International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Power Quality Improvement in Distribution System Using PI&SMC Controller

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A B S T R A C T

This chapter presents a control strategy for regulating the DC link voltage of a Cascaded H-Bridge Multilevel Inverter (CHBMLI)-based DSTATCOM. The proposed approach integrates an enhanced voltage balancing method with Sliding Mode Control (SMC) and Proportional-Integral (PI) controllers. The inclusion of the SMC controller effectively minimizes voltage overshoot and undershoot across the capacitors. Consequently, the reduced peak-to-peak voltage ripple in the DC link enables the use of smaller capacitors, contributing to a more compact DSTATCOM design. Additionally, the system addresses power quality issues by significantly reducing current harmonics. The lower harmonic distortion in the source current enhances overall supply utilization.

Keywords: Power Quality, Voltage, current, Power

1. INTRODUCTION

With the growing complexity of power systems and the increased use of distributed energy resources (DERs), maintaining high power quality has become a significant challenge. Nonlinear loads, such as adjustable speed drives, arc furnaces, and switching power supplies, introduce harmonics and demand reactive power. This leads to voltage distortions, imbalances, and flicker. These power quality issues negatively affect both utility and consumer equipment. To tackle these problems, Custom Power Devices (CPDs), like Distribution Static Compensators (DSTATCOMs), have been widely used. The effectiveness of a DSTATCOM largely depends on its control strategy. Traditional control methods, such as PI controllers, are simple but struggle with poor performance when dealing with nonlinearity and changes in parameters. In contrast, Sliding Mode Control (SMC) is a strong nonlinear control method that can manage system uncertainties and external disturbances. However, SMC alone may cause chattering, which impacts system performance. This paper combines PI control with SMC to take advantage of both methods. The hybrid controller improves voltage regulation, reduces harmonics, and enhances overall power quality in the distribution system.

2. CONVENTIONAL DSTACOM TOPOLOGY

A DSTATCOM is a shunt-connected power electronic device that uses a Voltage Source Converter (VSC) to inject compensating currents into the distribution network. The main components of a conventional DSTATCOM are:

- Voltage Source Converter (VSC): Converts DC to AC voltage and injects currents with the desired magnitude and phase.

- DC Energy Storage Device: Provides the needed DC link voltage.

- Coupling Transformer: Connects the VSC to the distribution line.

- Control System: Determines the reference currents and regulates the injected currents.

Working Principle:

The DSTATCOM compensates for reactive power and harmonics by generating currents that match in magnitude but are opposite in phase to the load currents. A reference current generation algorithm, such as Instantaneous Reactive Power Theory or Synchronous Reference Frame theory, helps the controller ensure that the source current stays sinusoidal and in phase with the voltage.

However, the conventional PI control in DSTATCOM has issues with:

- Poor dynamic response during fast load changes.

- Sensitivity to changes in parameters.

- Limited ability to reject disturbances.

These limitations require the use of a better control strategy like SMC.

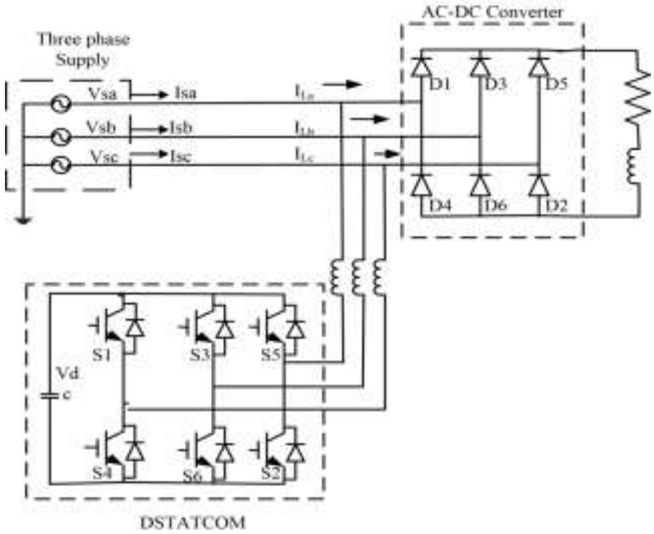

Figure 1 Two-level inverter based DSTATCOM circuit

3.3 SLIDING MODE CONTROL

Sliding Mode Control (SMC) is a strong nonlinear control technique. It forces the system states to "slide" along a predefined surface, known as the sliding surface, towards the desired equilibrium point. This happens even when there are disturbances and uncertainties in parameters.

3.1 Control Objectives - Keep the source current sinusoidal and in phase with the supply voltage.

- Regulate the DC link voltage.

- Compensate for harmonics and reactive power.

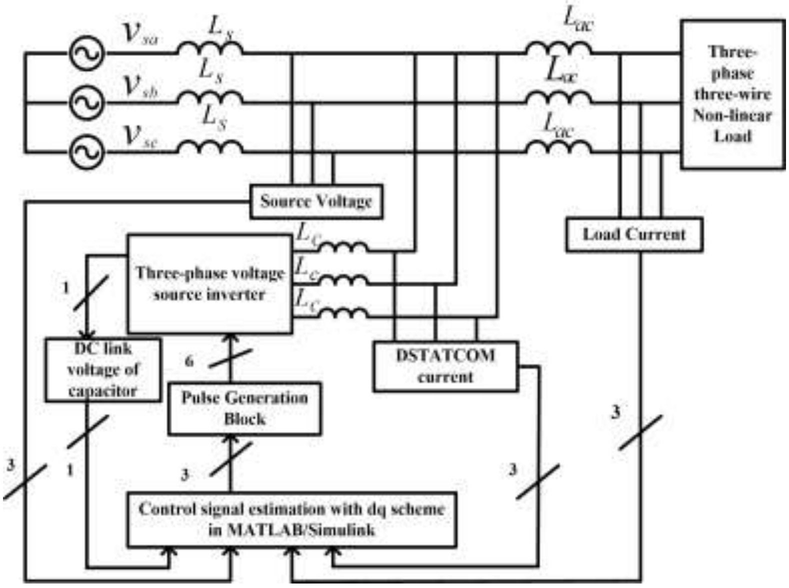

Figure 2 DSTATCOM control scheme

3.2 PI + SMC Hybrid Approach

PI Controller: Keeps the DC link voltage at its reference by adjusting the modulation index.

SMC: Controls the current injection to ensure strength against disturbances.

This hybrid setup combines a fast dynamic response from SMC with zero steady-state error from PI.

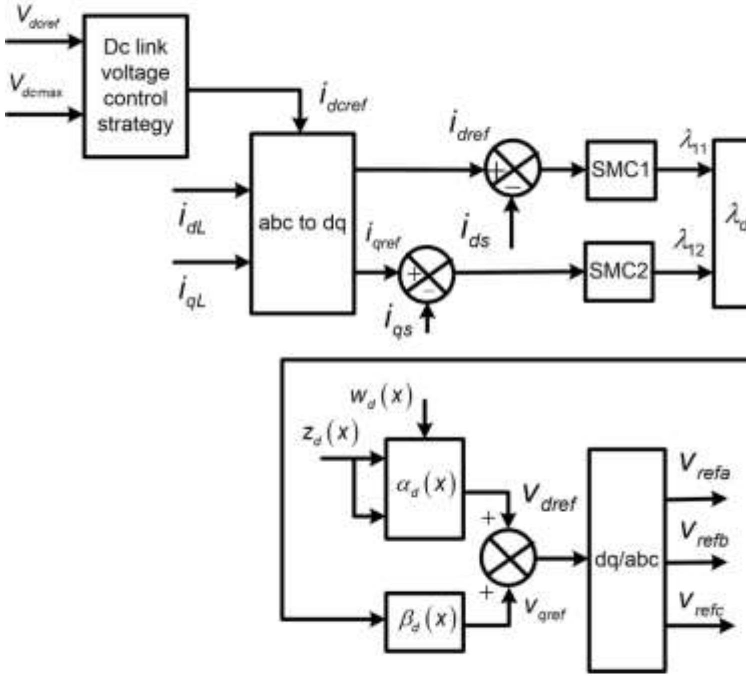

Figure 3 IRP theory with SMC

4 SIMULATION RESULTS

Table 1 DSTATCOM system parameters for simulation

Parameters	**Description**
AC line parameters	Three-phase, three-wire, 440V, 50 Hz
Line impedance	Rs=0.1Ω Ls=0.5mH
DC bus voltage of DSTATCOM	450 V
DC bus capacitance of DSTATCOM	2200μF
APF interfacing inductor	L_c= 1.4 mH
Commutation inductance	L_f = 1 mH
Load	Three-phase uncontrolled rectifier, R_{dc}=9.5Ω L_{dc}=16mH
Sampling time	T_s = 10 μs.

4.1 Simulation results with PI controller

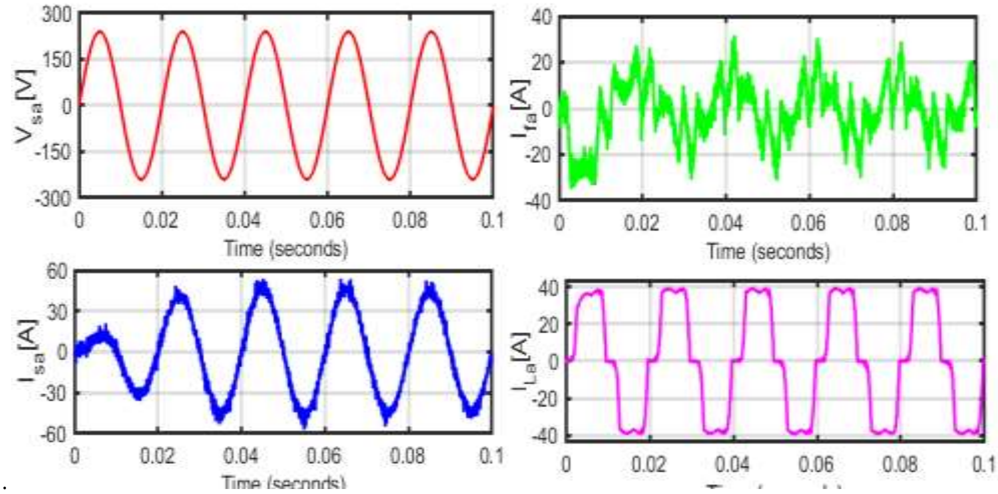

Figure 4 Simulated waveforms of DSTATCOM with PI controller

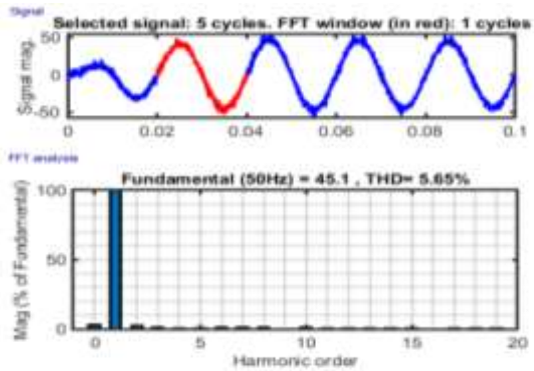

Figure 5 Source current THD with PI controller

4.2 Simulation results with SMC

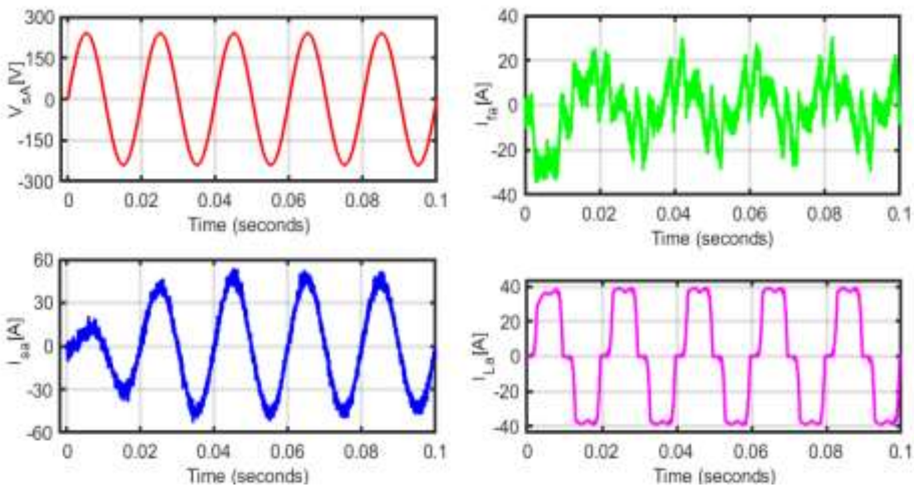

Figure 6 Simulated waveforms of DSTATCOM with SMC controller for single phase power system

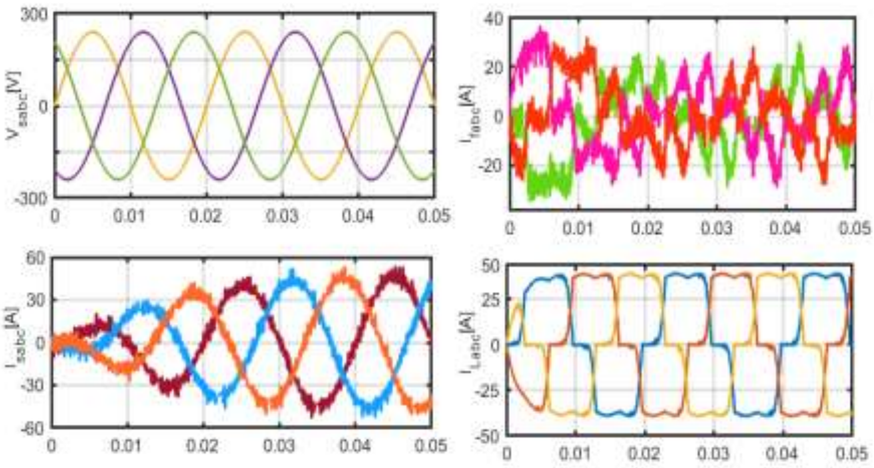

Figure 7 Simulated waveforms of DSTATCOM with SMC controller for three phase power system

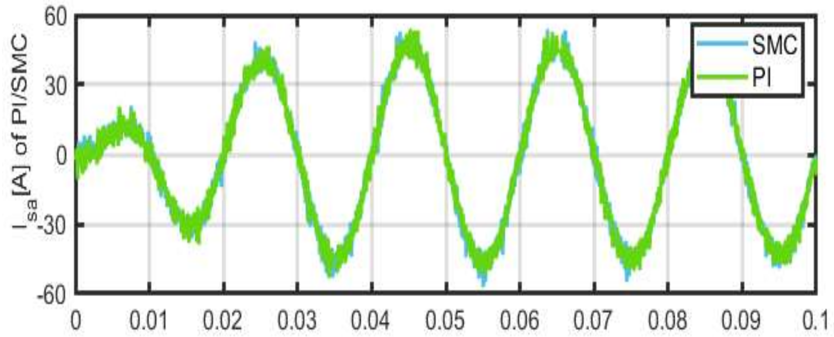

Figure 3.8 Simulated waveforms of DSTATCOM with SMC/PI.

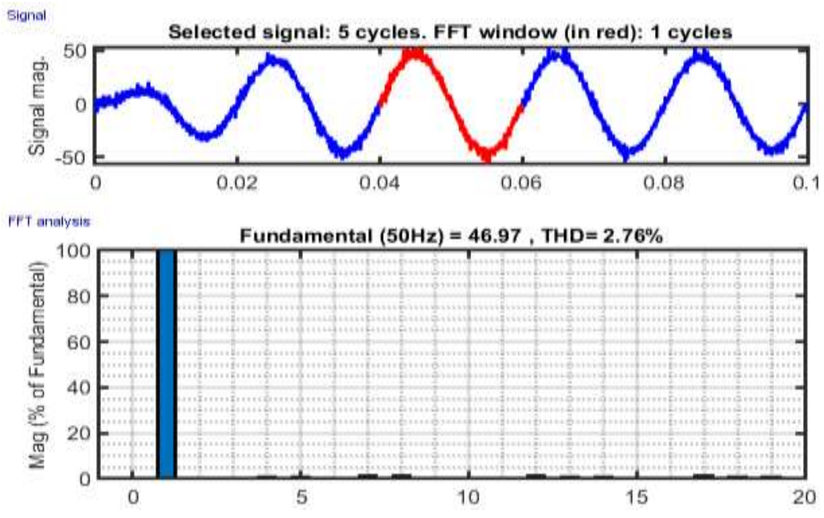

Figure 9 Source current THD with SM

5.Conclusion: -

The proposed hybrid PI and Sliding Mode Controller (SMC) for the DSTATCOM has shown that it can significantly improve power quality in distribution systems. The PI controller effectively regulates the DC link voltage. It ensures stability during normal operating conditions. Meanwhile, the SMC offers strong robustness against load changes, system nonlinearities, and external disturbances. Simulation results confirm that this combined approach achieves lower Total Harmonic Distortion (THD), a faster transient response, and better compensation of reactive power compared to traditional methods.

This hybrid control strategy not only improves the voltage profile and current quality but also boosts the overall reliability of the power distribution network. As a result, it provides a practical and effective solution for modern smart grids, where power quality standards are becoming stricter. Future work can focus on implementing hardware and testing it in real-time conditions to further validate its performance.

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