DSTATCOM Application for Distribution Network Power Quality Enhancement: A Review

Mohamed Amidu Kallon
Electrical Engineering Department
Pan African University
Institute for Basic Sciences,
Technology and Innovation
Nairobi, Kenya
kallon.mohamed@students.jkuat.ac.ke.

George Nyauma Nyakoe
Electrical and Electronic Engineering Department
Jomo Kenyatta University of Agriculture and Technology
Nairobi, Kenya
nyakoe@eng.jkuat.ac.ke

Christopher Maina Muriithi
Electrical and Electronic Engineering Department
Muranga University of Technology
Muranga, Kenya
cmmuriithi@mut.ac.ke

***Abstract*— The performance of electrical systems is becoming more affected by the increased voltage drop, power loss, and power quality problems. These issues can be drastically minimized by the incorporation of compensators in the distribution network. Distribution Static Compensator (DSTATCOM), like similar reactive power compensation systems, is a shunt connected unit of the Distribution Flexible AC Transmission System (DFACTS). DSTATCOM has been used for power system operation versatility and control in recent years, specifically to provide control for reactive power flow, power loss mitigation, power quality enhancement, and current and voltage control. Many researchers are presently carrying out studies on the optimal use of DSTATCOM in distribution networks. This paper presents a detailed summary of the recent approaches used by various authors to evaluate and determine the optimal use of DSTATCOM in distribution networks in order to enhance power quality. The methods and platforms used and the various research objectives are clearly outlined and discussed in detail. An analysis of the reviewed works is provided as well as suggestions for future research.**

Keywords*— *distribution network, DSTATCOM, power quality enhancement, Reactive power compensation.

I. INTRODUCTION

Power quality and voltage profile improvement are the prime motivator behind today's modern industry. Over the last decade, consumer awareness of the significance of a stable power supply has skyrocketed [1]. As a result, the study of power quality has interested many researchers and it is evident in the voluminous number of techniques that have been implemented to improve power quality.

When it comes to power quality enhancement of a power system, the control of reactive power is a critical factor. Reactive power lowers power transmission capacity, raises transmission losses, and reduces voltage control at the consumer end. Thyristor-Controlled Reactors (TCR), Thyristor-Switched Capacitors (TSC), etc. were used in the past to compensate for reactive power. There are several ways to reduce power quality issues in distribution and transmission networks, thanks to the advancements in the versatility of flexible alternating current transmission systems (FACTS) devices. The DSTATCOM is among the most powerful of these devices. DSTATCOM offers protection against voltage flicker and sags caused by quickly varying demands for reactive current to the distribution or transmission system of the utility [2]. A DSTATCOM is used in utility applications to provide lagging reactive control and to maintain system reliability. The DSTATCOM has been proven to be a device that is capable of addressing power quality issues [3]. A DSTATCOM is a quick reaction, solid-state power regulator that provides adjustable voltage control at its point of common coupling (PCC), and it's an electronic voltage source converter (VSC) that is wired in parallel to the utility's distribution system to mitigate power quality problems [4].

Whenever a DSTATCOM is connected to a specific load, it generates compensating current to ensure that overall demand follows utility link requirements. Internally, DSTATCOM generates inductive and capacitive reactive power [5]. It has a quick control mechanism that can provide the system with appropriate reactive compensation. DSTATCOM can be used to efficiently control voltage for a set of small induction motor loads that draw a high starting current that is about 5 to 6 times of maximum rating current and can interfere with the operation of other responsive loads on the network [6].

Due to the high effectiveness of DSTATCOM in enhancing distribution network performance, it has attracted many researchers to focus on newer methods of maximizing its benefits. This paper presents a review of the most recent approaches used by various researchers to maximize the benefits of DSTATCOM to enhance power quality and distribution system performance.

The rest of this paper is organized as follow: Section II gives a brief theoretical framework of DSTATCOM, Section III presents a detailed review of DSTATCOM's recent research approaches, and Section IV gives a comprehensive summary of DSTATCOM recent research techniques with some recommendations for future research work.

II. DSTATCOM BRIEF THEORETICAL FRAMEWORK

A. DSTATCOM and its Basic Structure

DSTATCOM is a custom control power technology built on a voltage source converter (VSC) that can serve as a source of reactive power in power systems. By generating reactive power or absorbing reactive power from the distribution network, the DSTATCOM can control the magnitude of the voltage at a certain AC bus where the device is connected. The illustrative DSTATCOM schematic diagram is shown in Fig. 1. The main mechanisms of DSTATCOM include the following: VSC (Voltage Source Converter), DC storage, Control unit, and Injection transformer.

Funded by the African Union (AU) through PAUSTI.

2021 IEEE PES/IAS PowerAfrica | 978-1-6654-0311-5/21/$31.00 ©2021 IEEE | DOI: 10.1109/POWERAFRICA52236.2021.9543214

B. Principle of Operation of DSTATCOM

The DSTATCOM is just a voltage source converter (VSC) that uses a linked tie reactance to compensate for load current and retain a constant voltage profile when connected in shunt to the distribution system by a coupling transformer. The injection transformer reactance in the storage system transforms the dc voltage to a set of three-phase AC output voltages, which are connected to the ac system and are in phase with the line voltage. The modification of the magnitude and phase of DSTATCOM's output voltages permits for efficient regulation of the reactive and active power transfer between DSTATCOM and the distribution network [7]. This configuration allows the system to generate or consume controllable reactive and active power. DSTATCOM absorbs reactive current or power if the load/line voltage is higher than the required load voltage; if the load voltage magnitude is smaller than the required load voltage, reactive current or power is supplied to the load to increase its voltage. DSTATCOM can compensate for either the bus voltage or the line current. Depending on the parameter it controls, it can function in two control modes [8]; voltage control mode and current control mode.

Voltage Mode Operation: For this mode, the DSTATCOM creates a sinusoidal voltage on the bus to which the device is connected. This can be accomplished regardless of supply voltage unbalance or distortion.

Current Mode Operation: The DSTATCOM forces the current from the source to become a balanced sinusoid regardless of the load current harmonics. In voltage sag reduction, the basic operating concept of a DSTATCOM is to control the bus voltage by producing or absorbing reactive power.

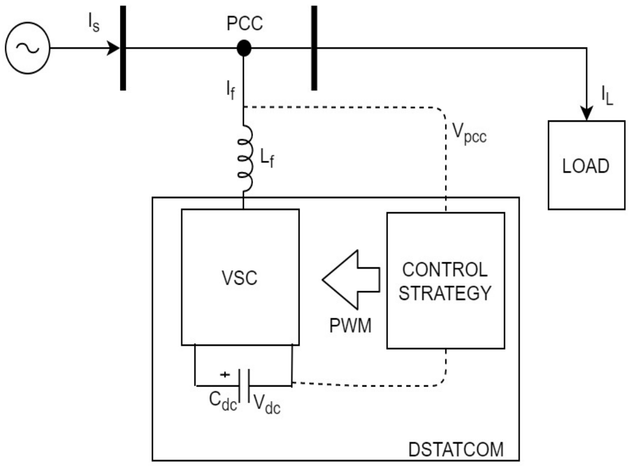

Fig. 1. Illustrative DSTATCOM Schematic Diagram [9]

III. REVIEW ON DSTATCOM RECENT RESEARCH TECHNIQUES FOR POWER QUALITY

There are many kinds of researches in the literature that focused on the enhancement of power quality in distribution networks by using DSTATCOM. Mahela et al [10] proposed a method to study the improvement of the quality of power using DSTATCOM, which is equipped with a battery power storage system and interacts with the distribution network with the integration of photovoltaic (PV) solar energy. In previous studies, DSTATCOM is controlled by a control scheme based on synchronous frame theory. A custom IEEE-13 node test system including solar photovoltaic production and DSTATCOM were used to perform harmonic mitigation and power quality analyses. The MATLAB/Simulink environment was used to perform the study. The effectiveness of the developed approach was validated by relating the simulation outcomes with the results extracted in real-time using a real-time digital simulator. The results showed that the developed approach is more useful for harmonic reduction and improvement of the quality of electrical energy in the distribution network combined with photovoltaic solar production. The approach's performance was also compared with the performance of previous approaches reported by other researchers to establish the adequacy of the harmonic mitigation method and the improvement of energy quality in the solar-powered grid.

Knowing fully well that the DSTATCOM device can be used to control reactive energy flow in distribution systems, Ahmed et al [11] designed a Fixed Frequency Sliding mode control (FFSMC) for application in DSTATCOM. To perform the proposed FFSMC, two test cases were performed. In the first case, the dipping/swelling of the main network voltage was taken into account, while in the second case, an unbalanced load condition was considered. The proposed FFSMC design was based on constant switching frequency operation and Gao's reaching law was used to eliminate the phenomenon under discussion [11]. A real-time simulation was performed using the MATLAB/SIMULINK environment to examine the functioning of the proposed control. The proposed FFSMC simulation results were compared with the conventional proportional-integral (PI) control. The results revealed the benefits of the proposed FFSMC in terms of low THD, robustness and acceleration.

Patel et al [12] presented a PV system control as DSTATCOM, known as PV-DSTATCOM, which has ACC (active current control) and FFCL (feed-forward control loops). In addition to power injection to the distribution network, the suggested photovoltaic system can be autonomously converted to DSTATCOM to provide a variety of support services, including reactive load current compensation, source current harmonic removal, power factor correction, and zero sequence component reduction. The high gain of third-order harmonics was introduced, thus alleviating the static error in the current PV inverter control cycle. The proposed structure of the FFCL and ACC was efficient and absolutely stable. A simplified perturb and observe based MPPT was employed to evacuate the PV array's maximum power. A series of transient studies were carried out using MATLAB/Simulink software to study the ability of FFCL and ACC design structure. In addition, a laboratory configuration was developed using the dSPACE-1104 platform, the results of the experiment were recorded, and detailed benchmarks were provided.

In order to improve power quality, Jahnavi et al [13] presented DSTATCOM with a combination of proportional resonance (PR) controller and comb filter. The proposed controller reduces the complexity of adjusting resonant controllers and also provides a better current harmonic response. Multiple harmonic compensations have been obtained in the network flow by installing a comb filter, which does not require adjustment for the compensation of individual harmonics, unlike the PR controller. Two different forms of comb filters were implemented, such as feedforward and feedback form, and the results were compared. The DSTATCOM topology used a constant switching technique (sine pulse width modulation, SPWM) for reactive power and harmonic compensation. The MATLAB/Simulink results were used to show the validity of the theoretical claims.

Mishra et al [14] developed a new hybridized fuzzy sliding mode control system for photovoltaic tied DSTATCOM topology for the elimination of disturbances in source currents and reactive energy compensation. A passive double inductor-capacitor (LCLC) filter was used in the photovoltaic output powered by DSTATCOM, which helps connect the solar system to a network. The existence of the standard capacitor in passive filters reduces DC-link voltage, which helps reduce DSTATCOM ratings in the suggested system. The multi-powered DSTATCOM switch signals were generated by the application of a new hybrid diffuse slider system. To improve DC-link voltage controller performance and to regulate the DC-link voltage, a fuzzy logic approach was used. Controller performance was compared with conventional reference signal generation algorithms to analyse the efficiency. An experimental prototype was established in the laboratory and the results were analysed to validate the success of the suggested controller.

DSTATCOM has an LC-type filter that generates a strong ripple on the PCC. This issue can be resolved by using a high-level LCL filter. Sinha et al [15] address the modelling of an LCL filter with DSTATCOM. The proposed model was developed in MATLAB with the aim of reaching a solution for PCC's high ripple. The results show weak harmonics of the electrical grid.

Duarte et al [16] have proposed an algorithm for the control of DSTATCOM that is based on an estimate of the voltage imbalance generated by consumers. The algorithm quantifies parcel voltage imbalances caused by providers (utility) and consumers by using instantaneous voltage and current measurements at PCC. A small-signal model was derived to develop controllers for DSTATCOM to compensate for negative and zero voltage sequences. The controllers were designed with a reference synchronization structure, with two internal current loops and two external voltage loops for each displacement sequence to ensure that DSTATCOM tracks the reference voltage generated by the unbalanced estimation algorithm. In order to validate the proposed method, numerical simulation results obtained from an unbalanced distribution network were used.

Zhen et al [17] proposed an integrated DSTATCOM with Y-Y connected transformer for reactive power compensation. Cascading DSTATCOM was connected to a set of taps on the transformer's primary winding to create an integrated structure. The proposed structure provides a flexible selection of connection point voltages for compensation between voltage classification and current classification. In order to find the reachable compensation range, the compensation capacity and winding current distribution constraint were analysed in detail. To enhance the dynamic operation of the system response, a feedforward compensation control strategy was adopted. To prevent the windings of the transformer from overcurrent, a reactive method of calculating the reference current was proposed, and the simulation and experimental results were introduced to verify the efficiency of the suggested system.

Ramakrishna et al [18] proposed a hybrid convergence technique to evaluate the development of power quality in a distribution network. For power quality analysis, a multi-tier modular converter device based on DSTATCOM was analysed. The proposed hybrid adapter was called adaptive recurrent neural network with a crow search optimization algorithm (ARNN-CSOA) and was used for modular multilevel converter (MMC) optimization based on the DSTATCOM device. The proposed advanced DSTATCOM method provides a fast watt controller with invisible power to compensate for loads, flickers, imbalances, power loss reduction, and voltage regulation. Using the proposed hybrid adapter method, PI controller barriers were identified in advance to provide appropriate MMC-based DSTATCOM measurements. The proposed method was implemented on MATLAB/Simulink platform and associated with different PWM methods such as the SVM and ANN process.

A Neural Network (NN) that is based on LMF (Least Mean Fourth) and LMS (Least Mean Square) control strategies was designed and applied in FPGA (Field Programmable Gate Array) for SAPF (Shunt Active Power Filter) to improve power quality in a three-phase four-wire distribution network by Malathi and Jayachandran, [19]. The suggested control technique was simulated in MATLAB/Simulink to find out the reference current and weight of active and reactive components. The test simulation results of the LMS-LMF control were compared with three other control methods. Neural Network Control was designed as a separate module in FPGAs. The introduction of FGPA exceeds the disadvantages of traditional controllers and provides a fast and accurate response. FPGA's control technique for SAPF was designed as a laboratory sample and the results were analysed and were found that they meet power quality standards.

Kantar and Tedeschi [20] introduced the design of DSTATCOM that is connected to the grid with an LCL (Inductor Capacitor Inductor) filter which is regulated by both SPWM (Sinusoidal-PWM) and direct-quadrature-zero (dq0) current controller. Using two resonant damping techniques, active damping (AD) and passive damping (PD), the LCL filter design of reducing high switching ripple was introduced. The current dq0 controller was designed and presented in detail, and harmonic removal, reactive compensation, and load balancing were realized by the DSTATCOM simulation model. The current dq0 controller was applied in the synchronous reference system, which rotates at the fundamental frequency and consists of harmonic compensation regulators that were based on the sum of the sine signal integrators connected parallel to the PI regulator. A neutral current offset was also performed to handle unbalanced loads using a 0-axis controller. The effect of AD and PD techniques on the system dynamic characteristics and efficiency were provided.

TABLE I below presents a laconic summary of the approaches discussed in this paper.

IV. CONCLUSION AND FUTURE WORK

In this paper, an intuitive survey on recently published researches on DSTATCOM power quality enhancement in distribution networks has been presented. Voltage profile improvement, power loss mitigation, minimizing total harmonic distortion, average voltage deviation, investment cost reduction, and system reliability improvement are observed to have been the main focus of DSTATCOM researches. Despite the many techniques that have been developed, there are minute improvements regarding DSTATCOM capabilities. This necessitates the need for comparative study on different applications of DSTATCOM optimization methods in terms of speed and accuracy. Little studies have been carried out on optimal allocation of DSTATCOMs for unbalanced distribution systems, therefore, it is imperative to focus on this area for future research work. It is observed that most studies have used only one DSTATCOM while few have used two DSTATCOMS. For research with 69 or more buses, it is recommended to use two or more DSTATCOMs while also considering their costs for effective compensation. In most of these recent researches, PV has been incorporated into the design of DSTATCOM to control the DC link voltage, it is recommended for wind energy to be considered for future work in this regard.

ACKNOWLEDGMENT

The authors greatly thank and acknowledge the African Union Commission (AUC) through the Pan African University Institute for Basic Sciences, Technology and Innovation (PAUSTI), for funding this study.

TABLE I. Summary of DSTATCOM Power Quality Approaches

No	Authors	Methodology Used	Strengths and Weaknesses
1	Mahela et al [10]	DSTATCOM equipped with PV solar energy and battery storage	Power quality (harmonics) was improved, the method performed better when compared to the real-time digital simulator, the approach shows better performance in the solar-powered grid than other techniques. There was no comparison using other renewable energy sources to measure the approach's superiority.
2	Ahmed et al [11]	Fixed Frequency Slider Control for DSTATCOM	For both voltage dip/swell modes and unbalanced load condition, the THD was drastically reduced by the proposed technique as compared to the traditional PI controller.
3	Patel et al [12]	PV system control as DSTATCOM, known as PV-DSTATCOM	Autonomous conversion of PV-DSTATCOM to DSTATCOM to provide a variety of support services, including reactive load current compensation, source current harmonic removal, power factor correction, and zero sequence component reduction. A high gain of third-order harmonics was introduced, thus alleviating the static error in the current PV inverter control cycle. The results were validated with a laboratory experiment using dSPACE-1104.
4	Jahnavi et al [13]	DSTATCOM with Proportional Resonance (PR) controller and comb filter	The complexity of adjusting the resonance controller was reduced, a better current harmonics reduction was achieved, the compared results show this approach was very robust.
5	Mishra et al [14]	Hybridized fuzzy sliding mode control	Disturbances in source currents and reactive energy compensation elimination, A passive LCLC filter connects the solar system to a network, DC-link voltage controller performance was improved, and a laboratory prototype was developed and the results were validated. However, a limited number of membership functions were used in the simulation.
6	Sinha et al [15]	High-level LCL filter	The new approach reduces the ripple at the PCC and hence helps the DSTATCOM's ability to further reduce harmonics.
7	Duarte et al [16]	Control Algorithm	Both negative and zero voltage sequence compensation were realized by DSTATCOM. Also, a proper unbalance assessment was conducted in this study.
8	Ramakrishna et al [18]	Adaptive Recurrent Neural Network with a Crow Search Optimization Algorithm (ARNN-CSOA)	The DSTATCOM based method provides a fast watt controller with invisible power to compensate for loads, imbalances, flicker, power loss reduction, and voltage regulation. PI controller barriers were identified in advance to provide appropriate MMC-based DSTATCOM measurements. No validation of the results was made.
9	Malathi and Jayachandran, [19]	Neural Network (NN) that is based on LMF and LMS control	The introduction of FPGA (Field Programmable Gate Array) exceeds the disadvantages of traditional controllers and provides a fast and accurate response. The power quality was improved and a laboratory prototype was developed.
10	Kantar and Tedeschi [20]	DSTATCOM based LCL filter	Harmonic removal, reactive power compensation, and load balancing were realized. The method's efficacy was not validated by comparing it to other approaches.

REFERENCES

[1] B. B. Ateba, J. J. Prinsloo, and R. Gawlik, 'The significance of electricity supply sustainability to industrial growth in South Africa', Energy Reports, vol. 5, pp. 1324–1338, Nov. 2019.

[2] R. T. Hock, Y. R. De Novaes, and A. L. Batschauer, 'A Voltage Regulator for Power Quality Improvement in Low-Voltage Distribution Grids', IEEE Trans. Power Electron., vol. 33, no. 3, pp. 2050–2060, Mar. 2018.

[3] J. P. Keshri and H. Tiwari, 'Quality of Power Enhancement of Distribution Network System Using DSTATCOM in Simulink Tool of MATLAB', in Lecture Notes in Networks and Systems, 2021, vol. 151, pp. 563–572.

[4] G. Sahu, R. K. Patjoshi, and R. Panigrahi, 'An instantaneous symmetrical component active power theory with finite control state based model predictive control strategy for distribution STATCOM', Int. J. Numer. Model. Electron. Networks, Devices Fields, vol. 34, no. 2, p. e2821, Mar. 2021.

[5] E. A. Almabsout, R. A. El-Sehiemy, O. N. U. An, and O. Bayat, 'A Hybrid Local Search-Genetic Algorithm for Simultaneous Placement of DG Units and Shunt Capacitors in Radial Distribution Systems', IEEE Access, vol. 8, pp. 54465–54481, 2020.

[6] S. Sannigrahi and P. Acharjee, 'Maximization of system benefits with the optimal placement of DG and DSTATCOM considering load variations', in Procedia Computer Science, 2018, vol. 143, pp. 694–701.

[7] O. D. Montoya, H. R. Chamorro, L. Alvarado-Barrios, W. Gil-González, and C. Orozco-Henao, 'Genetic-Convex Model for Dynamic Reactive Power Compensation in Distribution Networks Using D-STATCOMs', Appl. Sci., vol. 11, no. 8, p. 3353, Apr. 2021.

[8] C. Kumar, M. K. Mishra, and S. Mekhilef, 'A new voltage control strategy to improve performance of DSTATCOM in electric grid', CES Trans. Electr. Mach. Syst., vol. 4, no. 4, pp. 295–302, Jan. 2021.

[9] P. K. Ainah, K. Folly, and A. F. Sagonda, 'Increasing PV penetration with D-STATCOM in a radial LV Distribution Feeder', in 26th Southern Africa Universities Power Engineering Conference, 2018, pp. 6–112.

[10] O. P. Mahela, B. Khan, H. H. Alhelou, S. Tanwar, and S. Padmanaban, 'Harmonic mitigation and power quality improvement in utility grid with solar energy penetration using distribution static compensator', IET Power Electron., vol. 14, no.

5, pp. 912–922, Jan. 2021.

[11] T. Ahmed, A. Waqar, S. Haider, and A. Armghan, ‘Application of Fixed Frequency Sliding Mode Control for D-STATCOM in Power Systems’, in 2021 International Bhurban Conference on Applied Sciences and Technologies (IBCAST), 2021, pp. 524–529.

[12] N. Patel, N. Gupta, and B. C. Babu, ‘Photovoltaic system operation as DSTATCOM for power quality improvement employing active current control’, IET Gener. Transm. Distrib., vol. 14, no. 17, pp. 3518–3529, Sep. 2020.

[13] B. Jahnavi, S. B. Karanki, and P. K. Kar, ‘Power quality improvement with D-STATCOM using combined PR and Comb filter-Controller’, in 2021 1st International Conference on Power Electronics and Energy (ICPEE), 2021, pp. 1-6.

[14] S. Mishra, S. K. Dash, P. K. Ray, and P. S. Puhan, ‘Analysis and experimental evaluation of novel hybrid fuzzy-based sliding mode control strategy for performance enhancement of PV fed DSTATCOM’, Int. Trans. Electr. Energy Syst., p. 12815, Feb. 2021.

[15] R. K. Sinha, M. S. Das, and V. Acharya, ‘Mitigation of Overall THD for the D-STATCOM Fed Low Voltage Grid’, Int. J. Innov. Res. Technol. Manag., vol. 3404, no. 1, pp. 28–35, 2021.

[16] S. N. Duarte, B. C. Souza, P. M. Almeida, L. R. Araujo, and P. G. Barbosa, ‘Control algorithm for DSTATCOM to compensate consumer-generated negative and zero sequence voltage unbalance’, Int. J. Electr. Power Energy Syst., vol. 120, p. 105957, Sep. 2020.

[17] Z. Wang, X. Yin, Y. Chen, J. Lai, L. Li, and Z. Qi, ‘DSTATCOM integrated with Y-y connection transformer for reactive power compensation’, Int. J. Electr. Power Energy Syst., vol. 117, p. 105721, May 2020.

[18] E.Ramakrishna, P. B. Kumar, G. J. Krishna, and P. Sujatha, ‘Adaptive RNN with CSOA controlled based MMC-DSTATCOM for PQ enhancement in Distribution System’, Turkish J. Comput. Math. Educ., vol. 12, no. 2, pp. 876–888, 2021.

[19] S. Malathi and J. Jayachandran, ‘FPGA implementation of NN based LMS–LMF control algorithm in DSTATCOM for power quality improvement’, Control Eng. Pract., vol. 98, p. 104378, May 2020.

[20] E. Kantar and E. Tedeschi, ‘Load Compensation by DSTATCOM with LCL-Filter by Comparing Different Resonance Damping Methods’, in 2020 15th International Conference on Ecological Vehicles and Renewable Energies, EVER 2020, pp. 1–10.