A Survey on DC Bus Voltage Balancing Technique for the Cascaded H-Bridge STATCOM

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Abstract - In recent years, electric power systems are growing very rapidly. The most critical features of expanding power system are its resilience and efficiency. A resilient and efficient power system is one which remains in its state of equilibrium even after being subjected to disturbance. Occurrence of faults in a power system is unavoidable and it is cascading in nature which in worst case may lead to a complete shut down or blackout if not mitigated in time. Occurrence of a blackout has prompted the scientists to find new and efficient ways to stop or at least contain fault within short period of time before any major damage takes place. For this purpose, flexible AC transmission system (FACTS) devices have come into existence. One such device is STATCOM. STATCOM or static synchronous compensator is composed of an inverter and a DC voltage source. This brief presents an extensive survey on Cascaded H-Bridge STATCOM utilizing DC Bus Voltage Balancing Technique to Improve reliability under Grid Faults.

Index Terms- STATCOM, Cascaded H-Bridge STATCOM, DC Bus Voltage Balancing, Grid Faults, System Reliability, , Modular multilevel cascaded converter (MMCC), Low-Voltage Ride-Through(LVRT)

I. INTRODUCTION

Interconnected transmission systems are complex and require careful planning, design and operation. The continuous growth of the electrical power system, as well as the increasing electric power demand, has put a lot of emphasis on system operation and control. These topics are becoming more and more of interest, in particular due to the recent trend towards restructuring and deregulating of the power supplies. It is under this scenario that the use of High Voltage Direct Current (HVDC) and Flexible AC Transmission Systems (FACTS) controllers represents important opportunities and challenges for optimum utilization of existing facilities and to prevent outages.

STATCOM is also prone to faults which if not detected quickly, can cause distortion in its output which in turn affects its line compensation capabilities. If the fault is severe enough then it can disrupt its working completely. So, an effective fault detection and mitigation strategy is need for uninterruptable operation of STATCOM and efficient line compensation.

a. Low-voltage ride through

Voltage instability in a power system occurs due to lack of adequate reactive power during grid fault [7]. Injecting enough reactive power to the grid can enhance low voltage ride through (LVRT) capability of a wind farm and guarantees an uninterrupted operation of its units. LVRT is part of the grid code which states that wind turbines are required to remain connected to the grid for a specific amount of time otherwise they can be disconnected. This specific amount of time can be different from one grid code to another; also the severity of the fault might be different as well. Injecting reactive power for ensuring LVRT can be performed using var compensator devices such as STATCOM or capacitor banks.

b. Synchronous var compensation

STATCOM is a type of Flexible AC Transmission Systems (FACTS) device. FACTS are power- electronic based systems which improve controllability and increase power flow capability of a power system. In the same way, static synchronous compensator (STATCOM) is a power electronic-based synchronous var compensator that generates a three-phase reactive power in synchronism with the transmission line voltage and is connected to it by a coupling transformer [8]. STATCOM typically consist of a three-phase inverter using Gate Turn-off Thyristors (GTOs) or Insulated Gate Bipolar Transistors (IGBTs). The gates of this inverter are typically controlled using Pulse-Width Modulation (PWM) technique. STATCOM acts as a sink of reactive power (inductor) or a source of reactive power (capacitor). By varying the amplitude of the converter voltage with respect to the system bus voltage, STATCOM can continuously exchange power through the flow of a controlled current. The power exchange between STATCOM and rest of the system is purely reactive although an insignificant amount of active power is supplied by the grid to compensate for converter losses. This reactive power support enables the STATCOM improve the voltage profile of the system and reduce voltage fluctuation in event of grid disturbances. When STATCOM is utilized at distribution level for voltage regulation, it is called DSTATCOM. DSTATCOM and STATCOM follow the same operating principles. So throughout of this investigation, the terms STATCOM and DSTATCOM is used interchangeably.

II. STATIC SYNCHRONOUS COMPENSATOR (STATCOM)

STATCOM is a switching converter type VAR generator which is composed of a voltage source converter (VSC) or current source converter along with a dc source. This converter generates reactive power without using any reactive power storage components like capacitor or inductor. It generates or absorbs reactive power proportional to the difference in the voltage between the AC bus and the converter output terminal. STATCOMs are connected in shunt with the line via a coupling transformer.

For the purpose of providing reactive power compensation these SSGs are operated without an energy source and appropriate controlling similar to shunt connected condensers and they are hence called Static Synchronous condensers (STATCON) or Static Synchronous Compensators (STATCOM).

A STATCOM consists of a DC-AC switching converter which is connected to a DC source at one terminal and to an AC system bus at other end through a coupling transformer and a very small tie reactance (>1.5p.u.). Practically this reactance is provided by the per phase leakage inductance of the coupling transformer connected between system bus and converter. The DC-AC switching converters can be both voltage source and current source. The current source converters are almost immune to terminal short-circuit as they have innate output current control provided by the DC current source but the voltage source converter is preferred over the current source converters due to the following reasons: (1) the power semi-conductor devices used for current source converters are needed to have bi-directional current blocking capability. But the high power semi-conductor devices available now-a-days like, IGBT, GTO etc., which have gate turn-off capability, cannot block reverse voltage and if they do then they do it by causing a deleterious effect on many important parameters, (2) current source termination is done by using a current charged reactor. This type termination is practically lossier as compared to voltage source termination by voltage charged capacitor, (3) the current source converters need a voltage source termination at the AC terminal which is usually a capacitive filter, but the voltage.

source converters need a current source termination at the AC terminals which is provided leakage inductance of the coupling transformer, (4) the voltage source termination being a large DC capacitor provides protection to power semi-conductor devices against line over-voltages or transients naturally. But in case of current source converters an additional over-voltage protection arrangement or power semi- conductor devices with higher voltage rating is needed.

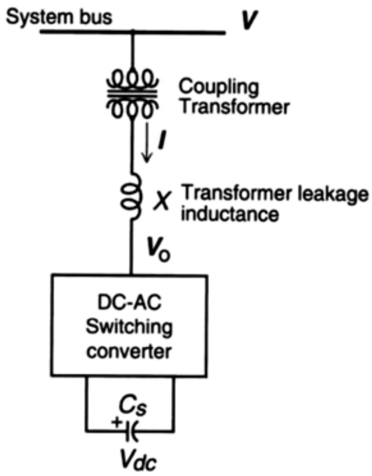
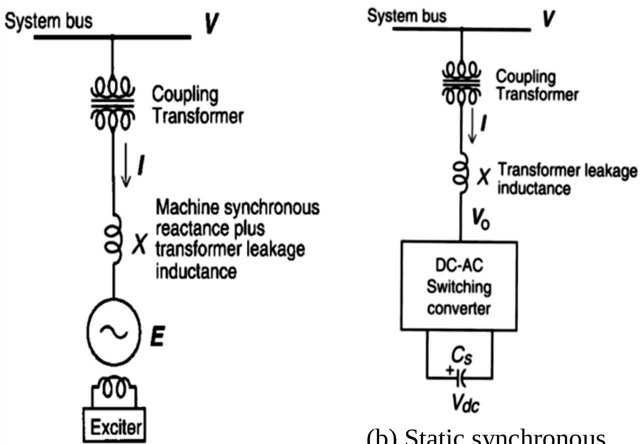


Figure 2.1 STATCOM Connected to system.

The STATCOM generally generates or absorbs only reactive power from the system bus. But if DC power storage devices like a battery, fuel cell, super conducting magnetic storage etc., are used at DC input terminal then real power exchange can be done using STATCOM.

The STATCOM is connected in shunt with the system bus. The basic operation of a static synchronous compensator is analogous to the rotating synchronous machine. In synchronously rotating machine exciter can be operated in overexcited as well as under excited mode to behave like capacitor and inductor and generate and absorb reactive power. The machine operates in overexcited mode by increasing machine's output voltage E above system voltage V and starts behaving like a capacitor and generates leading current at its output terminal.



(a) Synchronously rotating compensator

(b) Static synchronous compensator

Figure 1.2 Operation of a STATCOM

III. RELATED WORK

SR. NO.	TITLE	AUTHORS	YEAR	APPROACH
1	A DC Bus Voltage Balancing Technique for the Cascaded H-Bridge STATCOM With Improved Reliability Under Grid Faults	H. C. Chen and P. T. Cheng,	2017	The voltage balancing strategy to manage the peak current or the modulation index.
2	Modified DC-Bus Voltage Balancing Algorithm for a Three-Level Neutral-Point-Clamped PMSM Inverter Drive With Reduced Common-Mode Voltage	A. Choudhury, P. Pillay and S. S. Williamson,	2016	An improved dc-link voltage balancing algorithm for a three-level neutral-point-clamped inverter by considering phase current direction
3	DC capacitor voltage balancing control for delta-connected cascaded h-bridge STATCOM considering the unbalanced grid and load conditions,	J. J. Jung, J. H. Lee, S. K. Sul, G. T. Son and Y. H. Chung,	2016	A comprehensive control scheme for a delta-connected cascaded h-bridge (CHB) converter based static synchronous compensator(STATCOM)
4	Review of current control techniques for a cascaded H-Bridge STATCOM,	J. Muñoz, J. Rohten, J. Espinoza, P. Melín, C. Baier and M. Rivera,	2015	A comprehensive review of current control techniques suitable for a Cascade H-Bridge STATCOM
5	Reduced common mode voltage based DC-bus voltage balancing algorithm for three-level neutral point clamped (NPC) inverter drive,	A. Choudhury and P. Pillay,	2015	A reduced common mode voltage (CMV) based DC-link voltage balancing strategy for a neutral point clamped (NPC) three-level inverter
6	Impact of Practical Issues on the Harmonic Performance of Phase-Shifted Modulation Strategies for a Cascaded H-Bridge StatCom	C. D. Townsend, T. J. Summers and R. E. Betz	2014	Investigates subtle practical implementation issues which deteriorate the harmonic performance of this technique.
7	Reduced switching loss based DC-bus voltage balancing algorithm for three-level neutral point clamped (NPC) inverter for electric vehicle applications	A. Choudhury, P. Pillay, M. Amar and S. S. Williamson,	2014	A performance comparison study for two reported DC-bus voltage balancing algorithms is carried out,

H. C. Chen and P. T. Cheng, [1] as more distributed renewable energy sources are installed in the utility grid, the static synchronous compensators are applied to manage the power factor and the grid voltage in the medium-voltage level of the power system. The cascaded multilevel converter with single-star topology is well applied to this application. The dc-capacitor voltage balancing control is a fundamental issue, and it can be accomplished by negative-sequence current and/or zero sequence voltage injection. Unfortunately, the zero sequence voltage injection increases the risk of over-modulation and the negative-sequence current injection results in high peak current. This research work provides the voltage balancing strategy to manage the peak current or the modulation index. Besides, all the asymmetrical grid voltages are considered in the reported method to satisfy the grid fault operation. Laboratory test results verify that the reported method limits the peak current or manages the modulation index during the grid fault operation

A. Choudhury, P. Pillay and S. S. Williamson, [2] this research work presents an improved dc-link voltage balancing algorithm for a three-level neutral-point-clamped inverter by considering phase current direction. Detailed studies on the effects of change in load current direction on the dc-link capacitor voltages are presented. A maximum value of power factor is numerically derived, above which it affects the capacitor voltage balancing capability. Compared with the previously presented research work, the inputs to the space-vector pulsewidth-modulation block are the three phase currents and the difference between the two capacitor voltages. Depending on the states of the two dc-link capacitor voltages and phase current direction, redundant voltage vector sequences are selected. The selected vectors keep the capacitor voltage deviations within 5% of the total dc-link voltage. Two zero switching vectors (i.e., PPP and NNN) are also removed from all subsectors of the earlier reported strategy, which one used to produce higher common-mode voltages. Detailed simulation and experimental results are presented in this research work for a 6.0-kW surface permanent-magnet synchronous machine. Both the simulation and experimental results show the required performance of the reported system.

J. J. Jung, J. H. Lee, S. K. Sul, G. T. Son and Y. H. Chung, [3] In this research work, a comprehensive control scheme for a delta-connected cascaded h-bridge (CHB) converter based static synchronous compensator(STATCOM) is presented, especially focusing on improving dynamic performance by novel feedforward control method. The method can conspicuously improve the dynamics of circulating current regulation of delta connected CHB STATCOM especially under grid fault condition as well as load unbalance without excessive DC cell capacitor voltage fluctuation. The full scaled simulation results and the down scaled experimental results verify that stable operation is guaranteed for both emulated grid and load unbalance conditions.

J. Muñoz, J. Rohten, J. Espinoza, P. Melín, C. Baier and M. Rivera, [4] this research work presents a comprehensive review of current control techniques suitable for a Cascade H-Bridge STATCOM. Particularly, four different approaches are evaluated in this work: a linear strategy using Proportional Integral controllers in the dq frame, an exact input/output linearization technique with Proportional-Resonant controllers, a multiband hysteresis modulation control, and a predictive control scheme. The main advantages and drawbacks of each scheme are depicted in terms of stationary and dynamic performance, as well as harmonic content, complexity, and computational burden. The presented results are supported with simulated waveforms that highlight the main features of each control method.

A. Choudhury and P. Pillay [5] a reduced common mode voltage (CMV) based DC-link voltage balancing strategy is reported for a neutral point clamped (NPC) three-level inverter with permanent magnet synchronous machine. Compared to the earlier reported strategy, it completely eliminates the Vdc/2 corresponding CMV by eliminating the two zero voltage vectors (PPP, NNN) from the space vector switching sequences. Hence, it uses only one zero voltage (OOO) vector with the other redundant voltage vectors to produce the reference vector in inner subsectors. Detailed simulation and experimental studies are also carried out to show the effectiveness of the reported system with DC-link voltage balancing ability. Harmonic distortions are also compared with the previously reported scheme. Dspace® based real time operating system is used for real time implementation with 6.0 kW surface PMSM.

C. D. Townsend, T. J. Summers and R. E. Betz, [6] Phase-shifted carrier (PSC) modulation has become an industry standard in its application to multilevel H-bridge static compensators (H-StatComs). The technique uses the cancellation of harmonics within each phase leg to significantly improve the harmonic performance relative to the switching frequency. This research work investigates subtle practical implementation issues which deteriorate the harmonic performance of this technique. The effects of nonuniform dc bus voltages and capacitor voltage balancing strategies are investigated. Simulation and experimental results are presented which show that the harmonic performance of the PSC technique deteriorates as the number of voltage levels produced by the H-StatCom increases.

A. Choudhury, P. Pillay, M. Amar and S. S. Williamson, [7] A performance comparison study for two reported DC-bus voltage balancing algorithms is carried out, with a three-level NPC based permanent magnet synchronous machine (PMSM) drive for the electric vehicle propulsion application. Both the control algorithms are able to keep the two DC-link capacitor voltage variation within a tolerance level with wider range of speed and torque variation of the load drive cycle. However, with the second reported control strategy inverter total switching losses can be reduced considerably, compared to the first reported strategy. Both the losses are then compared with a conventional two-level inverter, with a wider variation in switching frequency. Results show a significant reduction in total inverter losses at higher switching frequencies with three-level inverter. Both the two- and three-level inverter control strategies are developed using space-vector pulse width modulation (SV-PWM) scheme. The switching and conduction loss distribution in different switches and diodes for both the two- and three-level inverters are also studied. Finally the total voltage harmonic distortion (%THDv), percentage torque ripple (%Trip), and capacitor voltage fluctuation (%Vcaprip) are also compared. Switching losses are calculated in a PLECS environment using data sheet parameters from Infineon and control logics are developed in MATLAB/Simulink. For this study a 110 kW surface-PMSM is considered. A scaled down prototype is built in laboratory for both the inverters and tested with a 6.0 kW surface-PMSM. Both the simulation and experimental results show satisfactory performance of the reported system.

IV. PROBLEM STATEMENT

More Distributed renewable energy sources installed to the utility grid are applied to mitigate the greenhouse gasses. However, such renewable energy sources lead to grid voltage distortion and unstable system. Therefore, static synchronous compensator (STATCOM) is widely applied to manage the power flow and regulate the grid voltage [1]. The STATCOM provides the reactive power to support the grid during fault conditions, which is commonly known as the LVRT capability. Therefore, the MMCC-SSBC needs to operate under unbalanced grid voltages. Voltage balancing control strategies to manage the converter output peak current or the maximum modulation index by the specific ZSV and NSC injection is still a big deal. The need for electrical power is increasing continuously due to which the need of a power system has occurred which can fulfill consumer's load requirements. Ideally the power system must opeate in such a way that its voltage, frequency, active and reactive power are maintained within desirable limits. If these line parameters deviate from their nominal values then this can cause system instability and power interruption.

V. CONCLUSION

This brief has dealt with the control and modulation of Cascaded H-Bridge (CHB) converters for STATCOM applications. With focus on DC Bus Voltage Balancing, the system performance under balanced and unbalanced operation have been investigated, for improved reliability under grid faults trying to highlight the advantages but also the challenges and possible pitfalls that this kind of topology presents for STATCOM applications. The concept of multilevel converters was first introduced in 1975. Multilevel converters are power conversion systems composed by an array of power semiconductors and several DC voltage sources. Depending on the selected topology, the number of levels of a multilevel converter can be de- fined as the number of constant voltage values that can be generated by the converter between the output terminal and a reference node within the converter

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