

Harmonic Mitigation in Nonlinear Load Systems Using D-STATCOM

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Abstract - Nonlinear loads such as adjustable speed drives, rectifiers, and power electronic converters inject significant harmonic currents into the power system, degrading power quality and causing excessive Total Harmonic Distortion (THD). This paper presents a simulation-based performance analysis of a Distribution Static Compensator (D-STATCOM) for harmonic mitigation under nonlinear load conditions. A MATLAB/Simulink model is developed to evaluate the system with and without the D-STATCOM. Without compensation, the voltage and current THD is observed to be approximately 27.21%, which is far above the limit recommended by IEEE Std. 519. With the D-STATCOM connected, the THD is reduced to approximately 7.58%, and the source current waveform becomes near-sinusoidal. The results demonstrate that the proposed D-STATCOM effectively mitigates harmonics and improves power quality, and directions for further improvement toward full standard compliance are discussed.

Keywords— D-STATCOM, Power Quality, Total Harmonic Distortion (THD), Nonlinear Load, IEEE 519, MATLAB/Simulink.

INTRODUCTION

The increasing use of power electronic equipment, such as variable frequency drives, uncontrolled rectifiers, arc furnaces, and computer power supplies, has led to a substantial rise in harmonic pollution in electrical distribution networks [2], [11]. These nonlinear loads draw non-sinusoidal current from the supply, resulting in voltage distortion, increased losses, overheating of transformers and cables, malfunction of sensitive equipment, and poor power factor [1], [26]. Left uncompensated, these effects can violate recommended power quality limits and reduce the reliability of the distribution system.

Custom Power Devices (CPDs), particularly the Distribution Static Compensator (D-STATCOM), have emerged as an effective solution for mitigating such power quality problems [1], [4]. A D-STATCOM is a shunt-connected voltage source converter (VSC) based device that injects a compensating current into the system to cancel the harmonic and reactive components drawn by the nonlinear load, thereby

making the source current sinusoidal and in phase with the source voltage [3], [5].

This paper investigates the performance of a D-STATCOM in mitigating current and voltage harmonics generated by a nonlinear load, using two test cases: (i) the uncompensated baseline system, and (ii) the system compensated with the D-STATCOM. The results are compared in terms of Total Harmonic Distortion (THD) and evaluated against the IEEE Std. 519 recommended limit [2].

LITERATURE REVIEW

The rapid growth of nonlinear loads such as variable frequency drives, uncontrolled rectifiers, arc furnaces, and electronic equipment has significantly increased harmonic distortion in distribution systems. These harmonics cause increased power losses, overheating of equipment, voltage distortion, and reduced system reliability [6], [12].

Passive filters were traditionally used for harmonic mitigation. However, they have limitations such as resonance problems, fixed compensation, large size, and inability to adapt to changing load conditions [12], [18]. Due to these drawbacks, researchers have shifted toward active compensation devices, particularly the Distribution Static Compensator (D-STATCOM).

D-STATCOM is a shunt-connected voltage source converter-based device that injects compensating currents to cancel harmonic and reactive components of nonlinear loads [6], [7]. Recent studies have shown that D-STATCOM can effectively reduce the Total Harmonic Distortion (THD) of source currents within IEEE Std. 519 limits.

Various control techniques have been proposed for D-STATCOM. Four-leg VSI-based configurations have been used successfully for compensating both nonlinear and unbalanced loads [6]. Fuzzy logic-based Instantaneous Reactive Power Theory (IRPT) control has been reported for improved performance under unbalanced and distorted conditions [7]. Adaptive filtering techniques and intelligent control methods have also been investigated for better harmonic extraction and dynamic response [14].

Some recent works have examined the combined effect of D-STATCOM with renewable energy sources and energy storage systems for enhanced power quality improvement [10], [13]. Optimal placement and sizing of D-STATCOM considering harmonic injection limits has also been studied using modern Some recent works have examined the combined effect of D-STATCOM with renewable energy sources and energy storage systems for enhanced power quality improvement [10], [13]. Optimal placement and sizing of D-STATCOM considering harmonic injection limits has also been studied using modern optimization algorithms [18].

Despite these advancements, challenges related to control complexity, DC-link voltage regulation, and performance under highly distorted conditions still remain. Therefore, continued research on efficient modeling and control strategies of D-STATCOM for harmonic mitigation is necessary.

SYSTEM CONFIGURATION

The test system includes a three-phase AC power source that supplies a nonlinear load, which is a diode or thyristor bridge rectifier connected to an RL load, through a distribution feeder [21]. The D-STATCOM is connected in parallel at the point of common coupling (PCC) via a coupling transformer or inductor. It includes a Voltage Source Converter (VSC) made up of IGBT switches, a DC-link capacitor, and a current control system based on hysteresis or PWM techniques. This control system produces switching signals that ensure the compensator current follows a reference value calculated using the instantaneous reactive power theory [16], [24], [29].

A. Nonlinear Load Model

The nonlinear load is represented as a three-phase rectifier bridge supplying a resistive-inductive DC load.

This is a commonly used model for studying harmonics, as it produces typical harmonics of the 5th, 7th, 11th, and 13th order in the source current [22], [28].

B. D-STATCOM Model

The D-STATCOM is implemented as a two-level, three-phase VSC with a DC storage capacitor on its DC side. The compensator is designed to supply a current that is equal in magnitude but opposite in direction to the harmonic and reactive components of the load current. This ensures that the current drawn from the source remains sinusoidal [21], [24], [27].

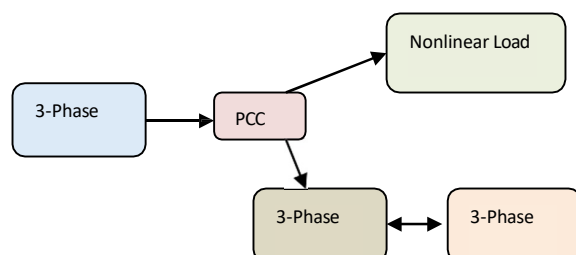


Fig. 1. Block diagram of the D-STATCOM based harmonic compensation system

CONTROL STRATEGY

The control scheme extracts the fundamental active component of the load current using a synchronous reference frame (d-q) transformation / instantaneous reactive power (p-q) theory [17], [30]. The reference source current is compared with the sensed source current, and the error is processed through a hysteresis or PI-based current controller to generate switching pulses for the VSC [15], [20]. This ensures the D-STATCOM dynamically compensates for the harmonic content of the nonlinear load current in real time [19].

SIMULATION RESULTS AND DISCUSSION

A. Case 1: Without D-STATCOM (Baseline)

When the nonlinear load is directly connected to the source, both the voltage and current waveforms experience noticeable distortion. The Fast Fourier Transform (FFT) analysis indicates a total harmonic distortion (THD) of about 27.21%, which exceeds the 5% threshold specified by IEEE Std. 519 for typical distribution systems [2]. This level of distortion is consistent with the harmonic profiles reported for uncompensated rectifier-fed nonlinear loads in recent literature [14].

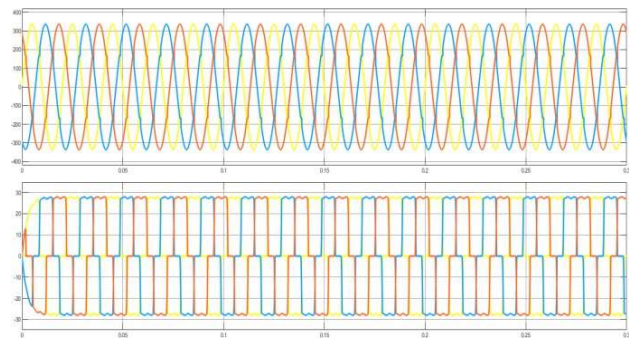


Fig. 2. Source voltage/current waveform without D-STATCOM (distorted).

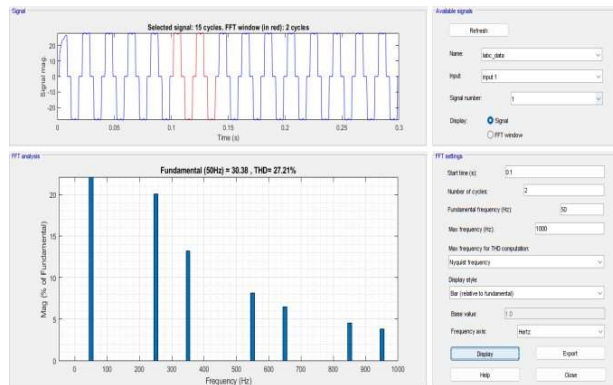


Fig. 4. Source current waveform with D-STATCOM (near-sinusoidal).

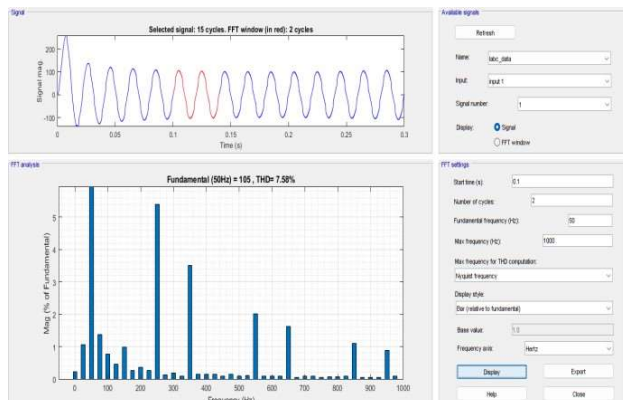


Fig. 5. Harmonic distortion With D-STATCOM (Compensated).

THD (%) Bar Chart

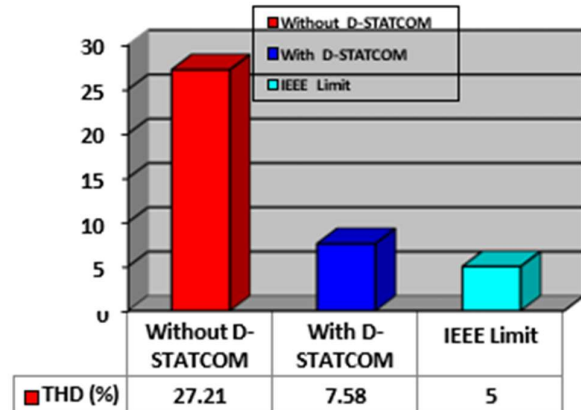


Fig. 6. THD comparison bar chart — Case 1 vs. Case 2.

TABLE I. THD Comparison Summary

Condition	THD (%)	IEEE 519 Limit
Without D-STATCOM	27.21	5%
With D-STATCOM	7.58	5%

The results confirm that the D-STATCOM significantly improves power quality. Although the compensated THD of 7.58% is marginally above the 5% limit prescribed by IEEE Std. 519, it represents a substantial improvement over the baseline and can be further reduced through refined controller tuning, a hybrid passive-active filter configuration, or an increased switching frequency, as discussed in Section V.

CONCLUSION

This paper presented a MATLAB/Simulink based performance analysis of a D-STATCOM for harmonic mitigation under nonlinear load conditions. The simulation results show that the D-STATCOM reduces the source current and voltage THD from 27.21% to 7.58%, bringing the system close to IEEE Std. 519 compliance and confirming the effectiveness of shunt compensation for power quality improvement [2]. Future work will focus on controller optimization and hybrid filtering techniques, including intelligent control approaches, to achieve full standard compliance [9], as well as hardware validation of the proposed scheme.

ACKNOWLEDGEMENT

The authors would like to express their sincere gratitude to Priyank Srivastava, Assistant Professor, Department of Electrical & Electronics Engineering, Oriental College of Technology, Bhopal (M.P.) for their invaluable guidance, continuous support, and constructive suggestions throughout the course of this research work on "Harmonic Mitigation in Nonlinear Load Systems Using D-STATCOM."

The authors also extend their thanks to the faculty members of the Department of Electrical & Electronics Engineering for providing the necessary technical resources and MATLAB/Simulink simulation facilities required to carry out this study.

Finally, the authors are grateful to their family and friends for their constant encouragement and moral support during the completion of this paper.

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BIOGRAPHIES



Ashraf Ali is currently pursuing his M.Tech in Power Electronics Engineering from Oriental College of Technology, Bhopal (2024–2026). His dissertation, titled "Performance Analysis of DSTATCOM for Power Quality Improvement Under Nonlinear Loads," involves modelling and simulation of a shunt-connected D-STATCOM in MATLAB/Simulink. He is also preparing a research paper titled "Harmonic Mitigation in Nonlinear Load Systems Using D-STATCOM." He is proficient in MATLAB/Simulink and aspires to pursue a career in instrumentation and control across process industries, power plants, oil and gas, and manufacturing automation.