronous Tie	1999	USA
Torn Avesta Polarit	0-164 MVar	Flicker mitigation EAF steel plant	2001	Finland
Evron	0-36 MVar	Balancing and active Filtering of railway load	2002	France
Holly	+/-100 MVar	Dynamic stability	2003	USA

III. MAIN CIRCUIT TOPOLOGIES

There are mainly two types of STATCOM main circuit Configurations: multi-pulse converter, multilevel converter [17, 18]. In multi-pulse converter, three-phase bridges are connected in parallel on the DC side, as shown in Figure 3. The bridges are magnetically coupled through a zigzag transformer, and transformer is usually arranged to make bridges appear in series viewed from the AC sides.

Each winding of the transformer is phase-shifted to eliminate selected harmonics and produce a multi-pulse output voltage. Pulse Width Modulation (PWM) can be applied to improve the harmonics content, at the expense of higher switching and snubber loss, and reduced fundamental Var rating. The disadvantages of multi-pulse converter configuration are phase-shift transformer makes the system complex and bulky; there will be a unique transformer design for each STATCOM installation.

Compare to the multi-pulse converter based STATCOM, multilevel converters are more flexible and have a wide application. They can be used as active power filters and to handle unbalanced loads. No phase shift transformer is required in this configuration, so a lower investment cost, plus a lower power loss, can be expected. The multilevel converter configuration can be further classified into three different configurations:

- 1- Diode-clamped converter [19]
- 2- Flying capacitor converter [20]
- 3- Cascade converter

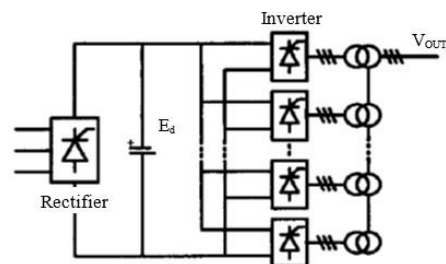


Figure 3. Multi-pulse convener diagram

The Concept of the cascade multilevel converter is put forward by Fang Zheng Peng in 1996 [21], A cascade converter is constructed by standard H-bridges in series. Each H-bridge converter unit provides three voltage levels (-U, 0, and U). A single phase STATCOM based on this configuration is shown in Figure 4. Figure 5 is a typical output waveform of a three level cascade converter.

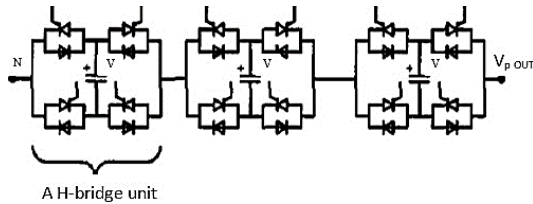


Figure 4. Cascade multilevel converter diagram (single phase)

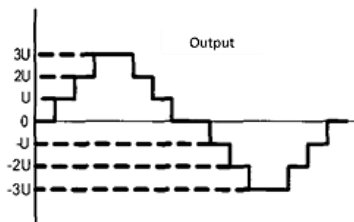


Figure 5. Typical output voltage waveform of a three level cascade converter

Compared with the other two multilevel configurations and the multi-pulse converter, the cascade converter eliminates clamping diodes, flying capacitors, or the bulky zigzag transformer, and so requires least component mounts. In addition, the modularity of this configuration makes it much easier to implement converters with a large number of levels. Larger DC-side capacitors are required compared to diode clamped and flying capacitor converter under balanced condition but it provides separate phase control to support significant voltage unbalance.

IV. OPERATION MONITORING AND FAULT DIAGNOSIS SYSTEM

The Operation Monitoring and Fault Diagnosis System (OMFDS), which has not been paid enough attention to, is a key part of the STATCOM installation. OMFDS provides real-time supervision, fault alarming, post-fault analysis, and user-friendly Human Machine Interface (HMI). As the information center of STATCOM, it collects and store data from all the subsystems and determines whether the STATCOM is in proper operation. The analysis results are provided to users through HMI, and can be also accessed by authorized remote OMFDS through Local Area Network or Internet.

Several articles are published to describe the OMFDS of a ±20 MVar STATCOM developed by Tsinghua University [22, 23]. This OMFDS has some disadvantages listed below:

- 1- The extensibility for signal inputs is restricted by the hardware architecture, so it is hard to adapt it for systems that are more complex.
- 2- Low conversion rate of A/D acquisitions (typically 48 points per cycle) and accuracy.
- 3- Inadequate fault alarming and self-diagnosis functions.

4- Low efficiency of communication between local and remote OMFDS.

A new OMFDS based on optical fiber links and CANBUS has been developed for the ±50 MVar cascade STATCOM developing by Tsinghua University. The OMFDS is built as a multi-level distributed monitoring system. It has three levels, scheduling level, controlling level, and data collecting level, shown in Figure 6 an optical network is constructed for communication between main control station and data collection units via CANBUS. CANBUS protocol supports up to 242 nodes, while 40 nodes are used in this OMFDS. Global Position System (GPS) is applied to provide standard clock of whole system. Remote computers based on Client-Server mode can browse the data and analysis results.

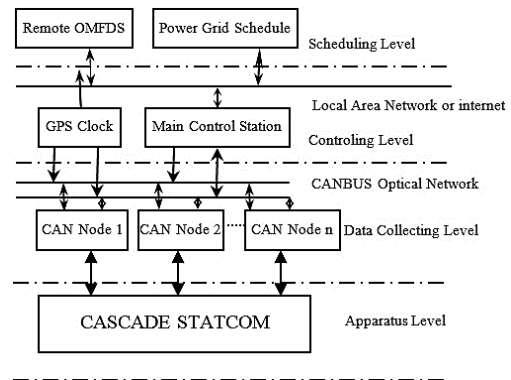


Figure 6. The structure of multilevel distributed monitoring system

V. STATE OF THE ART AND TRENDS

World power industry has had a rapid development in last two decades. Along with the rapid development, there are some problems in power systems, inadequate reliability, high line losses and unsatisfactory power quality. FACTS devices, including STATCOM, are greatly needed to solve these problems. For example in china country in 1990s, annual average addition of installed generation capacity was more than 17GW, and the total Installed capacity doubled every 8 years.

At the end of 2000, the total installed capacity reached 319.3 GW, ranking second place in the world. This number will reach 500 GW-750 GW in year 2010 and 2020 [24]. According to the simulation of China Central Power Grid with completion of Three Gorges Hydropower Station in 2010, about 1 GVar STATCOM need to be installed, and 1.2 GVar for SVC [25].



Figure 7. Overview of a 30 MVar STATCOM

The research of STATCOM in China began in 1994, and a ± 20 MVar STATCOM developed by Tsinghua University with Henan Power Administration, was put into operation in the Henan 220 kV power system in March, 1999 [26]. It is the first high power FACTS devices in operation, and makes China one of the four countries which could develop large capacity STATCOM in the world. It is first high power FACTS devices in operation, and makes China one of the four countries which could develop large capacity STATCOM in the world. It is based on multi-pulse converter configuration and consists of four six-pulse voltage source inverter units rated 5 MVA each, with a total capacity of ± 20 MVar.

Based on gate-turn-off Thyristor (GTO), it could realize continuous power flow control in either capacitive or inductive mode, and the response time for reactive power output is less than 30 ms. Figure 7 is the overview of the STATCOM. A ± 50 MVar cascade IGCT-based STATCOM was installed at Shanghai Huangdu 220 kV Transformer Station in 2005. It is expected to prevent transient voltage instability and reduce under voltage load shedding. Nanjing Automation Research Institute, China Electric Power Research Institute, North China Electric Power University, and Northeast China Institute of Electric Power Engineering were also engaged in device-level research in this area. There are several developing trends of STATCOM.

A. Power Valves

GTO, IGBT, IGCT, IEGT IGCT, IEGT will be employed to replace GTO and IGBT Respectively Injection Enhanced Gate Transistor (IEGT) is a newly developed MOS device, with a smaller gate power and higher turn-on and turn-off capacity compared with GTO. IEGT requires no individual snubber circuits and has FWD integrated in packages. Now the maximum rating of IEGT is 4500 V/1500 A [27].

Table 2. Comparisons between IGCT and GTO (4500 V/3000 A)

Items	GTO	IGCT
On-state voltage (V)	3.2	2.4
Maximum turn-on di/dt (A/ μ s)	500	3000
Typical turn-on loss (J)	5	0.5
Typical turn-off loss (3 kA) (J)	10	10
Snubber capacitor (3 kA) (μ F)	6	0
Maximum turn-off current (kA)	3	3-6
Gate drive power (500 Hz) (W)	80	15
Gate turn-off charge (Q_{gg}) (μ C)	8000	2000
Maximum turn-off dv/dt (V/ μ s)	500	≥ 4000
Storage time (t_s) (μ s)	20	1

The Integrated Gate-Commutated Thyristor (IGCT) combines the excellent forward characteristics of the Thyristor and the switching performance of the bipolar transistor. Snubber circuits are also not required in IGCT operation. Compared with GTO and IGBT, IGCT has better turn-off characteristics, lower conducting and switching loss, and higher reliability of gate drive along with simpler gate control. IGCT can operate at a frequency in the kHz range, giving possibilities to implement advanced algorithms in the control system. The ratings reach 5500 V/1800 A for reverse conducting IGCTs and 4500 V/4000 A for asymmetrical IGCTs [28]. Table 2 is the comparison between IGCT and GTO.

B. Cascade Multilevel Converter

Cascade multilevel converter will be the most popular configuration of STATCOM. The topology of cascade multilevel converter is relatively simple, and the synthesis of converter voltage is ai50 less restricted. The modular structure of the converter provides available redundancy and easy extensibility. The cascade converter is especially attractive for the implementation of FACTS controllers that do not involve the exchange of active power (which is difficult with isolated dc links) such as the STATCOM and Static Synchronous Series Compensator (SSSC).

C. Hybrid STATCOM

Hybrid STATCOM, the combination of STATCOM and other FACTS devices, such as Mechanically-Switched Capacitor (MSC), Thyristor Switched Capacitor (TSC), SSSC, will be widely used. Better performance and lower cost can be expected if STATCOM properly operates together with some other devices. STATCOM could provide the capacitive Var output upon immediate demand while TSCs or MSCs, etc., are responsible for the relatively slow Var compensation.

The H-STATCOM developed by Alstom consists of a +75 MVar STATCOM, a small fixed filter and a 127 MVar TSC, shown in Figure 8. The whole system provides a continuous variable reactive output of 0-225 MVar (capacitive). The specified reactive power output is available at 0.95 per unit system voltage, giving a maximum output current of $225/0.95 = 2.37$ per unit (on 1000 MVA base) [10]. STATCOM, together with SSSC, could also operate as a UPFC, which could maintain line voltage as well as control power flow in power system.

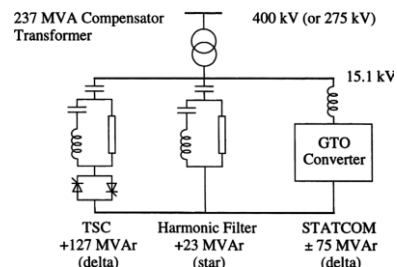


Figure 8. Hybrid STATCOM [10]

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VI. CONCLUSIONS

In recent years, along with the rapid increasing electric power requirement, the reconstruction of Iran's urban and transmission power network is more and more urgent. There will be huge demand for reactive power compensation to improve efficiency and stability of AC transmission systems during transmission upgrade process.

For challenges in feature energy of world with other countries, we need to attempt to improve power system networks. This paper introduces STATCOM technologies, and gives a description of its development in one advanced country same China. As one of the second generation FACTS devices, STATCOM should be given more attention for long-term consideration. A Cascade multilevel STATCOM, based on ETO, is introduced for illustration.

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