A Literature Review on Transformerless H-Bridge Cascaded STATCOM

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Abstract: - Load compensation, voltage balancing and voltage regulation are some of the major problems being faced by electric power utilities across the globe. If not addressed, these issues can cause power losses in lines, mal-operation of critical loads, damage to customer equipment, and potentially power system instability. Dynamic reactive power compensation is typically required to solve the above problems. Static Synchronous Compensator (STATCOM) is a rapidly acting high power electronic dynamic reactive power compensator which is increasingly being employed worldwide for the above purposes.

Keywords: - Active disturbances rejection controller (ADRC), H-bridge cascaded, passivity-based control (PBC), proportional resonant (PR) controller, shifting modulation wave, static synchronous compensator (STATCOM).

1. INTRODUCTION

Since the introduction of electrical energy in the 19th century, there have been significant technological developments and the modern day electric power systems have been built. These systems have grown in complexity and nowadays they are the result of a vast network of transmission interconnections, multiple types of generation resources and loads. Due to these technological advancements and many other scientific achievements, in the last century the quality of life for most people has increased significantly. However, the rapid growth of the population, the development of industry, the increase of generation sources at the load and the networks underlying unpredictability, are starting to strain the power generation systems. This means that the added load demands, growth of interconnections, economic restrictions, and factors such as global warming, that is a leading concern in the scientific field, and is slowly starting to pressure governments to turn to renewable energy systems as a means of replacing old and cheap energy productions methods that produce a significant amount of greenhouse gas, are starting to create balancing issues in the delivery systems.

The proposed STATCOM model may be consider in the design process. Based on its characteristics, the proposed control technique is named power decoupling control. Real and reactive power exchanged between the STATCOM and the power networks can be controlled independently by the proposed control technique, which is practical in both reactive and real power compensation applications. This study, however, mainly focuses on the reactive power compensation.

Static Synchronous Compensator (STATCOM) — is a shunt-connected reactive power compensation device that is capable of generating or absorbing reactive power and the output voltage of the STATCOM can be varied to control the specific parameters of an electric power system.

Static Synchronous Series Compensator (SSSC) — is a static synchronous generator operated as a series compensator whose output voltage is quadrate with the line current for the purpose of increasing or decreasing the overall reactive voltage drop across the line and thereby controlling the transmitted electric power.

Unified Power Flow Controller (UPFC) — is a combination of STATCOM and SSSC, which is coupled via a common dc link, and is controlled to provide concurrent active and reactive power compensation.

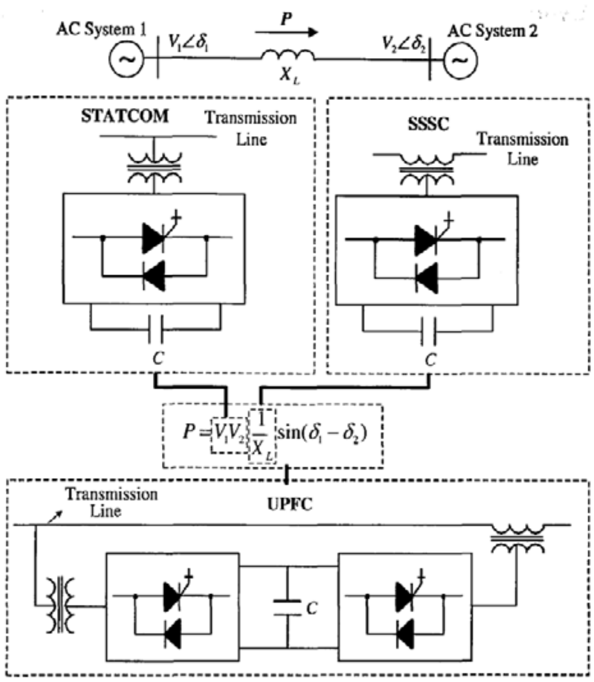

Fig. 1.1 Basic family o f converter-based FACTS controllers.

Among three FACTS controllers, the STATCOM has shown feasibility in term of cost effectiveness and easy shunt connection to the power system [6]. The STATCOM can provide dynamic voltage support, system stabilization, increased system capacity, and enhanced power quality for transmission and distribution system applications. Using a high-speed power semiconductor switching technique, the STACOM can rapidly respond to dynamic system events. Instead of directly deriving reactive power from the energy-storage components, the STATCOM basically circulates power with connected network. The passive components used in the STATCOM, therefore, can be much smaller.

2. SYSTEM MODEL

The single-line diagram of the STATCOM system is shown in Fig. 1.2, where is the voltage of the ac system which the STATCOM is connected to. Is the STATCOM output voltage.

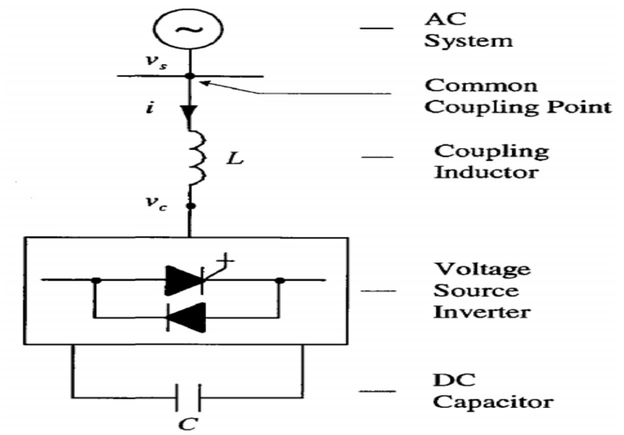

Fig. 1.2 Single-line diagram of the STATCOM system.

The STATCOM is connected to the ac system through the magnetic coupling, represented by L, which could be either an interface inductance or the leakage inductance of a coupling transformer.

The key component of the STATCOM is the voltage source inverter (VSI) that uses either IGBTs or GCTs as switches. C is the energy-storage capacitor providing the dc voltage for the VSI. In principle, the output voltage of VSI is a staircase-type wave synthesized from the dc-side voltage with appropriate switching combinations of inverter switches. The inverter output voltage is in phase with the system voltage and the current *i* leads or lags by 90° when the STATCOM provides the reactive power compensation. The exchange of reactive power between the STATCOM and the ac system can be controlled by varying the amplitude of the inverter output voltage.

Employing turn-off-capability semiconductor switches, switching power converters have been able to operate at high switching frequencies and to provide a faster response. This makes the voltage source inverter an important part in the STATCOM. The simplest voltage source inverter is the two-level inverter that has simple topology and modular structure. However, the two-level inverter produces high harmonic content in the inverter output voltage and high dv/dt due to fast switching. A series connection of switches is needed in high voltage applications and the problem of static/dynamic voltage sharing for series switches would occur. A new family of multilevel inverters has emerged as the solution for VSI working in high-power applications, particularly FACTS controllers.

3. LITERATURE REVIEW

R. Xu et al., [1] This research presents a Transformerless static synchronous compensator (STATCOM) system based on multilevel H-bridge converter with star configuration. This proposed control methods devote themselves not only to the current loop control but also to the dc capacitor voltage control. With regards to the current loop control, a nonlinear controller based on the passivity-based control (PBC) theory is used in this cascaded structure STATCOM for the first time. As to the dc capacitor voltage control, overall voltage control is realized by adopting a proportional resonant controller. Clustered balancing control is obtained by using an active disturbances rejection controller. Individual balancing control is achieved by shifting the modulation wave vertically which can be easily implemented in a field-programmable gate array. Two actual H-bridge cascaded STATCOMs rated at 10 kV 2 MVA are constructed and a series of verification tests are executed. The experimental results prove that H-bridge cascaded STATCOM with the proposed control methods has excellent dynamic performance and strong robustness. The dc capacitor voltage can be maintained at the given value effectively.

B. Gultekin and M. Ermis, [2] This research deals with the design methodology for cascaded multilevel converter (CMC)-based transmission-type STATCOM (T-STATCOM) and the development of a ±12 MVAR, 12 kV line-to-line wye-connected, 11-level CMC. Sizing of the CMC module, the number of H-bridges (HBs) in each phase of the CMC, ac voltage rating of the CMC, the number of paralleled CMC modules in the T-STATCOM system, the optimum value of series filter reactors, and the determination of bus bar in the power grid to which the T-STATCOM system is going to be connected are also discussed in this research in view of the IEEE Std. 519-1992, current status of high voltage (HV) insulated gate bipolar transistor (IGBT) technology, and the required reactive power variation range for the T-STATCOM application. In the field prototype of the CMC module, the ac voltages are approximated to sinusoidal waves by the selective harmonic elimination method (SHEM). The equalization of dc-link capacitor voltages is achieved according to the modified selective swapping (MSS) algorithm. In this study, an L-shaped laminated bus has been designed and the HV IGBT driver circuit has been modified for the optimum switching performance of HV IGBT modules in each HB. The laboratory and field performances of the

CMC module and of the resulting T-STATCOM system are found to be satisfactory and quite consistent with the design objectives.

B. Gultekin et al., [3] In this research work, the design and implementation of a 154-kV ± 50-Mvar transmission static synchronous compensator (T-STATCOM) have been carried out primarily for the purposes of reactive power compensation and terminal voltage regulation and secondarily for power system stability. The implemented T-STATCOM consists of five 10.5-kV ±12-Mvar cascaded multilevel converter (CMC) modules operating in parallel. The power stage of each CMC is composed of five series-connected H-bridges (HBs) in each phase, thus resulting in 21-level line-to-line voltages. Due to modularity and flexibility of implemented HBs, each CMC module has reached a power density of 250 kvar/m3, thus making the mobility of the system implementable. DC-link capacitor voltages of HBs are perfectly balanced by means of the modified selective swapping algorithm proposed. The field tests carried out at full load in the 154-kV transformer substation where T-STATCOM is installed have shown that the steady-state and transient responses of the system are quite satisfactory.

Table 1: Summary of Literature Review

SR. NO.	TITLE	AUTHORS	YEAR	METHODOLOGY
1	A Novel Control Method for Transformerless H-Bridge Cascaded STATCOM With Star Configuration	R. Xu et al.	March 2015	This research presents a Transformerless static synchronous compensator (STATCOM) system based on multilevel H-bridge converter with star configuration.
2	Cascaded Multilevel Converter-Based Transmission STATCOM: System Design Methodology and Development of a 12 kV ±12 MVAr Power Stage	B. Gultekin and M. Ermis	Nov. 2013	This research deals with the design methodology for cascaded multilevel converter (CMC)-based transmission-type STATCOM (T-STATCOM) and the development of a ±12 MVAR, 12 kV line-to-lines wye-connected, 11-level CMC.
3	Design and Implementation of a 154-kV \pm 50-Mvar Transmission STATCOM Based on 21-Level Cascaded Multilevel Converter	B. Gultekin et al.	May-June 2012	In this research work, the design and implementation of a 154-kV ± 50-Mvar transmission static synchronous compensator (T-STATCOM)
4	Recent Advances and Industrial Applications of Multilevel Converters	S. Kouro et al.	Aug. 2010	This research presents an overview of well-established multilevel converters strongly oriented to their current state in industrial applications to then centre the discussion on the new converters that have made their way into the industry.
5	A multilevel voltage-source inverter with separate DC sources for static VAr generation	Fang Zheng Peng, Jih-Sheng Lai, J. W. McKeever and J. VanCoevering	Sep/Oct 1996	A new multilevel voltage-source inverter with separate DC sources is proposed for high-voltage

S. Kouro et al., [4] Multilevel converters have been under research and development for more than three decades and have found successful industrial application. However, this is still a technology under development, and many new contributions and new commercial topologies have been reported in the last few years. The aim of this research is to group and review these recent contributions, in order to establish the current state of the art and trends of the technology, to provide readers with a comprehensive and insightful review of where multilevel converter technology stands and is heading. This research first presents a brief overview of well-established multilevel converters strongly oriented to their current state in industrial applications to then centre the discussion on the new converters that have made their way into the industry. In addition, new promising topologies are discussed. Recent advances made in modulation and control of multilevel converters is also addressed. A great part of this research is devoted to show non-traditional applications powered by multilevel converters and how multilevel converters are becoming an enabling technology in many industrial sectors. Finally, some future trends and challenges in the further development of this technology are discussed to motivate future contributions that address open problems and explore new possibilities.

Fang Zheng Peng, Jih-Sheng Lai, J. W. McKeever and J. VanCoevering, [5] A new multilevel voltage-source inverter with separate DC sources is proposed for high-voltage, high-power applications, such as flexible AC transmission systems (FACTS) including static VAr generation (SVG), power-line conditioning, series compensation, phase shifting, voltage balancing, fuel cell, and photovoltaic utility systems interfacing, etc. The new M-level inverter consists of (M-1)/2 single-phase full bridges in which each bridge has its own separate DC source. This inverter can generate almost sinusoidal waveform voltage with only one time switching per cycle as the number of levels increases. It can solve the size-and-weight problems of conventional transformer-based multipulse inverters and the component-counts problems of multilevel diode-clamp and flying-capacitor inverters. To demonstrate the superiority of the new inverter, an SVG system using the new inverter topology is discussed through analysis, simulation, and experiment.

4. PROBLEM IDENTIFICATION

The fundamentals of STATCOM based on multilevel H-bridge converter with star configuration. And then, the actual H-bridge cascaded STATCOM rated at 10 kV 2 MVA is constructed in previous research work. A PBC theory-based nonlinear controller is first used in STATCOM with this cascaded structure for the current loop control, and the viability is verified by the experimental results and the PR controller has been designed for overall voltage control and the experimental result proves that it has limited performance in terms of response time and damping profile compared with the PI controller. The experimental results may further improved and will confirm the feasibility and effectiveness. In addition, the findings of this study can be extended to the control of any multilevel voltage source converter.

5. CONCLUSION

The demands of electric power have been heavily increasing and the overall security and reliability of the electrical transmission network has become a world concern. In order to supply increased loads, improve reliability, and deliver energy at the lowest possible cost and with improved power quality, it has been widely recognized within the electric power industry that Flexible AC Transmission System. This review research presents a description and literature review of each of the above problems and the different methods, including STATCOM, which can be used in power industry to solve these issues. While STATCOM controllers have been developed for addressing either one or two of the above problems, the motivation for developing a new STATCOM controller for comprehensively addressing all the three problems, is presented.

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