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Original Article

Impact of D-STATCOM and SVC on Power Quality of Low Voltage Radial Distribution Networks

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Abstract - *The problem of voltage instability in Low-Voltage (LV) radial distribution networks is longstanding, mostly because of the insufficiency of the reactive power compensation, rising load demand, and the growth of nonlinear loads. FACTS devices, especially the Static Var Compensator (SVC) and Distribution Static Compensator (D-STATCOM), offer fast and efficient solutions to voltage deviation and power-quality issues. This paper discusses how SVC and D-STATCOM affect the voltage profile of a typical LV radial distribution feeder on the basis of MATLAB/Simulink modeling. The uncompensated system simulation results show that the system is uncompensated and it is operating at 0.889 p.u, which is lower than the acceptable limit. Addition of SVC boosts the voltage to 0.925 p.u., and addition of D-STATCOM boosts the voltage to 0.921 p.u. The Total Harmonic Distortion (THD) of D-STATCOM is much lower than that of SVC (0.80% better than 4.52%). The results show that both devices increase voltage stability, but D-STATCOM has a better power-quality performance, and thus is better adapted to the contemporary LV distribution systems.*

Keywords *- D-STATCOM, FACTS, Harmonic Distortion, Low-Voltage Distribution Network, Power Quality, Reactive Power Compensation, SVC, Voltage Profile.*

1. Introduction

The radial distribution networks (LV) are becoming susceptible to instability in voltages, excessive losses, and low-quality power due to the sudden increase in load demand, distributed generation, and nonlinear electronic devices. Low voltage may be common among end-of-line consumers, resulting in poor working equipment, overheating, and premature failure [1,2]. In the radial distribution, power flows in a single direction, that is, between the substation and the loads.

This intensifies voltage drops with an increase in distance between the source. The impedance of distribution lines is of significant influence in reducing voltage levels as the loading conditions deteriorate, particularly when the demand is at the peak [3]. Moreover, the introduction of distributed energy resources such as photovoltaic systems and wind turbines causes the power flow and the voltage change in both directions, which complicates the control of the voltage and makes the distribution network more difficult to operate [4].

Harmonic injection into LV networks has increased substantially due to the massive application of nonlinear loads, such as power electronic converters, electric vehicle chargers, and adjustable-speed drives. This comes along with increased load growth. Harmonic currents do not only distort the shape of the voltage waveforms, but also increase losses in power and thermal stress in conductors and transformers [5]. All these effects render the system less reliable and reduce the life span of electrical equipments. As well as being a steady-state problem, voltage instability in LV networks is a dynamic condition that can be influenced by power imbalance in a reactive manner, evolving load patterns, and renewable generation variability [6]. The voltage magnitudes can decrease to an amount that is below acceptable levels when reactive demand exceeds the amount of local compensation and may result in the occurrence of voltage collapse in weak feeders.

This has created a major operational challenge to the distribution utilities since they must maintain an acceptable voltage profile within the statutory allowance of ±5 percent. Without effective compensation schemes, LV feeders are susceptible to energy wastage, frequent customer grievances, and increased maintenance expenses. These facts underscore the need to have advanced and flexible voltage control techniques that can deal with steady-state as well as transient instability in the contemporary distribution systems [6].

Conventional voltage control devices like tap-changing transformers, capacitor banks, and synchronous compensators are not usually adequate, as they do not respond to dynamic changes quickly and are not controllable. Flexible AC Transmission System (FACTS) devices that are based on power electronics have enabled real-time reactive power compensation and voltage regulation to be done [8]. Two of them are the Static Var Compensator (SVC) and the Distribution Static Compensator (D-STATCOM), which are widely used in enhancing voltage stability at the distribution level [9].

Traditional devices, such as On-Load Tap Changers (OLTCs), are mechanically switched and thus are slower to react to and less versatile in their operation. Their primary use is to change the voltage gradually rather than rapidly remedy it in cases of rapid variation. Similarly, fixed or switched capacitor banks may support discrete reactive power; however, they are not able to maintain it continuously, resulting in over-compensation or under-compensation depending on the load conditions. Synchronous condensers can be used to dynamically supply reactive power, but they are quite costly to purchase and maintain since they contain moving components [10].

Contrarily, FACTS devices apply solid-state switching technology, which allows the reactive power injection or absorption to be continuously and promptly controlled. The SVC is normally founded on Thyristor-Controlled Reactors (TCR) and Thyristor-Switched Capacitors (TSC), which allows quick response to the variations in the system through adjusting reactive power according to the system fluctuations; its operation can, however, add harmonic content to the system operation [8]. The D-STATCOM uses a Voltage Source Inverter (VSI) topology that utilizes Insulated-Gate Bipolar Transistors (IGBTs) and enables the reactive power to be controlled precisely and with near-instantaneous control with reduced harmonic distortion levels [11].

The enhanced dynamic responsiveness of D-STATCOM would render it particularly suitable for distribution networks having rapidly changing loads and a greater share of renewable energy. Its ability to manage voltage at the Point of Common Connection (PCC) is an overall enhancement of feeder stability and quality of power. The use of FACTS devices, such as SVC and D-STATCOM, that are more controllable, efficient, and reliable in voltage management, is a significant advancement over the traditional methods of compensation as distribution systems become more intelligent and decentralized.

Although much literature is available on FACTS devices, the majority of research concentrates on transmission and medium-voltage networks. Little has been done to compare SVC and D-STATCOM in relation to Total Harmonic Distortion (THD) in low-voltage radial distribution networks, especially in developing countries where the problem of harmonic distortion and voltage instability is more acute. This gap inspires the current study DARK BLUE.

This paper evaluates the impact and compares the performance of SVC and D-STATCOM within an LV radial distribution network, regarding voltage improvement, minimization of harmonics, and general performance.

The novelty of the work is that it critically examines the FACTS devices in the context of a low-voltage radial distribution system: the work is a comparative analysis of SVC and D-STATCOM in a scaled and realistic low-voltage feeder model, which is not sufficiently studied in the current literature. Moreover, the total Harmonic Distortion (THD) is introduced as a performance indicator, complementing the voltage profile improvement

2. Literature Review

The problem of voltage stability in radial distribution systems has received extensive studies, with reactive power deficiency emerging as one of the key factors of the issue [13]—radial networks. Power is supplied in a sequence starting at the substation and to downstream loads, and because of the lack of alternative feeding paths, these systems are highly susceptible to voltage drops and reactive power imbalance.

The cumulative impact of the line impedance and reactance, in particular with an increase in the distance of the source, only leads to a progressive reduction in the magnitude of the voltages. This effect is more pronounced under heavy loading conditions, which can easily push bus voltages too high to allow acceptable operating conditions. Reactive power is vital in sustaining the level of voltage, and the lack of reactive power leads to the inability of the system to sustain a stable operating condition.

Recent research has shown that the unavailability of reactive power and low delivery capacity have a strong deteriorating effect on the Margins of stability of voltages, especially in weak distribution feeders with large R/X ratios [1]. At a reactive demand higher than supply, the voltage profile becomes worse, and this raises the chances of voltage collapse, particularly at peak demand or fault conditions.

Besides this, there is also the growing incorporation of distributed energy sources like rooftop photovoltaic systems and small wind turbines, whose variability and intermittency make reactive power management even more complex. Such sources of renewable energy can lead to reverse power flow and localized voltage increase, which poses more instability risks.

Voltage instability is hence a multidimensional problem that entails increased load, renewable integration, network topology, and reactive power coordination. In the absence of proper compensation plans, there is a possibility of more technical losses, lower reliability, and poor quality of power [12]. This has made it necessary to enhance the reactive power support systems in the radial distribution networks in recent power system studies and operation [2].

The use of FACTS devices has become eminent because of the quick response and better controllability. According to modern reviews, the use of FACTS technologies is effective in reducing the fluctuations of voltages and improving the dynamic performance of the distribution networks. As opposed to traditional mechanical devices used to provide mechanical compensation, FACTS controllers use switching based on power electronics, which provides a virtually instantaneous response to voltage disturbances. This rapid control is required in the contemporary grids where the loads vary and the variability of renewable energy is high. FACTS devices stabilize the magnitude of the voltages by dynamically injecting or absorbing reactive power and thereby minimizing line losses and enhancing the security of the entire system.

One of the first FACTS applications was Static Var Compensators (SVC), which uses Thyristor-Switched Capacitors (TSC) and Thyristor-Controlled Reactors (TCR) to control the reactive power flow. SVCs offer reactive support, which is adjustable through controlled firing angles of thyristors and improves steady-state voltage stability. There is a lot of literature that the SVCs are effective in minimizing the deviation of voltages and enhancing power transfer ability. Their working can, however, cause harmonic distortion because of the switching action of thyristors, especially when they are operated in partial modes of conduction [14]. These harmonics may spread around the network and have an impact on sensitive equipment unless properly filtered.

Regardless of these shortcomings, SVC is an effective method of medium- and high-voltage systems since it is cost-effective and comparatively easy to control [14]. Nevertheless, in low-voltage distribution systems with high nonlinear load penetration, harmonic sensitivity is a critical consideration, especially where the thyristor-based switching can cause distortion in a waveform [9]. With the distribution networks changing to a higher level of penetration of renewable energy sources and electronic loads, the more sophisticated FACTS solutions with enhanced harmonic performance are more preferable [12]. This has prompted the investigation of voltage-source inverter-based compensation equipment, including, but not limited to, D-STATCOM, which provides better control of power quality, a higher level of dynamic response, as well as lowering the overall harmonic distortion than traditional SVC implementations [11].

The D-STATCOM, however, is well known to have a better dynamic response and a successful harmonic mitigation capacity. The current studies have indicated that D-STATCOM enhances the voltage profile as well as power factor whilst keeping the Total Harmonic Distortion (THD) in the distribution systems low [11]. It is also in contrast to SVC; D-STATCOM utilizes a Voltage Source Inverter (VSI) architecture based on Insulated-Gate Bipolar Transistors (IGBTs) to allow continuous and smooth reactive control of power. D-STATCOM allows injecting or absorbing reactive current regardless of the size of the system voltage, and is therefore especially useful at low-voltage conditions, by producing a controllable AC voltage behind a coupling reactance.

D-STATCOM inverter-based topology offers quick reaction to the transient disturbances like load switching, motor starting, or fluctuation in renewable outputs [11]. Moreover, the more sophisticated methods of control, like controlling the hysteresis current, Pulse-Width Modulation (PWM), and adaptive controllers, contribute even more to its capacity to control the voltage under tight control and avoid the harmonic injection to a minimum [7]. Consequently, D-STATCOM is also able to keep the Total Harmonic Distortion (THD) within the IEEE recommended limits, which results in the quality of the waveform and less stress on network components [15].

A number of modern studies suggest using D-STATCOM in low-voltage networks with a high concentration of sensitive and nonlinear loads because of its high response and power-quality characteristics [15]. D-STATCOM can also be used in conjunction with the energy storage systems, as well as renewable sources, in smart grid settings to provide coordinated voltage regulation and reactive power control. It is designed in a modular format and is scalable to be used in decentralized deployment at important buses or weak feeder endpoints.

Thus, D-STATCOM is an important breakthrough in reactive power compensation technology, which has a high level of dynamic response, better harmonic reduction, and higher flexibility of operation than conventional equipment. These benefits predispose it especially to the contemporary LV radial distribution networks that are undergoing a fast technological and structural change with the integration of renewable energy and the growth of the nonlinear load.

Despite the significant contributions of existing studies, several research gaps remain. Most previous works have primarily focused on transmission and medium-voltage distribution systems, with limited attention given to low-voltage radial distribution networks, which are more vulnerable to voltage instability and harmonic distortion. In addition, many studies emphasize voltage profile improvement and loss reduction, while comparatively fewer investigations provide a detailed assessment of Total Harmonic Distortion (THD), particularly under nonlinear loading conditions. Furthermore, there is a lack of practical and simplified modeling approaches that reflect real-world low-voltage systems, especially in developing countries where network conditions are often weak and highly dynamic.

Therefore, a comprehensive comparative evaluation of SVC and D-STATCOM in a low-voltage radial distribution network, considering both voltage stability and harmonic performance, remains insufficiently explored.

This study addresses these gaps by developing a scaled MATLAB/Simulink model to analyze and compare the performance of these devices under realistic operating conditions.

3. Methodology

3.1. System Description and Modeling

The test system used in this case is the IEEE – 7 bus radial system with one substation bus as depicted in Figure 1[16]. It has the following data: Base Power 1 MVA, nominal Voltage 12.66 kV, and initial loss 1.44 kW.

It has seven (7) nodes and six (6) branches. It was modeled in MATLAB/Simulink. It also consists of the following: 415 V, 50 Hz supply, radial line with distributed loads, end-of-line consumer bus, and reactive power challenges under normal loading.

Three scenarios were investigated:

- Base Case (Uncompensated Feeder)
- Feeder with SVC
- Feeder with DSTATCOM

Table 1 is a list of the parameters that were used for the investigation, and Figure 1 shows the model of the LV feeder of scenario 1 (uncompensated feeder).

Table 1. Scaled-down LV Model Parameters

LV Distribution Line Parameters	
Line Voltage	400
Line Impedance (R+jX)/m	0.0413+j0.000095475
Line length (m)	200
Transformer Capacity (MVA)	0.2
Lump Load (kVA)	45
Load Power Factor	0.85
Frequency (Hz)	50

3.2. Static Var Compensator (SVC) Modeling

The SVC used in this study is based on Thyristor Controlled Reactor (TCR) and Thyristor Switched Capacitor (TSC) configurations, as shown in Figure 2. Reactive power injection was regulated by adjusting firing angles to maintain voltage at the terminal bus.

Table 2 and Figure 3 show the parameters of the modeled SVC and the simulated network in MATLAB/Simulink.

Table 2. Parameters of Modeled SVC and System

SVC Parameters	
DC Capacitor (µF)	0.17
Distribution System Voltage (V)	400
Interface Inductance (H)	44.01
SVC Var rating (MVar)	300
Fundamental Frequency (Hz)	50
Transformer (SVC) Power Rating (kVA)	100
Transformer (SVC) Power Rating (kV)	0.125/11

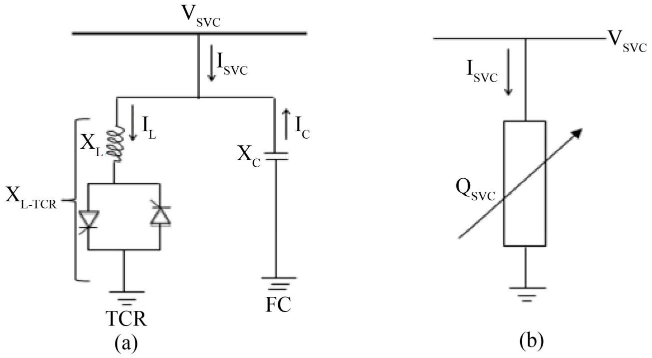

Fig. 2 (a) TCR-FC SVC functional diagram (b) SVC equivalent circuit

3.3. D-STATCOM Model (Scenario 3)

The D -STATCOM is modeled as a Voltage Source Converter (VSC) capable of absorbing and injecting reactive power at the point of connection, as depicted in Figure 4.

The D - STATCOM comprises:

1. Voltage-source inverter (IGBT-based)
2. DC-link capacitor
3. Coupling transformer

Its operation is based on voltage injection in quadrature with line current to regulate reactive power, as shown in Figures 4 and 5, respectively. The calculated parameters of the modeled network with the injection of D-STACOM are given in Table 3.

Table 3. D-STATCOM Modeled Parameters

D-STATCOM Parameter	
DC Capacitor (µF)	304
DC Link Voltage (V)	320
Interface Inductance (µH)	800
D-STATCOM Var rating (kVar)	3
Frequency (Hz)	50
Load Voltage (V)	400

3.4. Performance Metrics

Evaluation of performance was based on:

- Per-unit voltage magnitude
- Reactive power support (VAR support)
- IEEE Std. based Total Harmonic Distortion (THD). 519
- Regulation of voltage in the terminal bus.

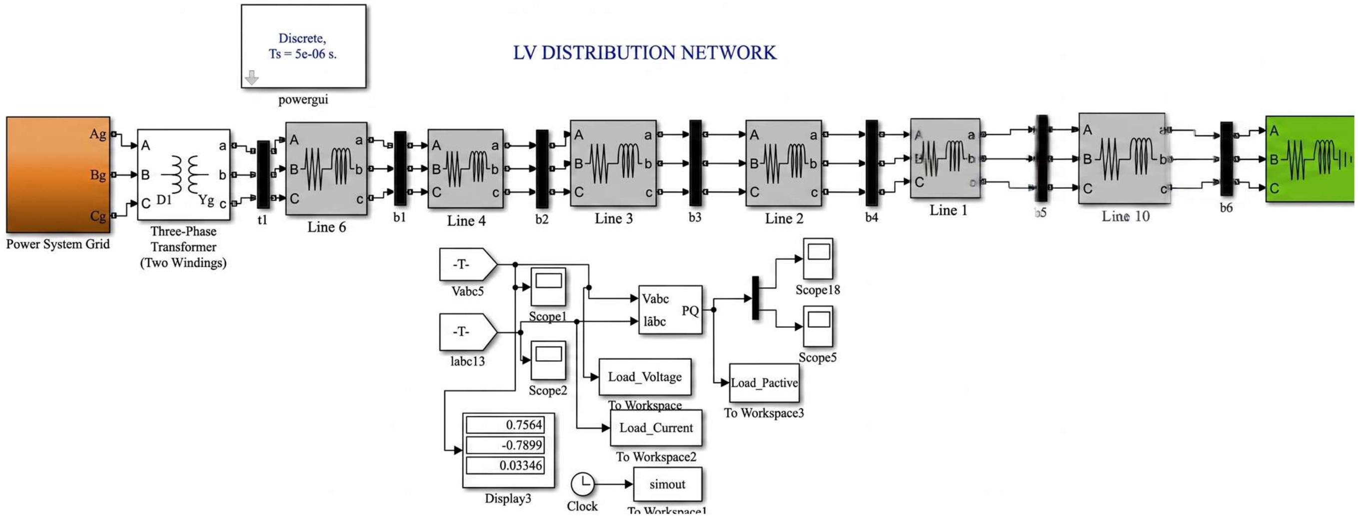

Fig. 1 Scaled-down LV distribution feeder without SVC and D-STATCOM injection

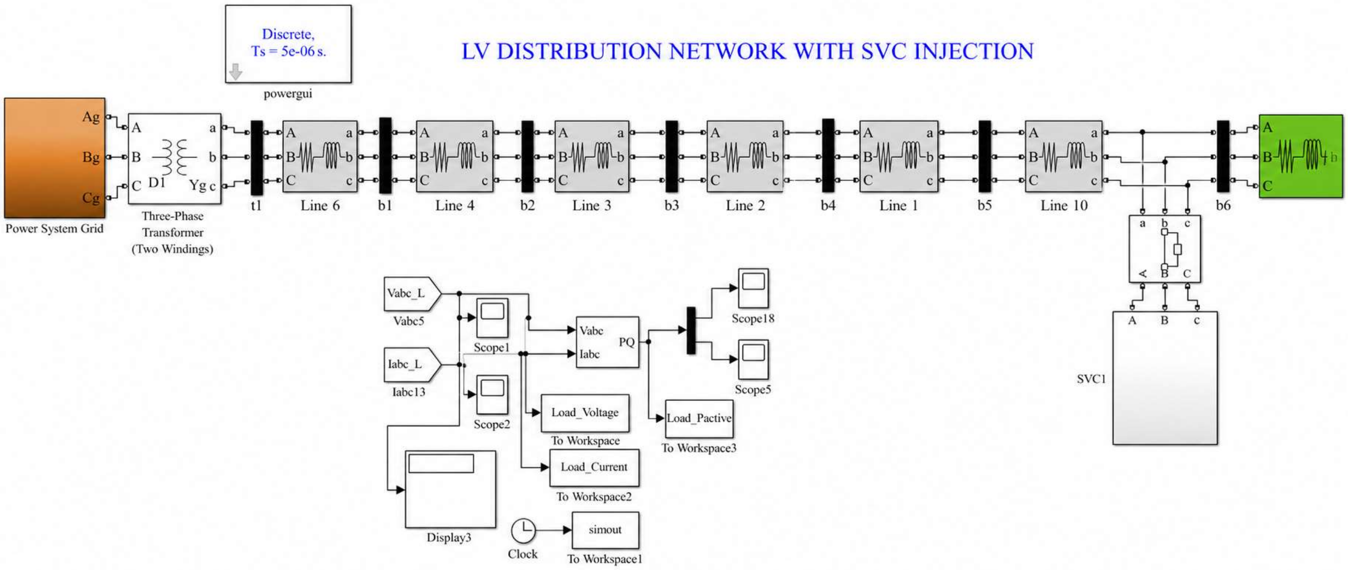

Fig. 3 Scaled-down LV distribution feeder with SVC injection

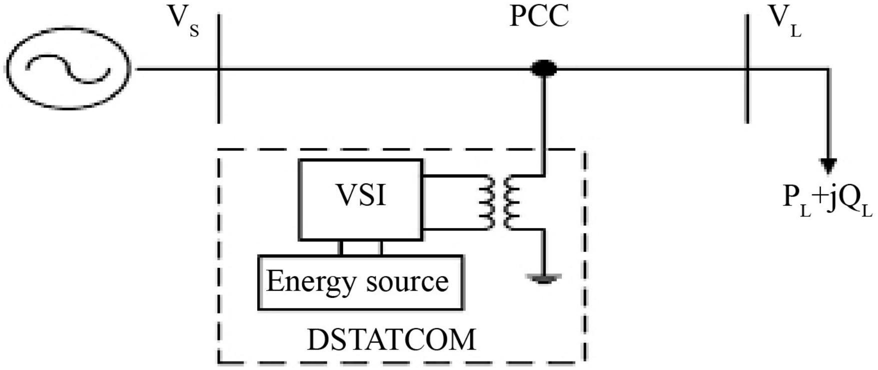

Fig. 4 D-STATCOM block diagram of a three-phase three-wire system

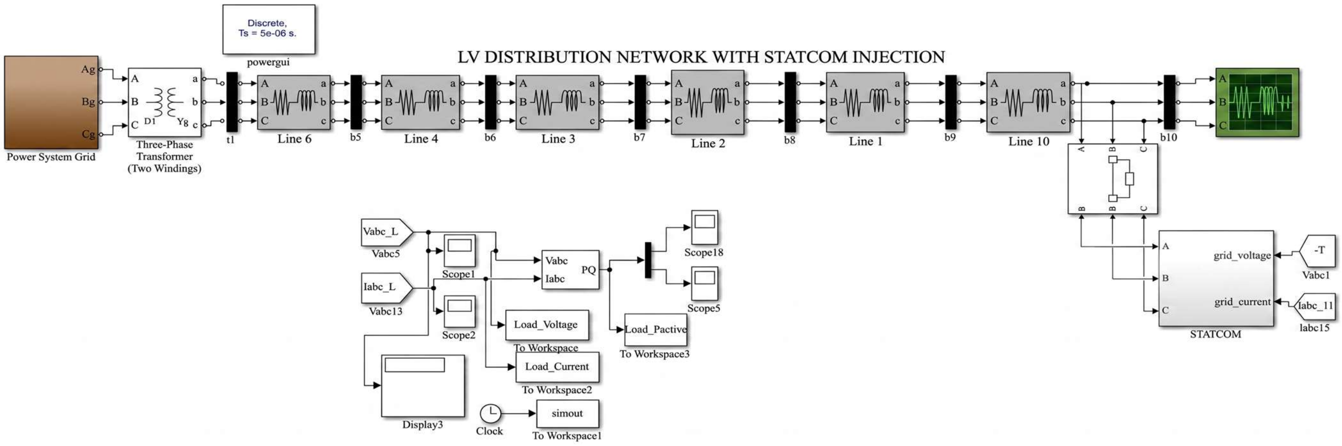

Fig. 5 Scaled-down LV distribution feeder with DSTATCOM injection

4. Simulation Results

4.1. Uncompensated Feeder (scenario 1)

A low-voltage radial distribution as described in Figure 1 is used as the Base case. As depicted in Figure 6, the base case shows that the voltage at the terminal bus is 0.889 p.u, which is below the acceptable limits. There is a significant voltage drop due to insufficient reactive power, high losses, and an unstable profile. This confirms the inherent weakness of LV radial feeders.

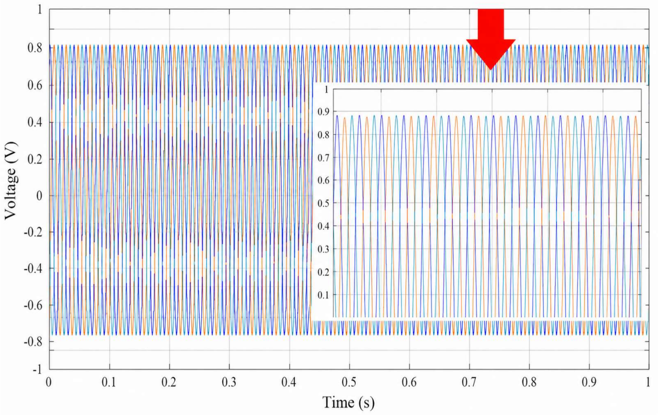

Fig. 6 Profile of Voltage waveform at LV distribution feeder (without SVC and D-STATCOM)

4.2. Feeder with SVC (Scenario 2)

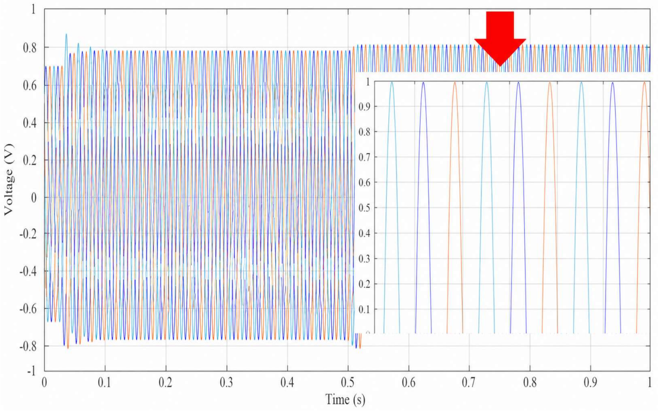

Fig. 7 Voltage profile of the LV feeder with SVC injection

After SVC incorporation, it was observed that the voltage improves to 0. 925p. u, there is slightly greater improvement than D-STATCOM, and harmonic distortion increases to 4.52%. This is attributed to thyristor switching operations as demonstrated in Figures 7 and 8, respectively.

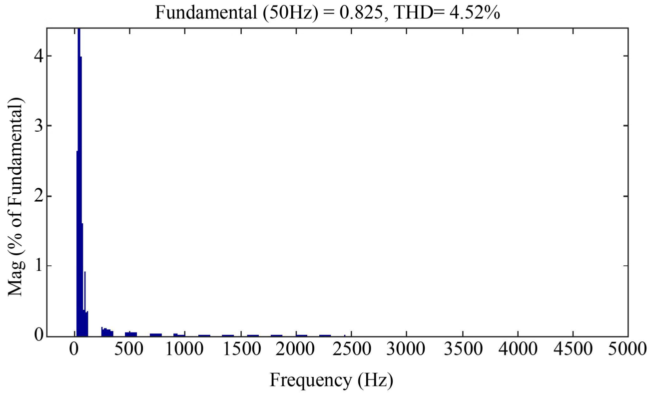

Fig. 8 Harmonics of LV Feeder with SVC

4.3. Feeder with DSTATCOM (scenario 3)

After DSTATCOM integration, it was observed that the voltage increases to 0.921 p.u., the voltage waveform becomes more stable and smoother, and the THD reduces to 0.80%, well below IEEE limits. The fast-switching capability of the VSC inverter produces minimal distortion, as demonstrated in Figures 9 and 10, respectively.

The higher THD value of 4.52% observed in the SVC is consistent with previous studies, which attribute increased harmonic distortion to thyristor switching operations, particularly under partial conduction modes. In contrast, the significantly lower THD value of 0.80% obtained with the D-STATCOM agrees with findings reported in [11], due to the use of PWM-based voltage source inverter control, which ensures smoother waveform generation. This contrast highlights the superior harmonic mitigation capability of D-STATCOM over SVC, making it more suitable for modern low-voltage networks with high penetration of nonlinear loads.

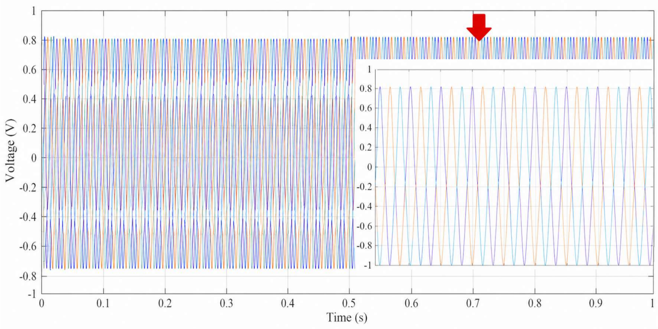

Fig. 9 Voltage profile LV feeder with D-STATCOM injection

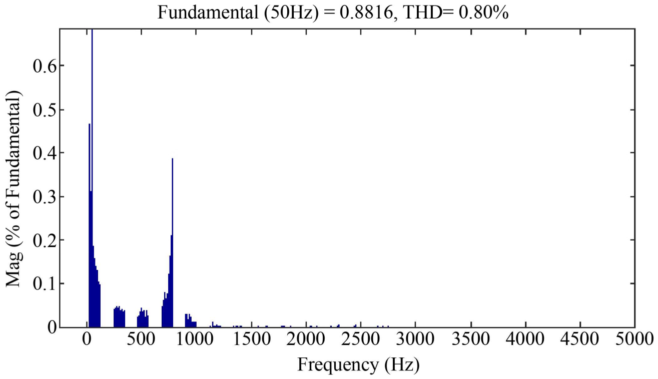

Fig. 10 Harmonics at LV Feeder with D-STATCOM

The simulation results demonstrate that both SVC and D-STATCOM significantly improve voltage performance in LV radial networks. However, key differences exist, as shown in Table 4.

Table 4. Performance between SVC and D-STATCOM

	FACTs DEVICES	
Parameters	**SVC**	**D-STATCOM**
Voltage Improvement	0.925pu	0.921pu
Harmonic Impact	4.52%	0.80%

The superior performance of DSTATCOM in harmonic reduction makes it more suitable for networks with sensitive electronic loads.

In terms of dynamic response, D-STATCOM responds faster due to solid-state inverter technology, while SVC has a moderate response due to thyristor firing control delays.
Overall, while the SVC yields slightly higher voltage improvement, the D-STATCOM clearly outperforms in overall power quality and system stability.

5. State of the Art

The findings of this work contribute to the further development of the existing state-of-the-art in enhancing the power quality of distribution networks. This work is in contrast to many other available studies, which concentrate on transmission or medium-voltage systems, as it offers validation of the FACTS device operation in a low-voltage radial distribution system. Moreover, the findings provide a viable comparison of the Total Harmonic Distortion (THD) performance of the SVC and D-STATCOM, with inverter-based compensation exhibiting the higher capability of harmonic reduction. These revelations justify the growing use of D-STATCOM in contemporary low-voltage grids that have large shares of nonlinear loads and renewable energy sources.

6. Conclusion

This paper evaluated the impact of DSTATCOM and SVC on the voltage profile of a low-voltage radial distribution network. Major conclusions are:

1. The uncompensated feeder operates at 0.889 p.u, below acceptable limits.
2. SVC improves the voltage to 0.925 p.u, while DSTATCOM improves it to 0.921 p.u.
3. DSTATCOM exhibits significantly lower THD (0.80%), making it superior for power quality enhancement.
4. SVC introduces higher harmonic distortion due to thyristor switching.
5. For modern LV networks with nonlinear loads, DSTATCOM is recommended.

Future work should explore adaptive or AI-based control of FACTS devices to optimize performance further.

Conflict of Interest

The authors declare that there is no conflict of interest.

References

[1] Molla Addisu Mossie et al., “A Computational Approach to Voltage Stability Enhancement and loss Reduction in Distribution System Using PSO – Optimized STATCOM and DG,” *Scientific Reports*, vol. 15, pp. 1-21, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[2] John Licari et al., “Addressing Voltage Regulation Challenges in Low-Voltage Distribution Networks with High Renewable Energy and Electric Vehicle Penetration: A Critical Review,” *Energy Reports*, vol. 14, pp. 2977-2997, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[3] Luqman Hwayyiz Asaad, “The Effects of Unbalanced Circuit in Power Loss and Efficiency,” *International Journal of Innovative Science and Research Technology*, vol. 8, no. 11, pp. 2702-2711, 2023. [CrossRef] [Publisher Link]

[4] Kehinde Makinde et al., “Voltage Rise Problem in Distribution Network with Distribution Generation: A Review of Technologies, Impact and Mitigation Approaches,” *Indonesian Journal of Electrical Engineering and Informatics*, vol. 9, no. 3, pp. 575-600, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[5] "IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems," *IEEE Std 519-2014 (Revision of IEEE Std 519-1992)*, pp. 1-29, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[6] Samson Ademola Adegoke et al., "Optimal Placement of Distributed Generation to Minimize Power loss and Improve Voltage Stability," *Heliyon*, vol. 10, no. 21, pp. 1-28, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[7] Sunday Adeleke Salimon et al., "Optimal Allocation of Distribution Static Synchronous Compensators in Distribution Networks Considering Various Load Models," *Sustainability*, vol. 15, no. 21, pp. 1-23, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[8] D.C. Oyiogu, CA. Obioraokeke, and A.O. Aniagboso, "A Comparative Analysis of STATCOM, SVC, TCSC and UPFC for Voltage Stability and Power Loss Reduction in Power System Network," *Iconic Research and Engineering Journal*, vol. 7, no. 7, pp. 500-510, 2024. [Google Scholar] [Publisher Link]

[9] Ban H. Alajrash et al., "A Comprehensive Review of FACTS Devices in Modern Power Systems: Addressing Power Quality, Optimal Placement, and Stability with Renewable Energy Penetration," *Energy Reports*, vol. 11, pp. 5200-5230, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[10] Math H.J. Bollen, and Fainan Hassan, *Integration of Distributed Generation in the Power System*, 2nd Ed., Wiley-IEEE Press, 2021. [Google Scholar] [Publisher Link]

[11] Wesam Rohouma et al., "D-STATCOM for Harmonic Mitigation in Low Voltage Distribution Network with High Penetration of Nonlinear Loads," *Renewable Energy*, vol. 12, pp. 1449-1464, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[12] Saad Alqahtani et al., "Impact of the High Penetration of Renewable Energy Sources on the Frequency Stability of the Saudi Grid," *Electronics*, vol. 12, no. 6, pp. 1-20, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[13] Stephen W. Mathenge, Edwell.T. Mharakurwa, and Lucas Mogaka, "Voltage Enhancement and Loss Minimization in a Radial Network through Optimal Capacitor Sizing and Placement based on Crow Search Algorithm," *Energy Report*, vol. 12, pp. 4953-4965, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[14] Oscar Danilo Montoya et al., "Enhancing Distribution Network Performance with Coordinated PV and D-STATCOM Compensation Under Fixed and Variable Reactive Power Modes," *Technologies*, vol. 14, no. 4, pp. 1-21, 2026. [CrossRef] [Google Scholar] [Publisher Link]

[15] Laura Patricia García-Pineda, and Oscar Danilo Montoya, "Optimal Reactive Power Compensation via D-STATCOMs in Electrical Distribution Systems by Applying the Generalized Normal Distribution Optimizer," *Algorithms*, vol. 16, no. 1, pp. 1-18, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[16] Meisam Mahdavi et al., "An Efficient Mathematical Model for Distribution System Reconfiguration using AMPL," *IEEE Access*, vol. 9, pp. 79961-79993, 2021. [CrossRef] [Google Scholar] [Publisher Link]