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Increasing System Dependability in CMI-Based STATCOM with Loop-Gain Shaped Control via Per Phase DC Bus Voltage Balancing

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ABSTRACT

In this study, a nine-level cascade multilevel inverter (CMI) employing multicarrier pulse width modulation (PWM) methods is investigated in detail to achieve higher voltage levels. The results of the simulation verify the core operational concept of the CMI. Various modulation techniques are used to compare the phase and line voltage total harmonic distortion (THD) performance. With a focus on its application in STATCOM (Static Synchronous Compensator) systems, the paper explores the notable applications of CMI. Specifically, a communication system with a multilayer H-bridge converter arranged in a star configuration is examined. Also discussed is a generalized per-phase DC-bus voltage balancing technique based on capacitor voltage balancing (CVC) for CMC-based STATCOMs. In order to provide light on the underlying workings of the system and improve performance, the research first applies the dq/abc park transformation before doing an open-loop transfer function analysis. This research contributes to the advancement of multilevel inverter technology by shedding light on operational principles and optimization strategies, particularly as they relate to STATCOM applications.

Keywords: *CMI, Statcom, Facts Devices, DC Voltage.*

1.0 Introduction

For many years now, reactive power compensation has already been widely used as a reliable and efficient method of controlling electric power grids. Fast speed, a small footprint, and low harmonics are just a few of the benefits of the STATiC synchronous Compensator (STATCOM), a novel reactive power compensator based on power electronics converter technology [1]. To this day, H-bridge cascaded STATCOM still faces two technological hurdles. To begin, the compensation performance is significantly impacted by the present loop control strategy. However, the compensatory effect is diminished due to various less-than-ideal aspects. These comprise the bandwidth limitation of the output control loop, the latency of the signal identification circuit, and the process by which the reference command current is generated [2]. Second, because H-bridge cascaded STATCOM is a complex system with multiple H-bridge cells in each phase, the dc capacitor voltage discrepancy issue—which is caused by different power losses among cells, switched patterns in different cells, and parametric uncertainties of active and passive elements inside cells—will disrupt the system's dependability and possibly even cause it to fail. As a result, several studies have sought to address these issues [3]

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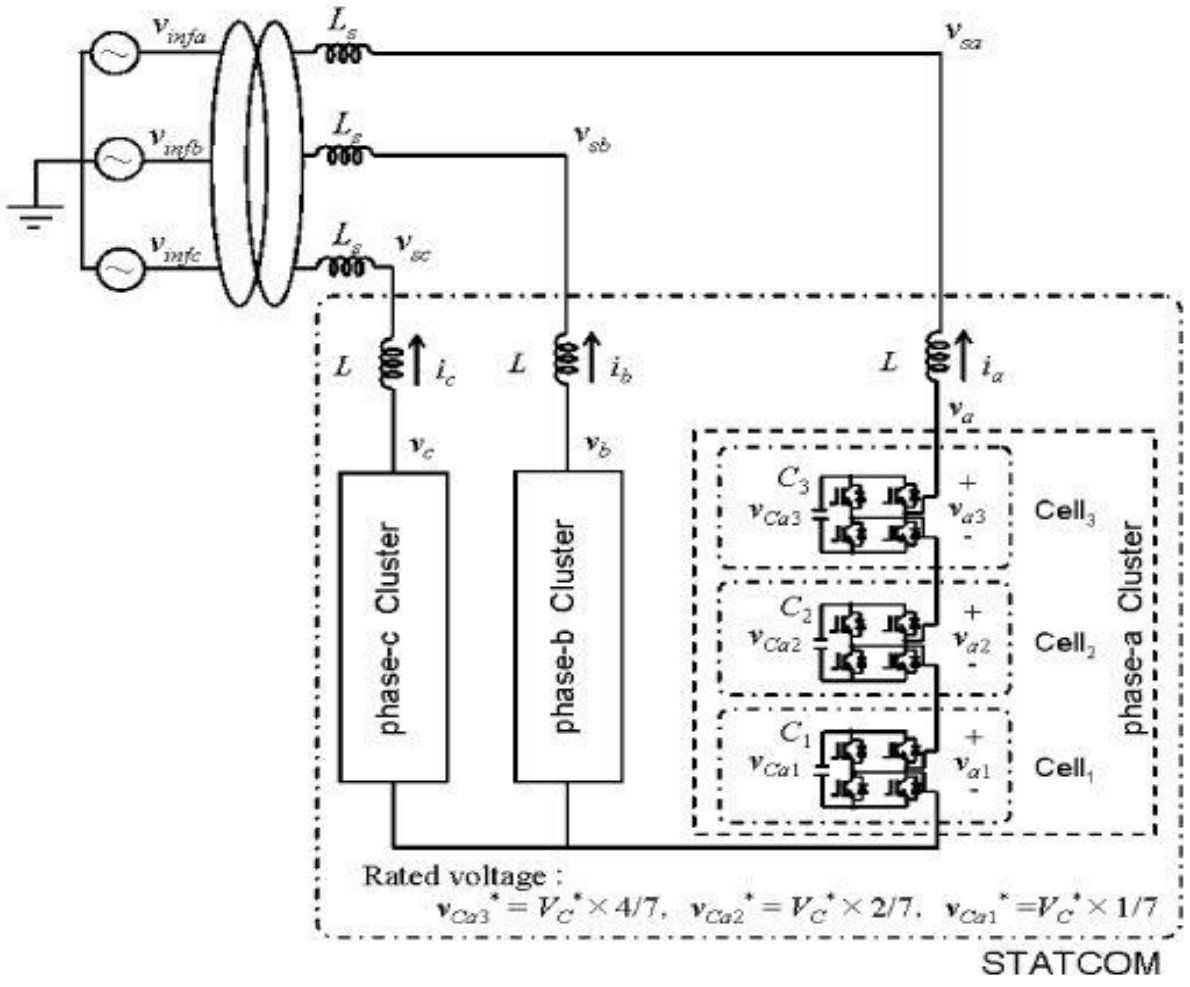
The general method to per-phase DC-bus voltage balancing using the CMC STATCOM is presented in this article. First, we analyze a control mechanism currently used by an extended STATCOM model. A per-phase DC-bus voltage balancing system is built [4] using the loop-gain shaping and the dq/abc park transformation as its foundation. Adding the suggested control to the DSP controller is straightforward and requires essentially no more computational resources. In general, series FACT controller and shunt FACT controller are the two types of FACT controllers available [5]. Through compensating for transient drops and spikes, series controllers enhance power system reliability. When it comes to transmission and distribution, shunt FACT controllers are often used because of their quick reaction time and low overall cost. The ability to regulate power from a few kilovolts to many megavolts makes multilevel inverters a powerful tool for STATCOM applications in transmission systems [6]. Cascade multilevel inverters (CMI) are becoming more popular due to their many advantages over other types of multilevel inverters. These include neutral point clamped multilevel inverters, flying capacitor multilevel inverters, and CMIs.

Compared to other multilevel inverter topologies, including flying capacitor and diode clamped multilevel inverter, its modular construction, capacity to attain at greater output voltage and power level, and fewer necessity of components set it apart [7].

Figure 1: Schematic of a CMI-based STATCOM



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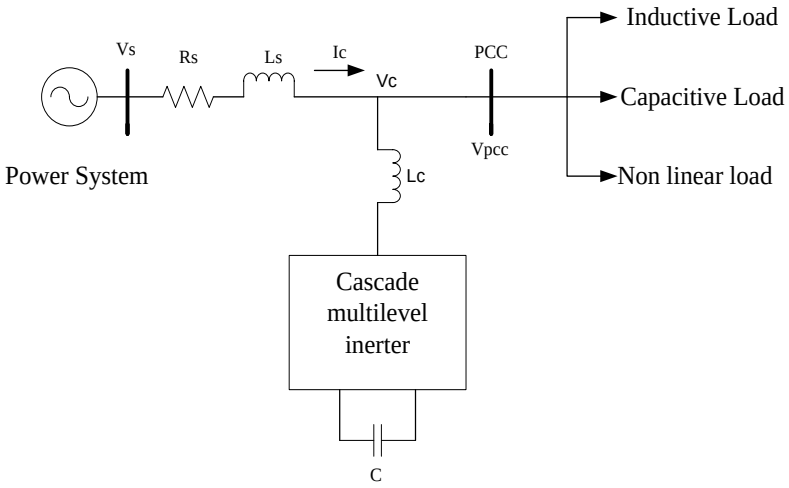
2.0 Configuration of CMI based statcom

It is possible to directly manage the current flowing via STATCOM in order to either absorb or deliver the required reactive current in order to achieve the objective of dynamic reactive current compensation [8]. Because of improvements made to the power quality of the grid, only active current is supplied by the grid.

2.1 Mathematical modling

Determining the steady-state and dynamic modelling equations is a crucial step in developing an acceptable control strategy for CMI-based STATCOM. In order to assess the system as a whole, mathematical modelling is required [9]. By simulating a power converter coupled to the transmission and distribution network through reactance, CMI-based STATCOM may be analysed. The circuit's settings are shown in Table I below. Each phase of this cascade multilevel inverter's three-phase, nine-level output voltage is generated by a series-connected H bridge string. The dc side just uses the dc capacitors and a voltage sensor for power and has no external connection. The STATCOM ac pulse width modulation (PWM) voltage has a higher frequency than the grid's sinusoidal voltage, thus an ac inductor is used in each cluster to smooth down the voltage [9]. As an additional benefit, the ac inductor helps eliminate PWM-induced ripples at the switch. Taking into account the intricacies of real-world industrial fields, spiking current and over loading might be issues when choosing an IGBT [10].

Figure 2: CMI based STATCOM – Single Line Diagram



Several assumptions of the CMI-based structure, including the system's modularity, the identical voltage level of each capacitor, and the same value of the DC link capacitor, are used in conjunction with Kirchhoff's law to establish the dynamic model of the system [11].

This is the equivalent circuit as the one in Figure 8.

$$L\frac{dI_S}{dt} + R.I_S = V_S - V_C \qquad \ldots 1$$

Because of the disparity between the network voltage and the STATCOM voltage, the coupling settings allow STATCOM to generate its own current, as shown below.

$$L\frac{d}{dt}\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} + R\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} - \begin{bmatrix} V_{ca} \\ V_{cb} \\ V_{cc} \end{bmatrix} \quad \ldots 2$$

Three-phase source voltages are denoted by Vsa, Vsb, and Vsc, whereas STATCOM voltages are denoted by Vca, Vcb, and Vcc.

2.2 DC bus voltage balancing

A cascading multilayer inverter is constructed up of H bridges that are connected in series with various DC capacitors. These bridges make up the inverter's fundamental building elements. Unbalanced DC voltage is a problem, and it's caused by differences in the parallel loss that are associated with each H bridge of the CMI. Unbalanced DC voltage has a number of unfavorable effects on the scheme, along with an increment in the harmonic currents of the current and a decline in the reliability of the synthetic output waveform from the converter [12]. Both of these effects are caused by the system's inability to properly balance the DC voltage. When the number of levels in a CMI increases, the regulation of the DC voltage that exists between those levels becomes a more important financial and logistical consideration [13].

Table 1: The Experimental Dystem's Circuit Parameters

Grid voltage	11 kV
Rated reactive	120 Kvar
AC inductor	10 mH
DC capacitor	4.68 mF
Number of Cells/Phase	4
PWM carrier frequency	1 kHz
Reactive Current	9 Amp

3.0 Control Architecture

There are only two degrees of freedom in the primary control loop, which are denoted by the symbols Idref and Iqref in Figure 2. These symbols are used to regulate the active current and the reactive current, respectively. Because Iqref is utilised for the creation of reactive power, the Idref can only be used to manage the approximate value of each DC bus's voltage [14]. The voltage loop and the Idref channel are responsible for ensuring that the overall DC bus voltage is balanced. However, the DC bus voltages of each phase are not regulated. When the STATCOM has no power losses, no active power is exchanged between the STATCOM and the AC system, and only reactive power is provided by STATCOM. This only occurs if the parameters and trigger signal of each H Bridge are identical [15].

Synchronization circuits that use a phase locked loop determine both the phase difference and the reference frequency [16]. Voltage and current measurements must be taken at the point of connection in order to perform the transformation from abc to dq in a vector. Two separate controllers, one for each DC bus, make up the DC regulator. DC link voltage within each phase and between phases must be balanced by these controllers.

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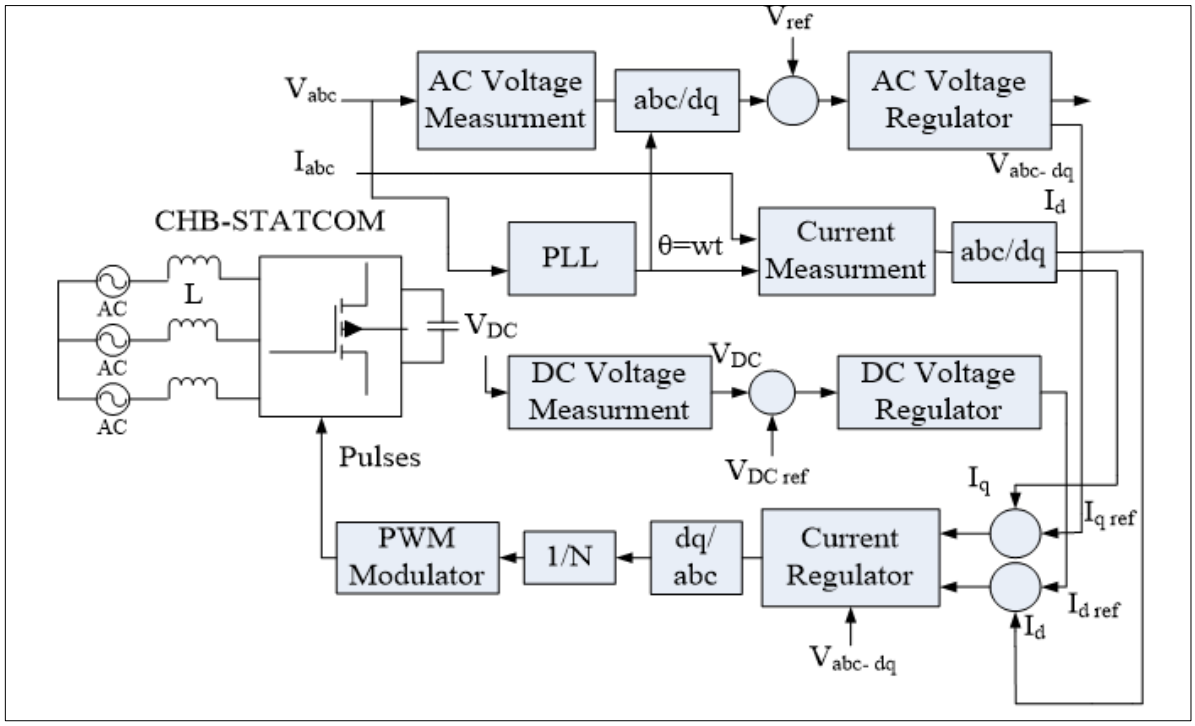
As shown in Figure 2, the dc voltage regulator, ac voltage regulator, and PWM modulator will work together to provide a tunable switching command that will be sent to the CMI STATCOM. Using modulation schemes, such as Phase-shifted pulse width modulation (PWM), simplifies the operation of the control system. Reason being, when more cascade bridge cells are added to a cluster, the control system becomes more complicated [17].

Figure 3: CMI-based STATCOM Controller



4.0 Simulation Results

The simulation results have been used to demonstrate the system's superiority by demonstrating its well specified dynamic performance, which includes meeting power requirement at the load side. Using a nine-level cascade multilevel inverter, which can provide an approximation of sinusoidal voltage in the form of a stepped 17-level output line voltage waveform, research has been conducted on a STATCOM. The control approach for a nine-level CMI is implemented in a simulation in this chapter, and the results are presented.

The STATCOM mathematical model lists the simulation parameters in table 1. The voltage and current waveforms in both the capacitive mode (a) and the inductive mode (b) at the point of common coupling are displayed in Figure 4, with a step shift occurring at 0.15 seconds. Maintaining the coupling parameter between the grid and STATCOM at its optimal level with a step change at 0.15 seconds, as seen in Figure 5, will result in the grid and STATCOM voltage at the same magnitude. With a step change at 0.15 seconds, Figure 6 shows the dynamic performance of the CMI-based STATCOM by measuring the difference between the reactive current supplied by STATCOM (Iq) and the reactive current reference (Iq*). The STATCOM supplied reactive current viewed some oscillations or spikes when the loads are changed from one mode to another mode. In contrast, STATCOM is accessible to absorb reactive current from power system to operate in inductive mode while it delivers reactive current to the power system in capacitive mode.

Figure 4: Waveform of Voltage and Current at the PCC in Capacitive Mode (a) and Inductive Mode (b)

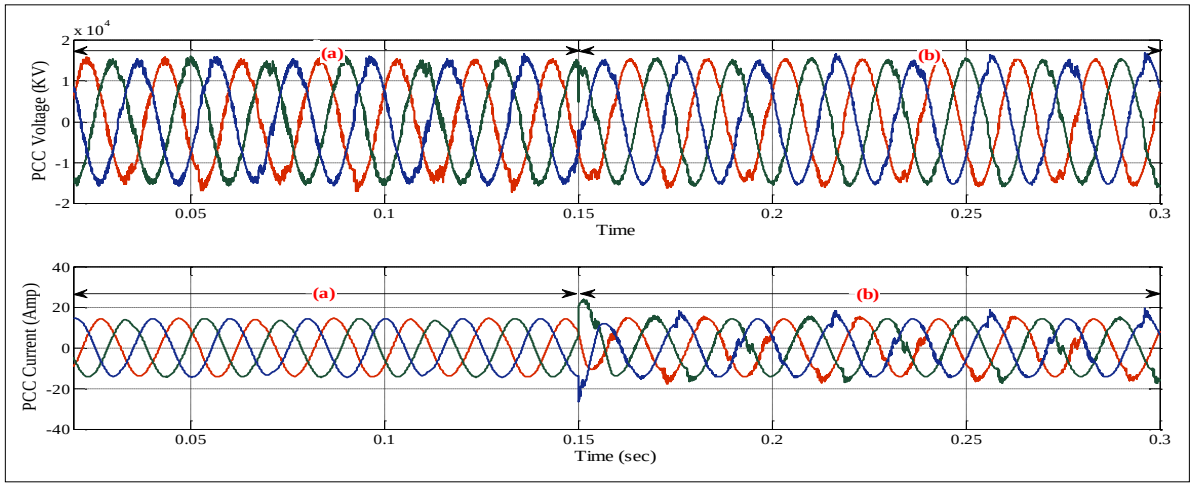


Figure 5: Grid (Vg) and STATCOM Voltage (VSTATCOM)

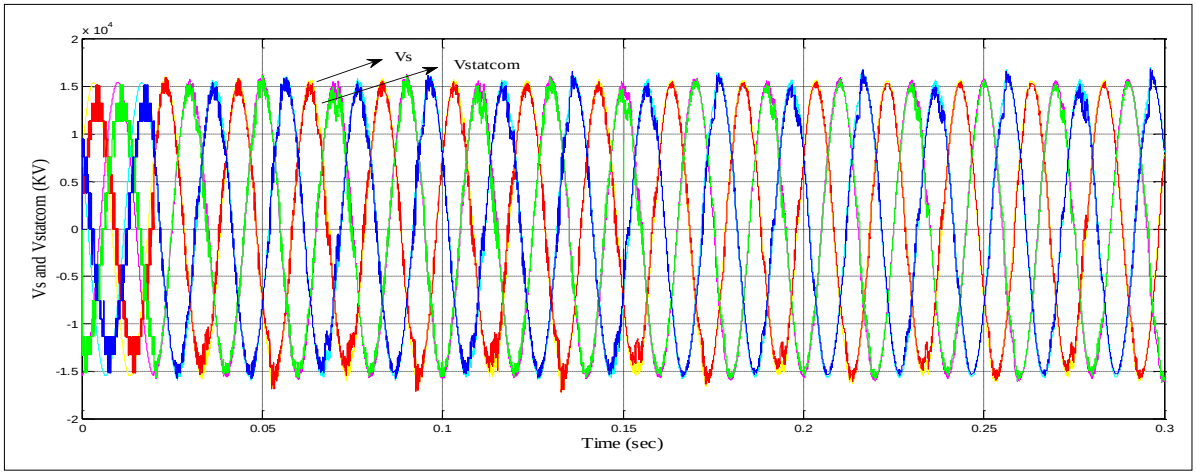
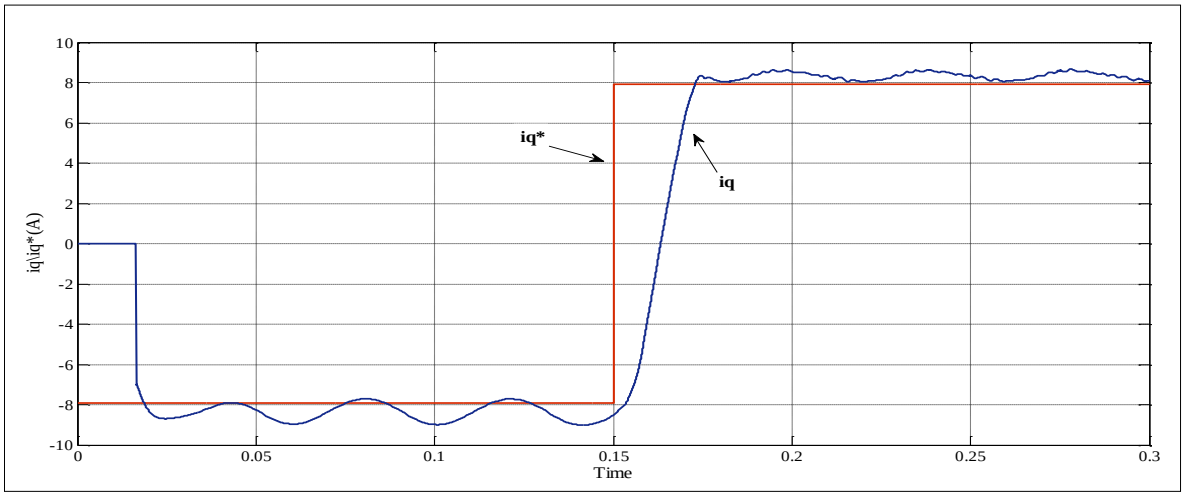


Figure 6: Reactive Current Component Tracking



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5.0 Conclusion

In conclusion, this work provides a comprehensive approach to address challenges associated with per phase DC bus voltage balancing in a STATCOM system, particularly in the context of a CMI-based configuration. The paper provides background data for the proposed method by analyzing the STATCOM system parameter model and evaluating conventional control methodologies. The primary contribution is the development of a per-phase DC bus voltage balancing mechanism that combines the dq/abc park transformation with a loop-gain shaped control scheme. By employing this tactic, the aim is to ensure the maintenance of a constant DC bus voltage, which is necessary for the system to function dependably. Moreover, the addition of a proportional resonant controller for global control of the DC capacitor enhances the system's performance and stability.

The importance of managing problems like reactive power accounting and DC voltage balancing—especially when managing clustered loads—is also emphasized in the article. If these issues are fixed, the recommended system's overall performance and dependability can be significantly increased. There is a clear emphasis on the need for a robust control structure to increase system dependability throughout the discussion. This highlights how crucial the recommended method is to achieving DC link voltage balancing and reactive power correction.

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