

Dynamical Behaviour of CMI based STATCOM

Abhay Agrawal and Sanjay Soni***

ABSTRACT

Cascade multilevel inverters (CMI) are superior to other multilevel inverter configurations in STATCOM applications owing to their distinguishing features, such as structural flexibility and control design feasibility in the service of lower device losses and high value of AC output voltage waveform quality. Voltage output stabilization and power factor correction at the point of common connection are two challenging difficulties that might lead to the system's dominance. In this work, the overall control architecture for the system is presented, provides information on how the 9-level CMI may be utilised as STATCOM to carry out dc link voltage balancing and reactive power compensation. The superiority of the system under varying loads and fault circumstances has been confirmed by computer modelling.

Keywords: *Point of Common Coupling (PCC); Cascade Multilevel Inverter (CMI); Line Ground (LG) Fault.*

1.0 Introduction

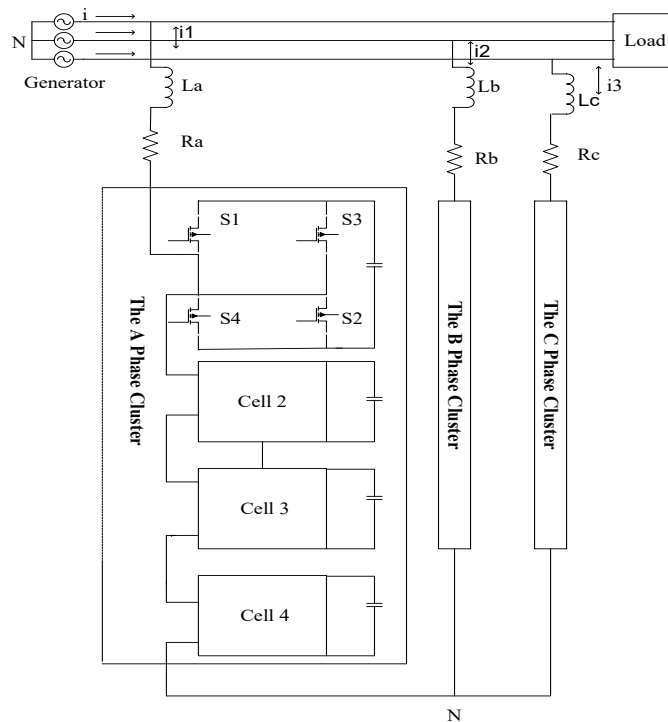
Continuous and accurate power management, such as voltage level regulation, power flow in overhead transmission management, and system stability improvement [1] are all made possible by converter-based FACTS controllers. By transferring power exchanged in a reactive manner between STATCOM and the grid, this FACTS device greatly improves voltage control and transient stability [2]. Since it requires fewer parts and is more efficient overall, the CMI converter is often used as a STATCOM [3, 4]. Other multilevel topologies, such as the diode clamped and flying capacitor, are also in use. Maximizing the figure of levels in the output voltage waveform is made feasible by the increased switching repetition with trade off flexibility between voltage regulation, switching losses, and harmonic performance. In comparison to other multilevel inverter topologies, reduced switching device losses, reduced component requirements, and simplified control are all advantages of cascade multilevel inverters. To prevent potential imbalance on the DC side of a number of H bridges, active power balancing is used to compensate for the power losses of each H bridge individually [5]. The grid voltage is used as a standard against which the reactive power is measured in order to compensate for it. Differences between dc-link voltages and the reference voltage are used to determine the amount of active power that must be supplied to the STATCOM.

**Corresponding author; Associate Professor, Department of Mechanical Engineering, Rewa Engineering College, Rewa, India (E-mail: abhayagrwalgec@gmail.com)*

***Associate Professor, Department of Industrial Production, JEC Jabalpur, RGPV Bhopal, Madhya Pradesh, India (E-mail: soni563@yahoo.com)*

By balancing measurements of dc link voltage and monitoring reactive power as needed, a well-designed controller and a carefully chosen modulation method may significantly boost a system’s dynamic performance. STATCOM system setup based on three-phase cascade multi-level inverters is shown in Figure 1.

Figure 1: CMI based STATCOM Layout



2.0 DC Voltage Balancing

When a cascade multilevel inverter (CMI) is used in a STATCOM application, the system’s practicality and modularity are both improved by the use of a separate dc capacitor; nevertheless, the dc voltage often becomes unbalanced as a result of the CMI’s internal losses. Poor waveform quality, unequal voltage pressure throughout switching devices, and overvoltage at any one connection are all conditions that may be avoided with proper dc voltage balancing. To offset the power losses caused by CMI’s internal components, a phase shift between the converter’s output voltage and the network voltage may be used to accomplish dc voltage balancing. In order to accomplish dc voltage balancing, it is necessary to STATCOM’s active power input to each H bridge may be changed. [6]. As illustrated in Figure 2, a DC voltage phenomenon in a system is created by measuring and calculating DC voltage of each individual H bridge with a reference dc potential and then sending the resulting error signal via a PI controller. As illustrated in Figure 2, the average of each cluster’s DC voltage (i.e. $V(dca)$, $V(dcb)$, and $V(dcc)$) is made to track the average of all clusters’ voltages (Vdc).

3.0 CMI based Statcom Mathematical Modelling and Control

3.1 Mathematical modelling

In this model, a CMI-based STATCOM is represented by a voltage source converter that is reactively connected to the transmission or distribution network. In Figure 3, V_s represents the

voltage of the power system, V_c represents the voltage of the STATCOM, I_c represents the current drawn by the STATCOM, and R and L represent the total resistance and inductance between the source and the STATCOM, respectively. As a result of the disparity between the network voltage and the STATCOM voltage, the STATCOM is able to generate its own current by adjusting the coupling parameters in the following ways:

$$L \frac{d}{dt} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} + R \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} - \begin{bmatrix} V_{ca} \\ V_{cb} \\ V_{cc} \end{bmatrix} \dots (1)$$

Where V_{sa} , V_{sb} and V_{sc} represents the three phase source voltages and denotes the three phase STATCOM voltages.

Type of ahead-or-behind current transmitting from STATCOM to the network or network to STATCOM is determined by the voltage magnitudes between STATCOM and network, which are as follows:

Figure 2: A Technique for Balancing DC Voltage

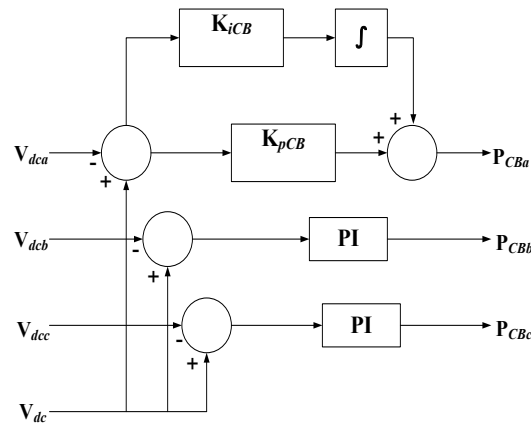
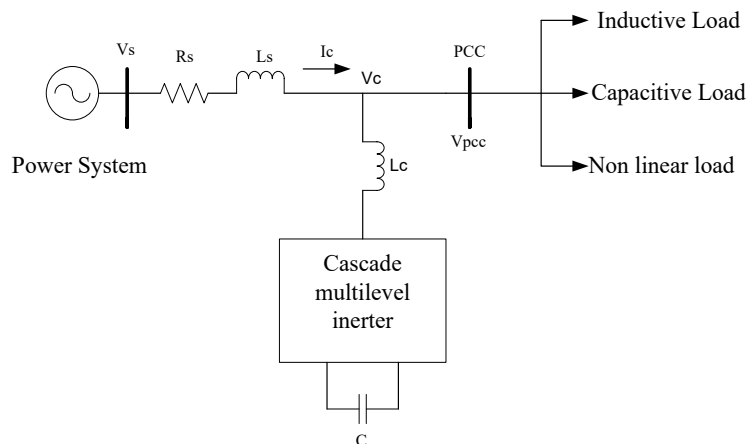


Figure 3: Linear Representation of a CMI-based STATCOM System



If $V_c > V_s$, then the STATCOM will be the source of the leading reactive current in the power grid. When $V_c < V_s$, a lagged reactive current flow from the power grid to the STATCOM.

Reactive power and active power exchange between STATCOM and network may be controlled and understood in terms of a mathematical model using equations (2-8) where the three-phase quantity is transformed into a synchronous dq reference frame using a matrix called [T].

$$[T] = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \dots (2)$$

$$V_s = \begin{pmatrix} V_{sd} \\ V_{sq} \end{pmatrix} = [T]V_s, \quad V_c = \begin{pmatrix} V_{cd} \\ V_{cq} \end{pmatrix} = [T]V_c \dots (3)$$

$$I_c = \begin{pmatrix} I_{cd} \\ I_{cq} \end{pmatrix} = [T]I_c \dots (4)$$

$$L \frac{d}{dt} \begin{bmatrix} I_{cd} \\ I_{cq} \end{bmatrix} + \omega L \begin{bmatrix} -I_{cq} \\ I_{cd} \end{bmatrix} + R \begin{bmatrix} I_{cd} \\ I_{cq} \end{bmatrix} = \begin{bmatrix} V_{sd} - V_{cd} \\ V_{sq} - V_{cq} \end{bmatrix} \dots (5)$$

$$V_s = \begin{bmatrix} V_{sd} \\ V_{sq} \end{bmatrix} = \begin{bmatrix} V_s \\ 0 \end{bmatrix} \dots (6)$$

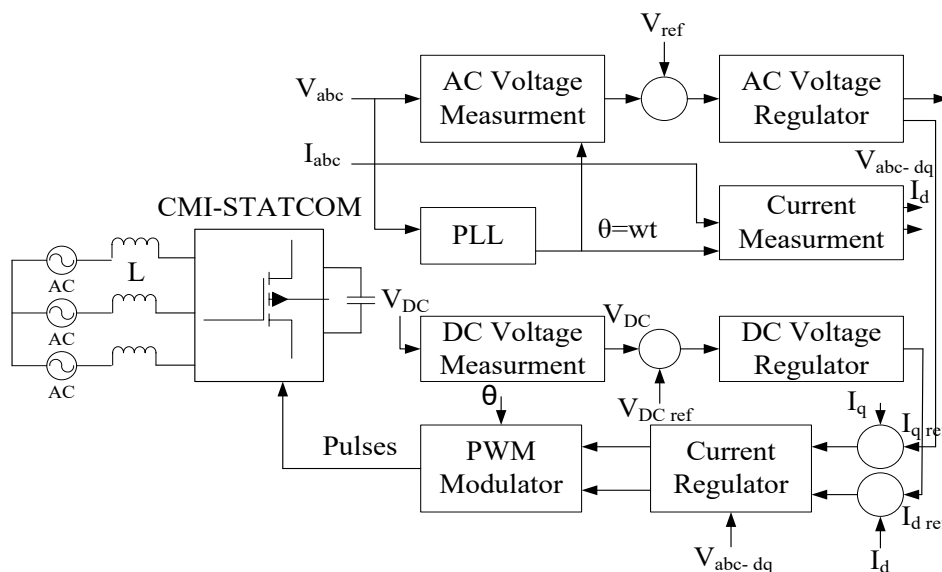
$$P_c = V_s I_{cd} \dots (7)$$

$$Q_c = V_s I_{cq} \dots (8)$$

3.2 STATCOM controller using CMI

Figure 4 shows a block schematic of the internal controls for a CMI-based STATCOM. For vector transformation like abc to dq, it is necessary to measure voltage and current at the point of common coupling, and the phase angle and reference frequency are calculated using phase locked loop synchronisation circuitry. Each phase of the dc link voltage may be balanced independently using the individual dc voltage controllers and the cluster voltage controllers that make up a DC voltage regulator [7]. The CMI STATCOM is to receive a programmable switching instruction from the dc voltage regulator, ac voltage regulator, and PWM modulator, as seen in Figure 4. As the number of cascade bridge cells per cluster rises, a modulation approach like Phase shifted PWM should be considered because of the simplicity with which the control system may be implemented.

Figure 4: Controller for CMI based STATCOM



4.0 Simulation Result

The simulation results demonstrate the system's superiority by revealing its clearly defined dynamic performance, such as meeting Demand for reactive power from the load side, while maintaining a constant dc link voltage throughout the inductive/capacitive operation. The mathematical description of STATCOM is used to compile Table I, which lists the simulation parameters. The waveforms of the three-phase STATCOM output voltage are shown in Figure 5 (A) in standby mode, (B) in inductive mode (0.02 to 0.15 sec), and (C) in capacitive mode (0.15 to 0.3 sec). Four capacitors are employed in a single phase CMI – STATCOM, and their dc voltage balance is shown in Figure 6.

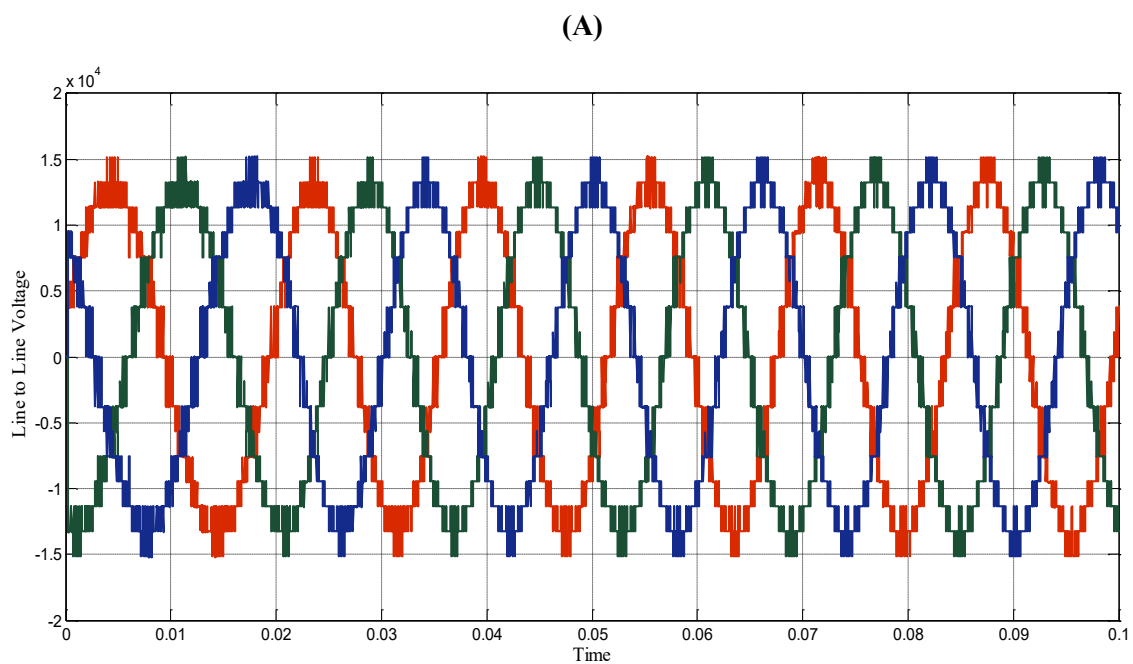
There is a 0.15-second transition time between the inductive mode (a) and the capacitive mode (b), as shown in Figure 7.

During the switch from inductive to capacitive mode, Figure 8 demonstrates the dynamic performance of CMI-based STATCOM by displaying the tracking between the reactive current reference (I_q^*) and the reactive current (I_q) given by STATCOM.

Table 1: Simulation Parameters

Rated Power	130 Kvar
Rated Voltage	11 kv
Number of Cells/Phase	4
DC Capacitor	5.66 mF
DC Voltage	1995 Vdc
Output waveform Frequency	50 Hz
Reactive Current (I_q^*)	9 Amp

Figure 5 STATCOM output waveform of the voltage in (A) the standby mode and (B) the inductive mode (a)/capacitive mode (b)



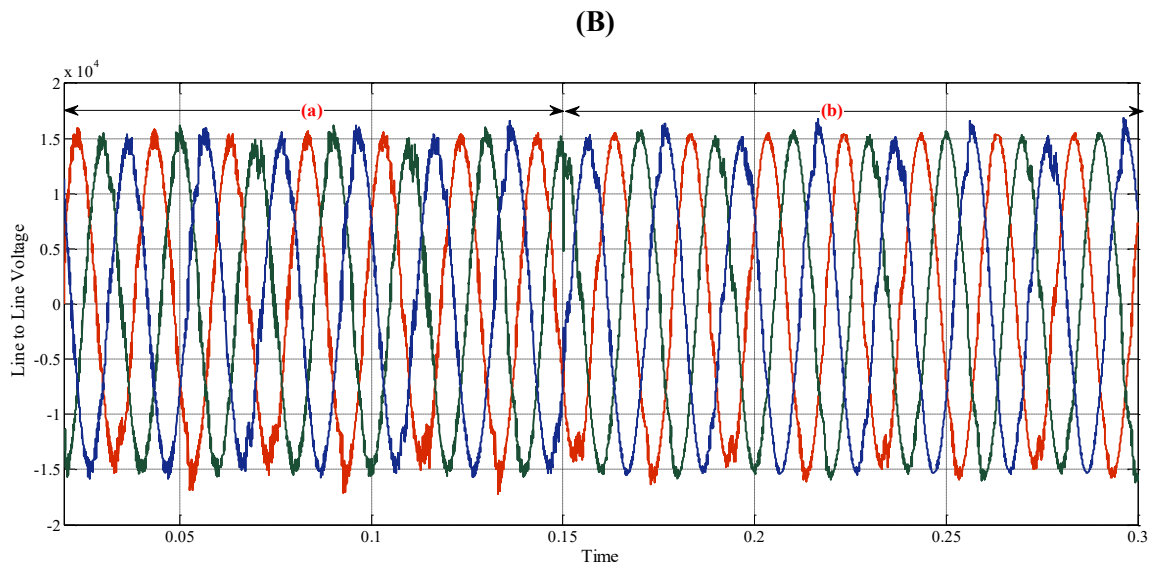


Figure 6: DC Voltage Balancing

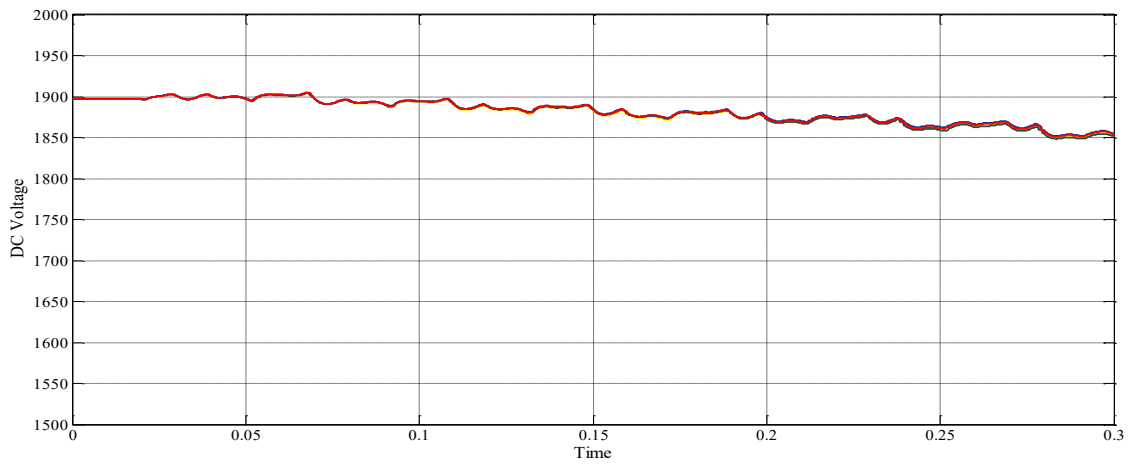


Figure 7: PCC Voltage and Current Waveform

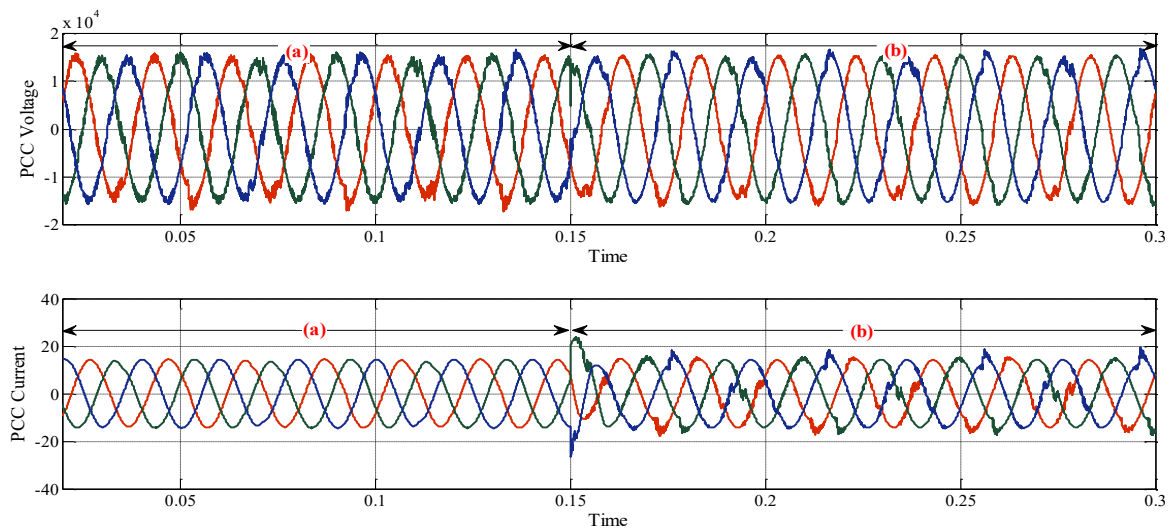
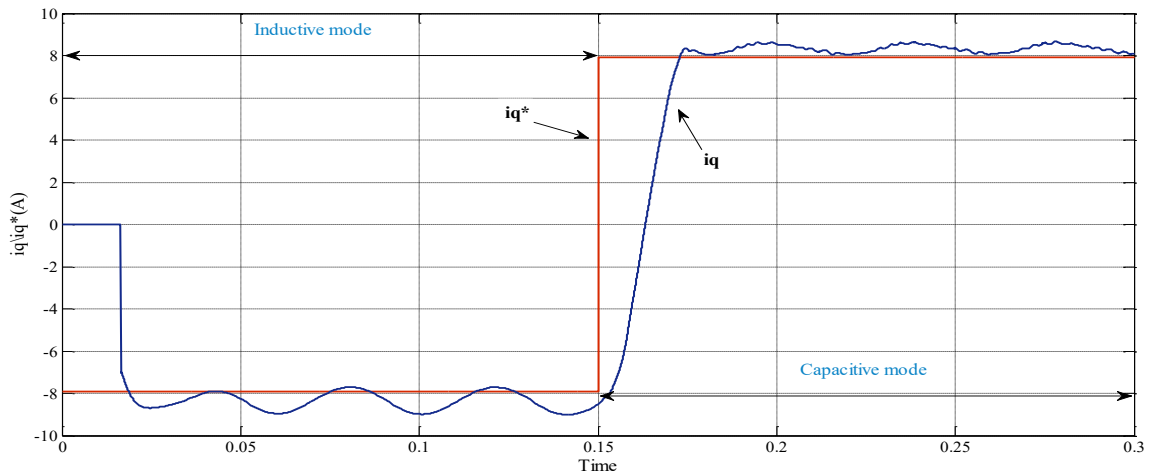


Figure 8: Reactive Current Component Tracking

5.0 Conclusion

In this particular research, a nine-level cascade multilevel inverter is used as a STATCOM in order to enhance the overall performance and efficiency of the system. The results of the simulation have shown that the system is preferable due to the fact that it lowers the reactive power consumption at the point of common connection and maintains the dc link voltage at a reference value even when subjected to changing loads and unbalanced fault circumstances. The results of the simulation have shown that this system is preferable. The efficacy of the control structure that was put into place for the cascade multilevel inverter that was used in the STATCOM application was validated by the results of the simulation.

References

- [1] B. Gultekin and M. Ermis, "Cascaded Multilevel Converter-Based Transmission STATCOM: System Design Methodology and Development of a 12 kV \pm 12 MVar Power Stage," in *IEEE Transactions on Power Electronics*, vol. 28, no. 11, pp. 4930-4950, Nov. 2013.
- [2] W. Song and A. Q. Huang, "Fault-Tolerant Design and Control Strategy for Cascaded H-Bridge Multilevel Converter-Based STATCOM," in *IEEE Transactions on Industrial Electronics*, vol. 57, no. 8, pp. 2700-2708, Aug. 2010.
- [3] N. Hatano and T. Ise, "Control Scheme of Cascaded H-Bridge STATCOM Using Zero-Sequence Voltage and Negative-Sequence Current," in *IEEE Transactions on Power Delivery*, vol. 25, no. 2, pp. 543-550, April 2010.
- [4] H. Sepahvand, J. Liao, M. Ferdowsi and K. A. Corzine, "Capacitor Voltage Regulation in Single-DC-Source Cascaded H-Bridge Multilevel Converters Using Phase-Shift Modulation," in *IEEE Transactions on Industrial Electronics*, vol. 60, no. 9, pp. 3619-3626, Sept. 2013.

- [5] J. I. Y. Ota, Y. Shibano, N. Niimura and H. Akagi, "A Phase-Shifted-PWM D-STATCOM Using a Modular Multilevel Cascade Converter (SSBC)—Part I: Modeling, Analysis, and Design of Current Control," in *IEEE Transactions on Industry Applications*, vol. 51, no. 1, pp. 279-288, Jan.-Feb. 2015.

- [6] Y. Li and B. Wu, "A Novel DC Voltage Detection Technique in the CHB Inverter-Based STATCOM," in *IEEE Transactions on Power Delivery*, vol. 23, no. 3, pp. 1613-1619, July 2008.

- [7] C. t. Lee *et al.*, "Average Power Balancing Control of a STATCOM Based on the Cascaded H-Bridge PWM Converter With Star Configuration," in *IEEE Transactions on Industry Applications*, vol. 50, no. 6, pp. 3893-3901, Nov.-Dec. 2014.