Investigation of Five Level Flying Capacitor and CHB Multilevel Inverter for D-STATCOM Applications

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ABSTRACT
D-STATCOM (Distribution Static Synchronous Compensator) is a versatile solution for mitigation of power quality related problems in distribution system. It can be configured and controlled in variety of ways depending upon the requirements of mitigation of particular problem. The control schemes are tuned to provide solutions for voltage regulation, reactive power compensation, power factor correction or harmonics mitigation. The heart of the D-STATCOM is a voltage source inverter. This voltage source inverter may take form of simple 2/3 level inverter or a multilevel inverter. The multilevel inverters,although being expensive, are preferred due to their several advantages. Therefore, in this paper, two configurations of multilevel inverter namely flying capacitor and cascaded H-bridge are used to configure a D-STATCOM. The D-STATCOM is controlled with dq theory based control technique. The results presented to compare the performance these two configurations for power quality parameters of harmonics and stress on switching devices.

Keywords: D-STATCOM, harmonics, flying capacitor, cascaded H-bridge

INTRODUCTION
The nonlinear loads are becoming increasingly common in commercial buildings due to the proliferation of electronic devices. The impacts of nonlinear loads on power quality in commercial buildings is assessed with measurements of harmonic distortion levels and voltage variations [1]. The impacts of nonlinear loads on power quality can be significant and may result into harmonic distortion, transformer and motor overheating and neutral conductor overloading [2].
The modern power systems are increasingly being subjected to nonlinear loads in homes and industries. The combination of existing linear and modern nonlinear load is still balancing out. But as large linear loads are increasingly replaced by multiple smaller nonlinear loads, the combined effect can be detrimental and hard to mitigate due to the distributed nature of these many small disturbing nonlinear loads [3]. The harmonic distortion levels in the network are significantly affected by the presence of nonlinear loads. Many researcher have demonstrated the power quality related problems through simulation, experimentation and case studies of nonlinear loading. It is recommended that the nonlinear loads should be compensated appropriately to ensure the reliability of power system [4, 5].
Many researchers have worked upon improving the power quality issues of distribution system. Some of the common solutions for power quality improvement being passive and active filters, UPQC, CPD etc. [6]. The custom power device of [7] with closed loop controller for mitigation of voltage sags, swells and harmonics is a promising solution. However, the role of STATCOM in distribution system looks even more promising [8].

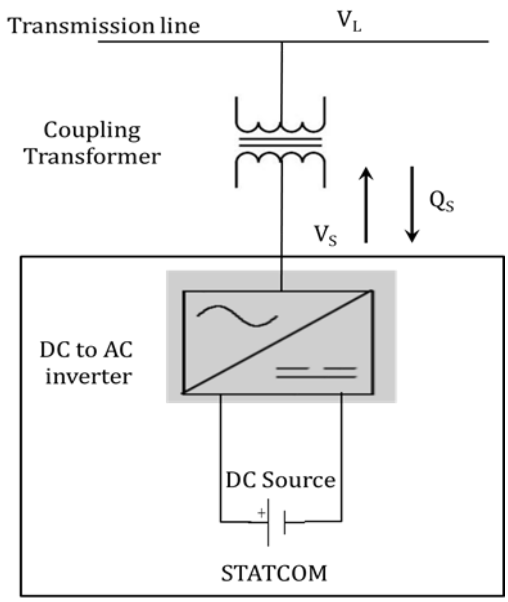

Figure 1: basic structure of Statcom

The recent developments of Flexible AC Transmission Systems (FACTS) is giving rise to a new family of power electronic equipment like STATCOM for controlling and optimizing the performance of power system. The use of voltage-source inverter (VSI) has been widely accepted as the next generation of reactive power controllers of power system to replace the conventional VAR compensation of thyristor-switched capacitor (TSC) and thyristor controlled reactors (TCR).STATCOM is a shunt-connected static VAR compensator whose capacitive or inductive output current (reactive power) can be controlled independent of the AC voltage system. The basic structure of STATCOM is shown in figure 1.

The key components of STATCOM are - DC to AC converter which is a voltage source inverter, a coupling transformer, a controller and an energy storage device. When a STATCOM is specifically designed for distribution system, it is referred as D-STATCOM. A D-STATCOM improves power quality by regulating voltage and reducing harmonics in distribution systems. A D-STATCOM can address problems related to voltage flicker. For the purpose of reducing the current harmonics produced by nonlinear loads, the D-STATCOM injects a reactive current into the system [9].

At the distribution levels, the D-STATCOM has been identified as a reliable device for reactive power compensation [10]. The D-STATCOM can be configured in variety of ways as it can mitigate harmonics, compensate reactive power and regulate voltage at PCC. A voltage source inverter is heart of the D-STATCOM, controlled with PWM or some advanced PWM control techniques. The control strategies are developed for various functions like reactive power compensation, harmonics mitigation or voltage regulation and hence various power quality problems are addressed [11].

Multilevel inverters are commonly used in DSTATCOMs due to their ability to generate high-quality output waveforms with reduced harmonic distortion. The multilevel converters can operate at high voltage levels using semiconductors devices with lower ratings. As a result, they provide benefits such as decreased electromagnetic interference, lower voltage rating of and decreased stress on power switches [17]. The multilevel inverters are configures as diode clamped or flying capacitor or CHB inverters [12]. In medium and high voltage distribution systems, reactive power compensation is accomplished by the multilevel inverter STATCOM [13]. . A cascaded H-bridge multilevel STATCOM is proposed in [14] for voltage regulation. The D-STATCOM control for voltage regulation can make up for up to 25% dip or swell in voltage value. The SPWM [15] is also used in D-STATCOM for maintaining voltage accomplished by compensating reactive power.The utilization of a multilevel inverter-based D-STATCOM proves to be a viable approach for harmonics mitigation. In the case of a two-level D-STATCOM discussed in [16], there is a noticeable decrease in THDby up to 4.73%. Conversely, the THD value after compensation is even lower, standing at 2.75%, as observed with the five-level STATCOM configuration.

The flying capacitor configuration avoids voltage balancing issues that arises due to power losses in the inverter [18]. The phase shift PWM modulation for flying capacitor configuration is effective for voltage regulation and power factor correction [19] The flying capacitor based D-STATCOM of [20] has reported THD of 3% with compensation. The circuit configuration of a 5 level CHB inverter is mentioned in figure 2 and that for flying capacitor configuration is mentioned in figure 3.

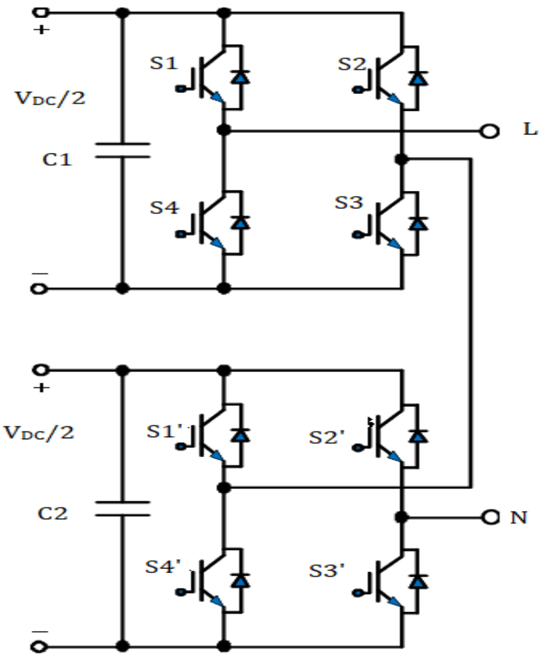

Figure 2: 5 Level CHB Inverter

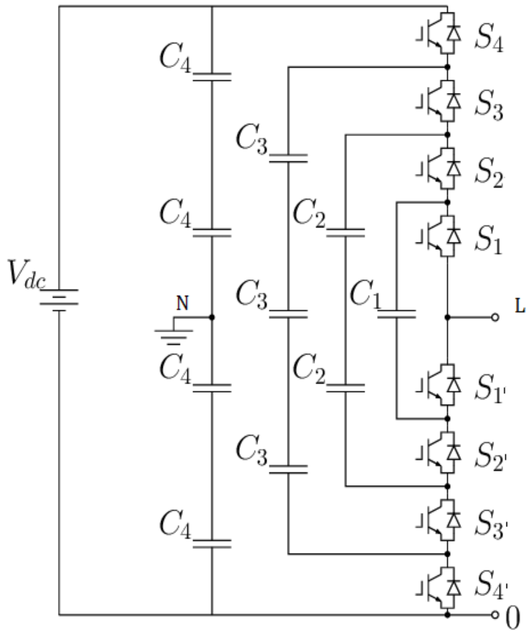

Figure 3: 5 Level Flying Capacitor Inverter

Simulation and Results

A MATLAB Simulink modelsfor D-STATCOM were developed with a 5 level flying capacitor inverter and a CHB inverter for same no. of levels. The D-STATCOM is controlled with dq theory based controller. The d-q theory is based on time domain reference signal eradication technique [21 - 22]. It performs the operation for voltage and current waveforms in steady state or transient states. The synchronous reference frame theory transforms three-phase AC voltage or current into a two-axis d-q reference frame that rotates in sync, employing Park's transform.

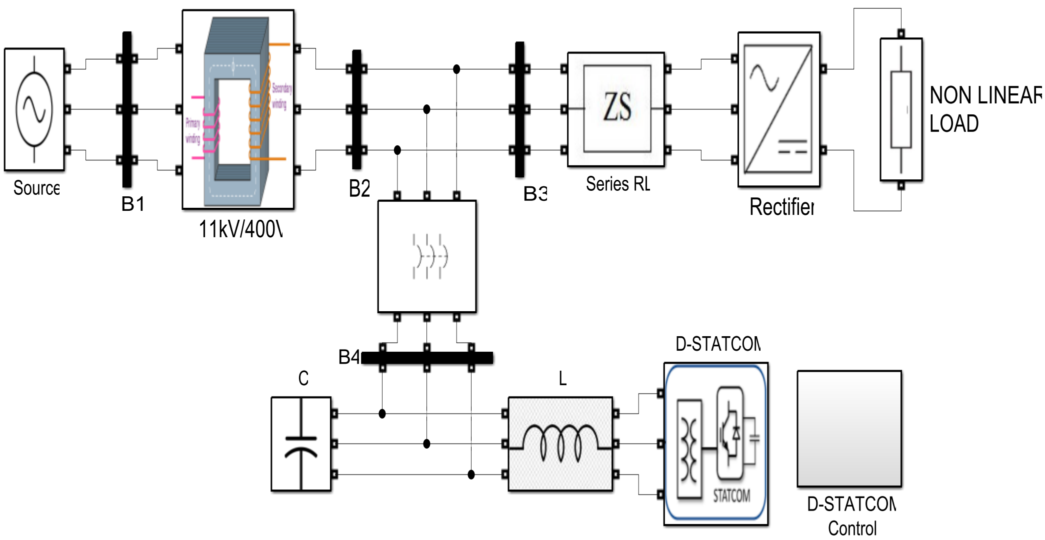

Figure 4: Simulation model of D-STATCOM

$$\begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = \begin{bmatrix} \cos\theta & \cos(\theta-120) & \cos(\theta+120) \\ \sin\theta & \sin(\theta-120) & \sin(\theta+120) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

This conversion becomes necessary as the fundamental component is changed into a steady value, suitable for low-pass filtering within a synchronized reference frame. This process retains the high-frequency components that can be readily extracted. Using a low-pass filter also prevents potential phase complications in the signal, an issue that could emerge if a high-pass filter were employed to filter a DC component. To apply this theory, the load current is transformed from a three-phase configuration to a d-q reference frame.The derived direct (d) and quadrature (q) components encompass both alternating current (AC) and direct current (DC) constituents. The DC portion signifies the fundamental component, while the AC segment signifies the harmonic component. Essential components are manifested within the d component, while the q component reflects the presence of harmonic content. The necessary signals for the inverter are determined through the inverse Park transformation.

$$\begin{bmatrix} {i_a}^* \\ {i_b}^* \\ {i_c}^* \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin(\theta) & 1 \\ \cos(\theta-120) & \sin(\theta-120) & 1 \\ \cos(\theta+120) & \sin(\theta+120) & 1 \end{bmatrix} \begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix}$$

The simulation model is seen in figure 4 and the specifications of the system are mentioned in table 1. The control scheme of dq theory based control is shown in figure 5. The results are noted by running the model with flying capacitor multilevel inverter configuration separately and CHB configuration separately. The reading of waveforms of voltage and current at PCC, current THD and voltage and current waveforms across the switching devices are noted.

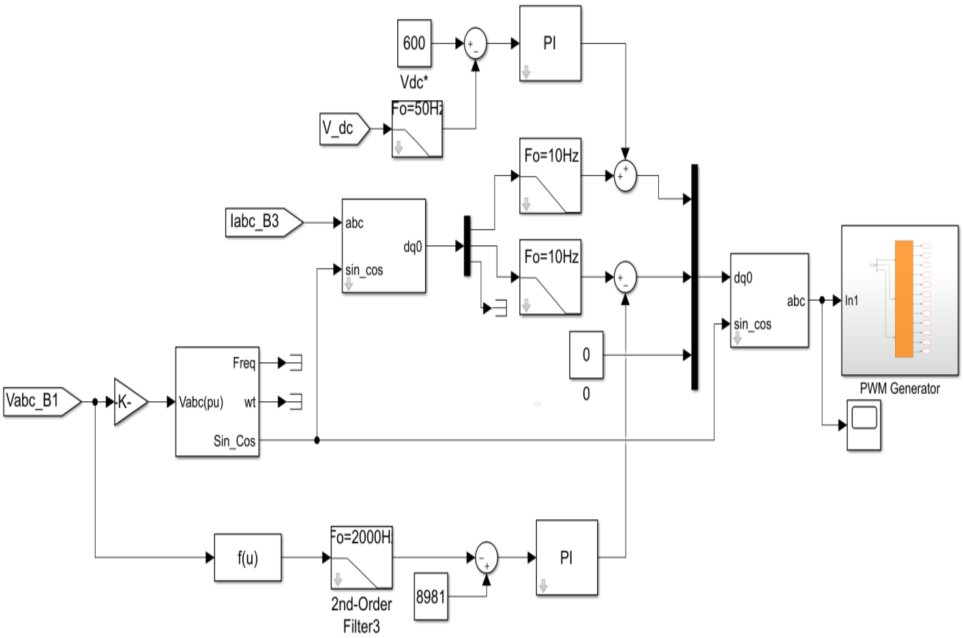

Figure 5: D-STATCOM Control using DQ theory

Table 1: System Specifications

Source	11 KV, 50Hz
Transformer	11KV / 400V, 20kVA, 50 Hz
Line & Load Parameters	Diode bridge rectifier fed RL load with P = 10KW Q = 10KVAR
STATCOM Parameters	Flying Capacitor DC link Voltage = 600V Capacitance = 250 μF Cascaded H-Bridge DC link Voltage = 150 V per bridge Capacitance = 1000 μF
Switching Frequency	5 KHz
LC Filter	L = 150 mH, C = 5000 μF

Initially, the system is executed without compensation and waveforms of voltage current at PCC are noted as seen in figure 6. The nature of the waveform shows distortions and the current THD without any power conditioning is noted to be 15.13% as seen in THD graph of figure 7.

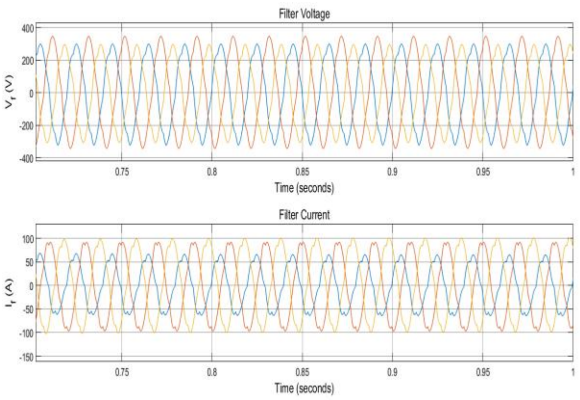

Figure 6: voltage and current waveforms

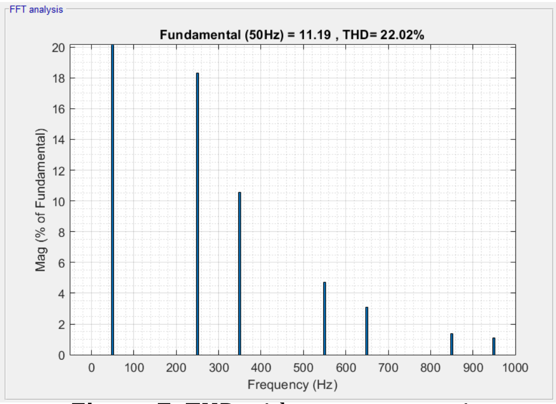

Figure 7: THD without compensation

The voltage and current waveforms of compensated system with flying capacitor MLI based D-STATCOM are mentioned in figure 8 and the corresponding current THD is mentioned in figure 9. The value of current THD after D-STATCOM compensation is brought down for 22.02 % to 2.52%. This value if less than that reported by [20] which stood at 3%.

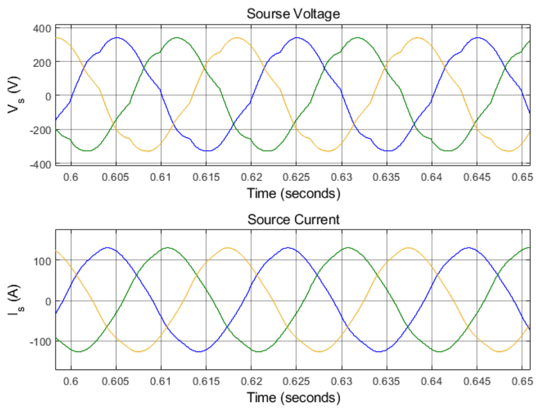

Figure 8: post compensation waveforms with flying capacitor MLI based D STATCOM

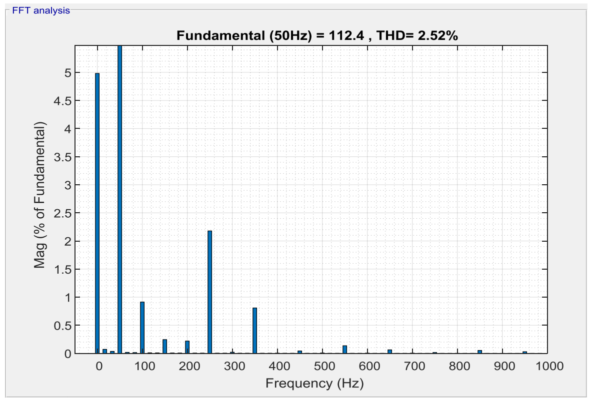

Figure 9: post compensation TDH with flying capacitor MLI based D-STATCOM

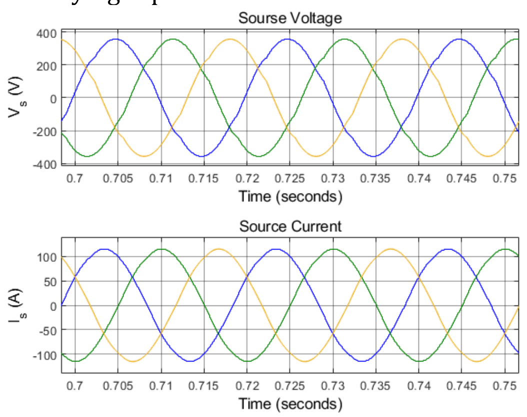

Figure 10: post compensation waveforms with CHB MLI based D STATCOM

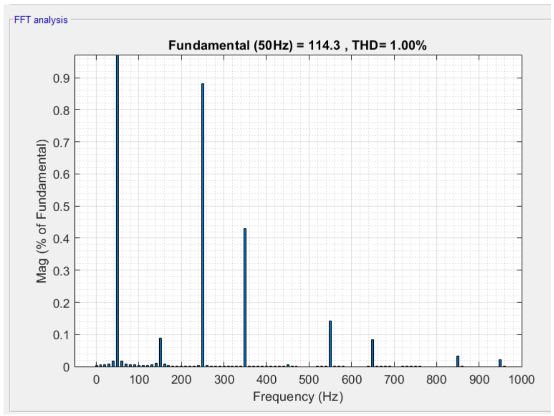

Figure 11: post compensation current TDH with CHB MLI based D-STATCOM

In the case when same system is worked out with 5 level CHB MLI based D-STATCOM the post compensation waveforms of voltage and current are seen to be even further smoothened as compared to that for the flying capacitor MLI based D-STATCOM. The waveforms are seen in figure 10 and THD bar graph is seen in figure 11.The value of current THD with cascaded H-bridge MLI D-STATCOM is seen to be 1.00 %. Upon comparing the two multilevel inverter D-STATCOM following observations as in table 2 are recorded.

Table 2: comparison of flying capacitor and cascaded H-bridge MLI configurations

Particulars	Flying capacitor	Cascaded H-Bridge
Complexity	Voltage balancing is challenging with increase in no. of levels	Control logic complexity increases with increase in no. of levels
Performance	Suffers voltage unbalance	Achieves better voltage balance
Voltage handling	Requires careful management to prevent overvoltage or undervoltage conditions	It can be extended to handle higher voltage by adding more H-bridge modules
Scalability	Limited due to complexity management issues	Morescalable as additional H-bridge stages can be added to achieve higher voltage levels
THD	2.52 %	1.00 %
Power Factor	0.94	0.997

CONCLUSION

Multilevel inverter plays an important role in the field of modern power electronics and is widely used for many high voltage and high power industrial and commercial applications. As the number of levels increases, the number of voltage sources and power switches increases, voltage balancing issues, and complexity in pulse width modulation control arise. A five level configuration is suitable to explore for achieving better performance resulting in compact system. This paper presents comparison of 5 level flying capacitor and cascaded H-bridge multilevel inverter based D-STATCOM for harmonics mitigation. The CHB configuration has report better THD mitigation as compared to flying capacitor configuration. Comparing the size, CHB has lesser no. of capacitors and hence can be small sized. There exists a further scope for making it even more compact by using modified CHB configurations for D-STATCOM.

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