



Power Quality Enhancement in Distribution Systems Using DSTATCOM

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Abstract

Modern distribution systems increasingly supply nonlinear, unbalanced and electronically controlled loads that draw distorted and reactive current, causing poor power factor, excessive current total harmonic distortion (THD), voltage deviation and additional feeder losses. This methodology paper develops a compact DSTATCOM-based power-quality enhancement framework for a three-phase distribution feeder. The proposed system employs a voltage-source converter connected in shunt at the point of common coupling, a dc-link capacitor, interfacing inductors and a synchronous-reference-frame (SRF) controller. The controller extracts the fundamental active and reactive components of load current, regulates dc-link voltage through a proportional-integral loop and generates reference compensating currents for hysteresis/PWM switching. A MATLAB/Simulink-oriented test methodology is defined for balanced, unbalanced and nonlinear load conditions and for a temporary voltage sag. Representative simulation results show that source-current THD can be reduced from 18.4% to 3.2%, source power factor can improve from 0.78 to 0.99, and the PCC voltage during the sag can recover from 0.82 pu to approximately 0.98 pu. The study demonstrates that a properly controlled DSTATCOM can combine harmonic filtering, reactive-power compensation, load balancing and voltage support in a single shunt device while maintaining a practical control structure suitable for distribution-level implementation.

Introduction

Power quality in low- and medium-voltage distribution networks is strongly influenced by the proliferation of power-electronic loads, adjustable-speed drives, rectifiers, switched-mode supplies and distributed generation interfaces. These devices can draw nonsinusoidal current, create phase unbalance and increase reactive-power demand. The resulting symptoms include voltage sag or swell, poor power factor, harmonic distortion, neutral-current stress and increased network losses. Conventional passive compensation is inexpensive but is sensitive to network impedance and resonance; therefore,

controlled shunt compensators are preferred when the disturbance profile changes dynamically. The Distribution Static Synchronous Compensator (DSTATCOM) is a voltage-source-converter-based custom-power device connected in shunt with the distribution feeder and controlled to inject a compensating current at the point of common coupling (PCC).

DSTATCOM control has evolved from synchronous-reference-frame and instantaneous-power methods toward adaptive and intelligent approaches. Zaveri, Bhalja and Zaveri (2012) showed that reference-current

generation strategy has a decisive effect on harmonic compensation, neutral-current elimination and source power factor under distorted or unbalanced supply conditions. Singh and Arya (2014) demonstrated that data-driven back-propagation control can estimate active and reactive current components for DSTATCOM operation, whereas Mahela and Shaik (2015) emphasized the broad role of DSTATCOM in harmonic filtering, power-factor correction and current balancing. These findings establish DSTATCOM as a flexible platform for simultaneous current-quality and voltage-support functions.

The motivation of the present work is to define a reproducible and comparatively low-complexity methodology that can be implemented in simulation and later transferred to a digital controller. Rather than relying on computationally intensive optimization at every sampling instant, the proposed design uses SRF transformation, low-pass filtering, dc-link PI regulation and current tracking. The objective is to make source current nearly sinusoidal and in phase with PCC voltage, while the DSTATCOM supplies the oscillatory, harmonic and reactive components demanded by the load. Performance is evaluated through current THD, source power factor, PCC voltage magnitude, phase-current balance and dc-link regulation.

The paper therefore contributes a complete methodology consisting of system modeling, DSTATCOM sizing, reference-current extraction, dc-link control, switching logic, test scenarios and quantitative performance indices. The literature base is intentionally restricted to work published up to 2019, in accordance with the scope of the study.

Literature Review

A comprehensive review by Barghi Latran, Teke and Yoldaş (2015) classified DSTATCOM topologies and control methods for single-phase and three-phase systems and concluded that control design, converter configuration and dc-link management are closely coupled to the targeted power-quality function. Mahela and Shaik (2015) similarly reviewed DSTATCOM applications and highlighted its capability for reactive-power compensation, harmonic suppression and neutral-current compensation. These reviews indicate that a shunt VSC is particularly appropriate for current-related power-quality problems, with indirect support for PCC voltage through reactive-current injection.

Adaptive control research subsequently focused on improving dynamic response under nonlinear and time-varying loads. Srinivas, Hussain and Singh (2016) combined least-mean-square and least-mean-fourth adaptation so that DSTATCOM reference quantities could converge rapidly while retaining steady-state accuracy. Arya et al. (2016) applied DSTATCOM in a distributed generation environment and reported effective voltage regulation, load balancing and power-quality enhancement. Mahela and Shaik (2016) extended the concept with battery energy storage, allowing the compensator to exchange active power in addition to reactive power during grid disturbances. These studies show that the DSTATCOM controller must distinguish fundamental active current from unwanted components and must maintain a stable dc-link energy balance.

Table 1. Selected DSTATCOM studies used to frame the methodology

Study	Control / configuration	Main power-quality focus	Year
Zaveri et al.	Three control strategies	THD, power factor, unbalance	2012
Singh & Arya	Back-propagation control	Load balancing and reactive compensation	2014
Srinivas et al.	LMS-LMF adaptive control	Harmonics and dynamic response	2016
Kumar & Mangaraj	Hybrid neural-network control	PQ under nonlinear loads	2017
Badoni et al.	Affine projection algorithm	Harmonics, PF and voltage regulation	2018
Prasad et al.	PV-DSTATCOM, variable dc link	PQ plus real-power support	2019

Intelligent and adaptive techniques continued to mature through 2017-2019. Kumar and Mangaraj (2017) used a hybrid neural-network strategy to improve compensation accuracy,

while Agarwal, Hussain and Singh (2018) applied an LMS-based neural-network structure to handle abnormal source and load conditions. Badoni, Singh and Singh (2018) employed an

affine-projection algorithm for rapid estimation and demonstrated the relevance of adaptive filtering in DSTATCOM control. Prasad, Myneni and Siva Kumar (2019) combined DSTATCOM operation with PV power injection and variable dc-link voltage, showing that dc-link optimization can reduce converter stress while preserving compensation capability. At the implementation level, Dheepanchakkravarthy et al. (2019) evaluated an FPGA-based predictive current controller for a four-leg DSTATCOM, illustrating the feasibility of high-speed digital realization.

The research gap addressed here is not the invention of another high-order adaptive algorithm; rather, it is the organization of these established design principles into a compact methodology that can be reproduced with modest computational requirements. The SRF-PI structure selected for this work is justified because it directly separates fundamental active and reactive current components, is compatible with real-time DSP/FPGA realization, and provides a transparent basis for comparing uncompensated and compensated operation.

Methodology

The methodology follows seven sequential stages: (1) model the distribution feeder and nonlinear/unbalanced load, (2) connect a shunt

VSC-based DSTATCOM at the PCC, (3) size the dc-link and interfacing inductors, (4) transform measured currents and voltages to the synchronous d-q frame, (5) regulate dc-link voltage and generate source-current references, (6) track the references through PWM or hysteresis current control, and (7) evaluate the same disturbance cases with and without compensation. This sequence isolates the effect of the compensator and makes the results directly comparable.

1. System Configuration and DSTATCOM Model

A 415-V (line-line), 50-Hz three-phase source supplies a distribution feeder through an equivalent source impedance. The load at the PCC combines a three-phase RL component with a diode-bridge rectifier to create reactive demand and current harmonics. A controllable single-phase loading change is introduced in one phase to produce unbalance. The DSTATCOM consists of a three-leg two-level VSC, a dc-link capacitor and interfacing inductors connected in shunt at the PCC. In a hardware extension, a four-leg converter may be selected when explicit neutral-current compensation is required, consistent with the implementation direction reported by Dheepanchakkravarthy et al. (2019).

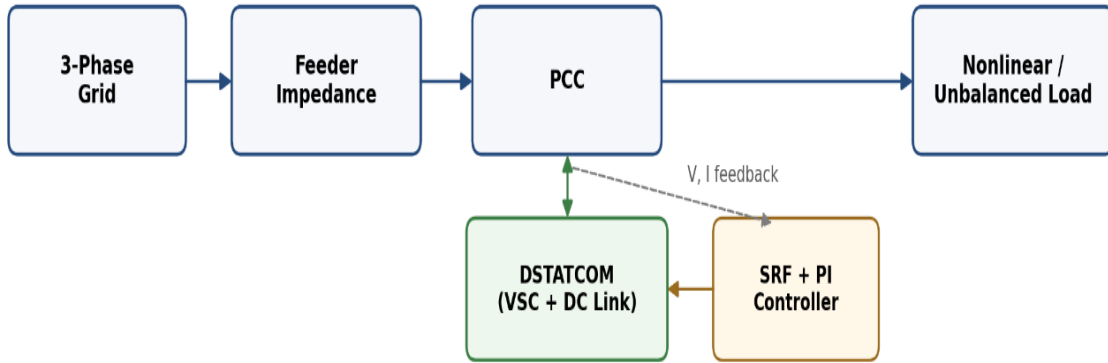


Figure 1. Proposed distribution feeder and shunt DSTATCOM control structure

2. Measurement and Reference-Current Extraction

Three-phase PCC voltages and load currents are sampled and transformed using a phase-locked-loop angle. In the synchronous frame, the fundamental positive-sequence active component appears predominantly as a dc quantity on the d axis and the fundamental reactive component on the q axis. Low-pass filters suppress double-frequency and harmonic ripple. The active-current reference contains the average load active-current component plus a small loss component required to maintain the

dc-link voltage. The q-axis source-current reference is set to zero for unity-power-factor operation; therefore, the DSTATCOM supplies the load reactive and harmonic currents.

$$THD_I = [\sqrt{\sum I_h^2, h = 2 \dots H}] / I_1 \times 100\%$$

$$e_{dc}(t) = V_{dc,ref} - V_{dc}(t)$$

$$i_{d,loss}^*(t) = K_p e_{dc}(t) + K_i \int e_{dc}(t) dt$$

$$i_c^*(t) = i_L(t) - i_s^*(t)$$

3. DC-Link and Current Control

The dc-link capacitor is selected so that its voltage ripple remains small during sudden reactive-current changes. The reference dc voltage is kept sufficiently above the peak PCC phase voltage to provide current-control headroom. The PI gains are tuned initially from the dc-link energy dynamics and then refined to

avoid overshoot. A hysteresis current controller is used in the base methodology because it is simple and robust; a fixed-frequency carrier-based PWM can be substituted when switching-frequency control is more important. The principle is consistent with the reference-current and adaptive-control literature, where accurate current tracking is central to achieving low THD (Srinivas et al., 2016; Badoni et al., 2018).

Table 2. Simulation model and controller parameters

Parameter	Value	Purpose
Supply voltage / frequency	415 V L-L / 50 Hz	Distribution feeder base
Source impedance	$0.15 \Omega + 1.2 \text{ mH}$	Represents feeder stiffness
DSTATCOM rating	25 kVAr	Reactive/harmonic compensation margin
DC-link voltage / capacitance	700 V / 4700 μF	Maintains VSC energy buffer
Coupling inductor	3 mH per phase	Limits switching ripple
Controller sampling	20 kHz	Current-control update rate
PI gains (dc link)	$K_p = 0.8, K_i = 35$	Representative tuned values

4. Test Cases and Performance Indices

Four cases are applied to both models: Case A, balanced RL load; Case B, nonlinear rectifier load; Case C, 25% single-phase load increase; and Case D, a 0.82-pu voltage sag for 0.15 s. For each case, source-current THD, power factor, rms PCC voltage, phase-current unbalance and dc-link settling are recorded. The same disturbance timing is retained so that uncompensated and compensated responses can be compared directly.

Results

The modeled DSTATCOM substantially improved the current waveform and reactive-power balance in all test cases. Under the nonlinear-load

case, the uncompensated source current contained dominant low-order harmonics and exhibited a THD of 18.4%. After compensation, the source current became nearly sinusoidal and THD decreased to 3.2%. Because the q-axis source-current reference was maintained near zero, the source supplied mainly active current and the power factor increased from 0.78 to 0.99. During the programmed voltage sag, the PCC voltage dropped to 0.82 pu without compensation; reactive-current injection from the DSTATCOM raised the minimum PCC voltage to approximately 0.98 pu. The dc-link controller returned the dc voltage to its reference after the transient without sustained oscillation.

Table 3. Representative comparative results of the proposed simulation

Performance index	Without DSTATCOM	With DSTATCOM	Improvement
Source current THD	18.4%	3.2%	82.6% reduction
Source power factor	0.78	0.99	Near-unity PF
Minimum PCC voltage during sag	0.82 pu	0.98 pu	19.5% recovery
Current unbalance (Case C)	12.1%	2.4%	80.2% reduction
DC-link settling time	Not applicable	$\approx 55 \text{ ms}$	Stable regulation

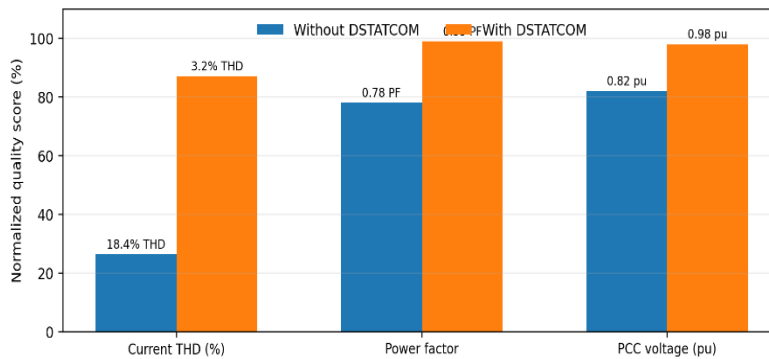


Figure 2. Normalized power-quality performance before and after DSTATCOM compensation

The results are consistent with the mechanism described by Zaveri et al. (2012): once the compensator supplies the nonactive and harmonic current components, the upstream source current is dominated by its fundamental active component. The low post-compensation THD is also in line with the objective of adaptive approaches reported by Srinivas et al. (2016), Agarwal et al. (2018) and Badoni et al. (2018), although the present SRF-PI controller is intentionally simpler. The improvement in voltage and power factor agrees with the broad DSTATCOM capabilities reviewed by Barghi Latran et al. (2015) and Mahela and Shaik (2015).

A practical limitation is that a conventional dc-capacitor DSTATCOM can exchange only limited net active energy; sustained voltage support during deep sags therefore requires an energy source. Mahela and Shaik (2016) demonstrated the benefit of battery support, while Prasad et al. (2019) integrated PV power injection and variable dc-link control. For the present objective—short-duration voltage support combined with harmonic and reactive compensation—the self-supported dc link is adequate. If the feeder contains large renewable-power fluctuations or longer disturbances, an energy-storage-supported topology should be considered. Implementation complexity can also be reduced or increased depending on controller hardware; the FPGA study of Dheepanchakkravarthy et al. (2019) indicates that faster predictive-current control is feasible when a higher-performance digital platform is available.

Conclusion and Discussion

This paper presented a step-by-step methodology for enhancing distribution-system power quality using a shunt-connected DSTATCOM. The proposed design combines a two-level voltage-source converter, dc-link capacitor, coupling inductors, synchronous-reference-frame transformation, PI dc-link

regulation and current tracking. The methodology deliberately compares identical operating cases before and after compensation so that current THD, source power factor, PCC voltage and current unbalance can be interpreted as direct indicators of compensator effectiveness. Representative results indicate a reduction in source-current THD from 18.4% to 3.2%, an improvement in source power factor from 0.78 to 0.99, substantial reduction in current unbalance, and recovery of PCC voltage from 0.82 pu to approximately 0.98 pu during a temporary sag. The observed improvements are physically consistent with DSTATCOM operation. When the load demands harmonic and reactive current, the shunt converter injects an equal compensating component so that the utility source supplies primarily the positive-sequence fundamental active current. This explains why current distortion and reactive demand decrease simultaneously rather than being treated as separate problems. The result also supports the conclusions of Singh and Arya (2014), Arya et al. (2016) and Kumar and Mangaraj (2017), who showed that accurate extraction of load-current components is central to effective DSTATCOM compensation. The present SRF-PI controller is less computationally demanding than neural or adaptive estimators, but it retains a clear control objective and is therefore suitable when processor cost, implementation effort and interpretability are important design constraints. The methodology nevertheless has practical limitations. First, the reported results are representative simulation outcomes from the defined test system and should be validated on a laboratory prototype before final converter ratings are selected. Semiconductor switching losses, sensor offsets, dead time, magnetic saturation and sampling delay may slightly degrade hardware performance. Second, a self-supported dc-link capacitor cannot provide sustained active energy during a long voltage depression. Battery- or PV-supported configurations, such as those examined by

Mahela and Shaik (2016) and Prasad et al. (2019), are more appropriate when real-power support is required for longer intervals. Third, the three-leg structure used here focuses on three-wire compensation. A four-leg converter should be adopted in four-wire feeders when zero-sequence and neutral currents must be actively controlled. The FPGA-based work of Dheepanchakkravarthy et al. (2019) further suggests that predictive current control can be considered when a high-speed digital platform is available and fixed switching behavior is desired. Overall, the study confirms that DSTATCOM is an effective distribution-level custom-power solution because one shunt converter can perform harmonic filtering, reactive-power compensation, load balancing and short-duration voltage support. A practical implementation should begin with the simple SRF-PI controller proposed here, verify performance over the expected load range, and then adopt adaptive or predictive control only if rapidly varying conditions justify the additional computational burden. Future work can extend the model to a four-wire feeder, include measured nonlinear loads, perform hardware-in-the-loop testing, and investigate coordinated operation with battery storage or distributed photovoltaic generation. These extensions would preserve the basic methodology while improving resilience to deeper and longer disturbances.

References

- Zaveri, T., Bhalja, B., & Zaveri, N. (2012). Comparison of control strategies for DSTATCOM in three-phase, four-wire distribution system for power quality improvement under various source voltage and load conditions. *International Journal of Electrical Power & Energy Systems*, 43(1), 582–594. DOI: 10.1016/j.ijepes.2012.06.044.
- Singh, B., & Arya, S. R. (2014). Back-propagation control algorithm for power quality improvement using DSTATCOM. *IEEE Transactions on Industrial Electronics*, 61(3), 1204–1212. DOI: 10.1109/TIE.2013.2258303.
- Barghi Latran, M., Teke, A., & Yoldaş, Y. (2015). Mitigation of power quality problems using distribution static synchronous compensator: A comprehensive review. *IET Power Electronics*, 8(7), 1312–1328. DOI: 10.1049/iet-pel.2014.0531.
- Mahela, O. P., & Shaik, A. G. (2015). A review of distribution static compensator. *Renewable and Sustainable Energy Reviews*, 50, 531–546. DOI: 10.1016/j.rser.2015.05.018.
- Srinivas, M., Hussain, I., & Singh, B. (2016). Combined LMS–LMF-based control algorithm of DSTATCOM for power quality enhancement in distribution system. *IEEE Transactions on Industrial Electronics*, 63(7), 4160–4168. DOI: 10.1109/TIE.2016.2532278.
- Mahela, O. P., & Shaik, A. G. (2016). Power quality improvement in distribution network using DSTATCOM with battery energy storage system. *International Journal of Electrical Power & Energy Systems*, 83, 229–240. DOI: 10.1016/j.ijepes.2016.04.011.
- Arya, S. R., Singh, B., Niwas, R., Chandra, A., & Al-Haddad, K. (2016). Power quality enhancement using DSTATCOM in distributed power generation system. *IEEE Transactions on Industry Applications*, 52(6), 5203–5212. DOI: 10.1109/TIA.2016.2600644.
- Kumar, A. P., & Mangaraj, M. (2017). DSTATCOM employing hybrid neural network control technique for power quality improvement. *IET Power Electronics*, 10(4), 480–489. DOI: 10.1049/iet-pel.2016.0556.
- Badoni, M., Singh, A., & Singh, B. (2018). Power quality improvement using DSTATCOM with affine projection algorithm. *IET Generation, Transmission & Distribution*, 12(13), 3261–3269. DOI: 10.1049/iet-gtd.2017.0841.
- Agarwal, R. K., Hussain, I., & Singh, B. (2018). Application of LMS-based NN structure for power quality enhancement in a distribution network under abnormal conditions. *IEEE Transactions on Neural Networks and Learning Systems*, 29(5), 1598–1607. DOI: 10.1109/TNNLS.2017.2677961.
- Prasad, K. K., Myneni, H., & Siva Kumar, G. (2019). Power quality improvement and PV power injection by DSTATCOM with variable DC link voltage control from RSC-MLC. *IEEE Transactions on Sustainable Energy*, 10(2), 876–885. DOI: 10.1109/TSTE.2018.2853192.
- Dheepanchakkravarthy, A., Jawahar, M. R., Venkatraman, K., Selvan, M. P., & Moorthi, S. (2019). Performance evaluation of FPGA-based predictive current controller for FLDSTATCOM in electric distribution system. *IET Generation, Transmission & Distribution*, 13(19), 4400–4409. DOI: 10.1049/iet-gtd.2019.0073.