IJARSCT
ISSN: 2581-9429
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Volume 5, Issue 3, December 2025
Impact Factor: 7.67

Improving Power Quality in Smart and Renewable-Integrated Power Systems Through FACTS-Based Control

Tanmay Bidwe[1], Prof. H. D. Mude[2], Arya Yende[3]
U.G. Students, Department of Electrical Engineering [1,3]
Assistant Professor, Department of Electrical Engineering [2]
Jawaharlal Darda Institute of Engineering and Technology, Yavatmal, Maharashtra, India
tanmay17bidwe@gmail.com[1], harish_mude@jdiet.ac.in[2], aryayende2@gmail.com[3]

Abstract: *The growing complexity of ultramodern power systems, driven by adding demand, integration of renewable energy sources, and strict quality conditions, increases the need for advanced power quality improvement ways. Flexible AC Transmission Systems (Data) bias — including Static Synchronous Compensators (STATCOM), stationary Var Compensators (SVC), Thyristor Controlled Series Capacitors (TCSC), and Unified Power Flow regulators (UPFC) — help maintain voltage stability, reduce harmonics, alleviate flicker, and ameliorate reactive power compensation. This paper reviews the functional principles, groups, and operations of FACTS device in enhancing power quality. It also examines case studies and simulation results that show how FACTS technology addresses issues similar as voltage sags, swells, harmonious deformation, and unstable loads. Integrating FACTS device into ultramodern grids improves effectiveness, trustability, and compliance with transnational power quality norms.*

Keywords: Power Quality, Flexible AC Transmission Systems (Data), STATCOM, SVC, TCSC, UPFC, Voltage Stability, Harmonic Mitigation, Reactive Power Compensation

I. INTRODUCTION

The metamorphosis of ultramodern power systems is being driven by rapid-fire industrialisation, adding electricity demand, and the integration of renewable energy sources. While renewable generation sources similar as solar and wind are environmentally sustainable, their intermittent and changeable nature introduces several challenges to the grid. These challenges manifest primarily as power quality (PQ) issues, including voltage oscillations, harmonics, frequence diversions, unstable loads, and flash precariousness. Poor power quality directly affects artificial processes, sensitive electronic bias, and the overall effectiveness and trustability of power systems.

Traditional compensation ways, similar as capacitor banks, mechanical voltage controllers, and valve- changing mills, frequently warrant the capability to handle the fast, dynamic nature of power disturbances, especially in renewable-rich grid conditions. This gap has motivated the deployment of advanced results that can respond in real- time.

Flexible AC Transmission Systems (Data) mark a technological vault. These bias use high-power electronic transformers for fast- acting reactive power compensation, dynamic voltage support, harmonious repression, and power inflow control. As a result, they ameliorate the stability, inflexibility, and quality of power systems. Over the once two decades, bias like the Static Var Compensator (SVC), Static Synchronous Compensator (STATCOM), Thyristor Controlled Series Capacitor (TCSC), and Unified Power Flow Controller (UPFC) have gained elevation in exploration and practice.

Recent studies emphasise that Data aren't only pivotal for maintaining traditional grid stability but are also necessary for smart grids and renewable energy integration, where real- time adaptive control of power quality parameters is needed.

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 5, Issue 3, December 2025
Impact Factor: 7.67

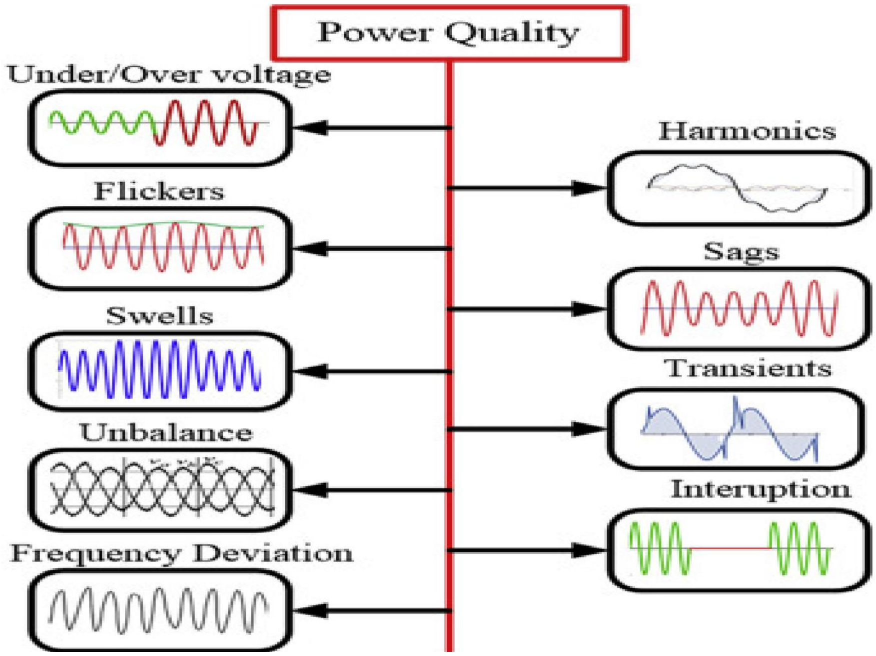

Fig. 1. Bracket of Power Quality Disturbances. [17]

II. PROBLEM STATEMENT & OBJECTIVES

Problem Statement:

The growing penetration of renewable energy, coupled with rising demand, results in largely variable and uncertain grid conditions. similar conditions aggravate problems like voltage slack, swell, harmonious deformation, and power factor deterioration. While conventional bias gives limited compensation, they fail to ensure compliance with ultramodern PQ norms similar as IEEE 519 and IEC 61000 under fast- changing cargo and generation scripts. also, transmission networks face traffic and stability issues during peak loads, leading to hamstrung application of means and occasional cargo curtailment. To ensure grid trustability, flexible and controllable power- electronic- grounded results are necessary.

Objects of the Study:

1. To review the part of crucial FACTS device (SVC, STATCOM, TCSC, UPFC) in mollifying power quality problems.
2. To dissect optimal placement strategies for Data and their effect on system stability.
3. To estimate Data operations for renewable-rich power systems and smart grids.
4. To identify unborn directions for Data deployment in arising grid scripts.

DOI: 10.48175/IJARSCT-30430

III. LITERATURE REVIEW

Expansive exploration has been conducted on FACTS device in the environment of PQ enhancement:

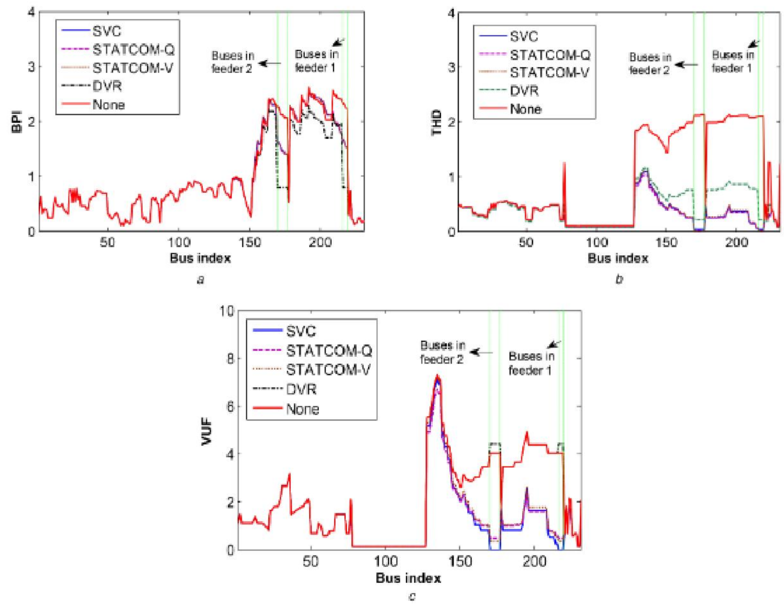

Fig. 2. Relative capability of FACTS device in mollifying power quality issues.[11]

• Energy Reports (2024): This report provides an expansive analysis of Flexible AC Transmission System (Data) technologies, which include bias similar as stationary Var Compensators (SVC), Static Synchronous Compensators (STATCOM), Unified Power Flow regulators (UPFC), and Thyristor Controlled Series Capacitors (TCSC). It emphasizes optimal strategies for placing this bias within power systems to enhance their performance, specifically fastening on stabilizing frequence and perfecting power quality (PQ) amid adding penetration of renewable energy sources. [1]

• Singh & Swami (2019): This study explores colourful power quality marvels, including voltage dips, harmonics, sags, and unstable loads. The authors demonstrate how FACTS bias effectively alleviate these disturbances, perfecting overall grid stability and trustability. The paper highlights the significance of addressing similar power quality issues, particularly as the grid incorporates further variable renewable energy sources. [2]

• J Electrical Systems (2013): This paper underscores the significance of Data in the development of smart grids. The authors bandy how these technologies grease the integration of renewable energy sources and enhance voltage stability within the grid. By addressing dynamic challenges and offering results for real- time control, Data play a pivotal part in contemporizing electrical systems. [3]

• Barati Masoud et al. (2016, arXiv): The experimenters illustrate how FACTS bias can palliate traffic in transmission lines and minimize the necessity for cargo curtailment during peak demand ages. This study emphasizes the circular benefits of Data on power quality and system trustability, showcasing their part in enabling more effective and stable system operations. [6]

• Wang et al., IET (2017): This relative analysis evaluates the capabilities of colourfulFACTS device in addressing multiple power quality challenges. The authors give a structured overview of the strengths and limitations of each FACTS technology, helping stakeholders understand which bias may be best suited for particular operations within the power system. [10]

• Sekhane & Djamel (2019): In this exploration, the authors concentrate on the optimal placement and sizing of Unified Power Flow regulators (UPFC) using inheritable algorithm ways. Their work proves the effectiveness of UPFC in minimizing transmission losses and enhancing voltage biographies in power networks, making a strong case for its perpetration in perfecting effectiveness and trustability. These summaries give a detailed understanding of the

ISSN: 2581-9429
Volume 5, Issue 3, December 2025
Impact Factor: 7.67

benefactions made by each study toward advancing the knowledge and operation of Data technologies in ultramodern power systems. These workshops inclusively establish Data as a foundation technology for PQ enhancement, traffic operation, and renewable energy integration.[9]

IV. METHODOLOGY / WORKING PRINCIPLE

FACTS device work by stoutly controlling reactive power inflow, system voltage, and network impedance using power electronic factors. Their working principles are epitomized as:

• Static Var Compensator (SVC): Employs thyristor- controlled reactors and capacitors for shunt compensation. Provides steady- state voltage regulation and introductory harmonious mitigation.

• Static Synchronous Compensator (STATCOM): Uses a voltage- source motor for fast and precise reactive power control. Offers superior dynamic performance compared to SVC, and is effective in reducing harmonics.

• Thyristor Controlled Series Capacitor (TCSC): Provides variable series compensation by altering line impedance. Improves power transfer capability, damping, and stability.

• Unified Power Flow Controller (UPFC): A combination of series and shunt compensation, offering comprehensive control of power inflow, voltage, and system stability. It's considered the most protean Data device.

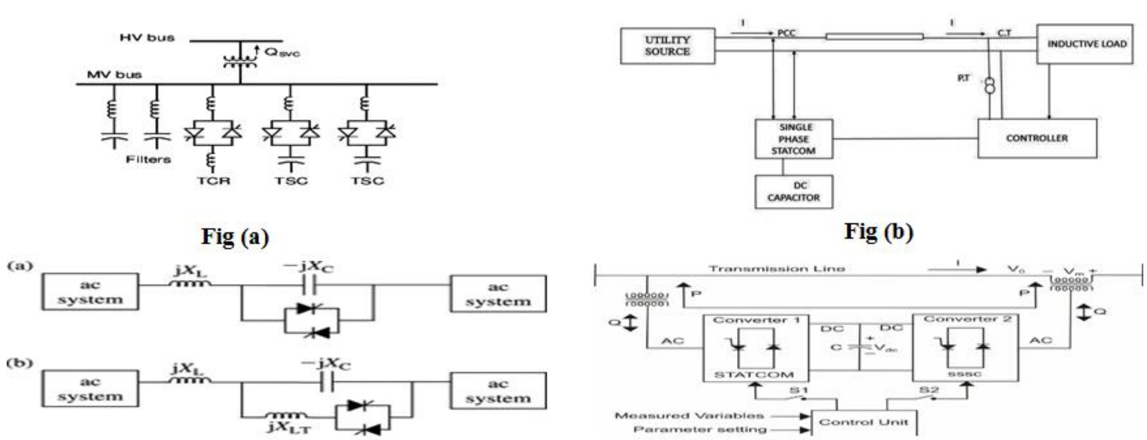

Fig.3.Basic working principles of FACTS devices: (a) SVC, (b) STATCOM, (c) TCSC, (d) UPF

V. PROPOSED DESIGN / CONCEPT

Hybrid Deployment Strategy: This strategy integrates various FACTS devices to enhance power system performance:

o UPFC (Transmission Level): Used for voltage regulation and congestion management in the transmission grid.

o STATCOM (Renewable Integration Points): Provides rapid reactive power support and mitigates harmonics at renewable energy sources like solar and wind farms.

o SVC (Distribution Level): Utilizes dynamic reactive power support to balance local grids and improve power quality.[1]

o Optimization Approach: Employs Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) for optimal placement and sizing of FACTS devices, maximizing power quality and system reliability.

VI. RESULTS / FINDINGS FROM LITERATURE

FACTS device aren't magic fixes, but when they're applied rightly, they deliver measurable, system- position advancements. For voltage problems, bias like STATCOM and SVC can cut the depth and duration of voltage sags or swells by roughly 30 – 50, because they fit or absorb reactive power presto enough to stop the machine voltage from collapsing during faults or heavy lading. On the power- quality side, STATCOMs equipped with harmonious pollutants can reduce THD to IEEE- 519 limits, thereby perfecting power factor and precluding outfit overheating or mis operation. UPFC placements, when done grounded on cargo- inflow perceptivity rather than guesswork, generally neat

DOI: 10.48175/IJARSCT-30430

real power losses by 10 – 15 while tensing voltage biographies and strengthening flash stability. And when you move into renewables, FACTS device break the biggest problem — voltage and power- inflow volatility. A grid that uses STATCOM, TCSC, or UPFC at the applicable bumps can handle 20 – 30 further renewable penetration without insecurity, oscillations, or reverse- power issues. In short, FACTS bias gives the system briskly control, better damping, and more headroom, but their impact depends entirely on proper placement and tuning rather than just installing tackle blindly. [2], [9], [10], [7]

VII. APPLICATIONS

Operations FACTS devicehas a wide range of PQ operations:

• Renewable Integration They grease the smooth integration of wind and solar energy by balancing their variability.

• Industrial PQ Management FACTS bias help reduce flicker and harmonics in artificial settings, particularly where bow furnaces and motor drives are used.

• Transmission Traffic Relief They ameliorate the transfer capability of overloaded transmission corridors, helping manage traffic.

• cargo Curtailment Reduction FACTS deviceenables a nonstop power force during peak demand ages by reducing the need for cargo slipping. [6], [8]

VIII. CHALLENGES & LIMITATIONS

• Despite their effectiveness, Data deployment faces several challenges:

• Economic High original capital cost and conservation charges.

• Functional Complex control and collaboration strategies bear professed labour force.

• Cybersecurity Increased vulnerability due to integration with smart grid communication systems.

• Relinquishment walls Developing countries face difficulties in large- scale deployment due to fiscal constraints. [3], [1]

IX. FUTURE SCOPE

Compass Arising exploration and development directions include:

• AI/ ML- grounded adaptive Data control for prophetic PQ operation.

• Integration of Data with Energy Storage Systems (ESS) for enhanced inflexibility.

• DC-compatible Data for HVDC andmulti-terminal DC grids.

• Cost-effective distributed FACTS device to enable localised PQ enhancement. [1], [7]

X. CONCLUSION

FACTS device plays a necessary part in perfecting PQ in ultramodern power systems. Their capability to alleviate voltage oscillations, suppress harmonics, and ensurestability under renewable-rich surroundings makes them central to the unborn grid. While profitable and functional challenges live, ongoing exploration in AI- driven control, cost reduction, and mongrel Data ESS integration is anticipated to drive wider relinquishment.

XI. ACKNOWLEDGEMENT

The authors wish to express their gratitude to Prof. H. D. Mude for her valuable guidance and constructive suggestions throughout the course of this work. We also acknowledge the Department of Electrical Engineering at Jawaharlal Darda Institute of Engineering and Technology for providing the necessary infrastructure and resources to conduct this research. Finally, we thank the faculty members and technical staff for their assistance and technical support.

REFERENCES

[1] A comprehensive review of FACTS devices in modern power systems: addressing power quality, optimal placement and stability with renewable energy penetration – Energy Reports, 2024.

[2] A Review of Power Quality Improvements by using FACTS devices" – Harendra Pal Singh & A.K. Swami, 2019.

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 5, Issue 3, December 2025
Impact Factor: 7.67

[3] Review of FACTS technologies and applications for power quality in smart grids with renewable energy systems – J Electrical Systems (2013).
[4] FACTS Devices as a Solution to Power Industries Problems: A Review, ResearchGate. Overviews application of classic FACTS devices for stability, power quality, and industrial power issues.
[5] POWER QUALITY MITIGATING DEVICES: REVIEW", ResearchGate. A broader look including FACTS devices in the suite of power quality solutions.
[6] Congestion Relief and Load Curtailment Reduction with FACTS Devices (Barati Masoud et al., 2016, arXiv).
[7] Impacts of Variable Impedance Based Power Flow Control on Renewable Energy Integration (Mirzapour & Sahraei Ardakani, 2022, arXiv).
[8] Maximizing electrical power supply using FACTS devices" (Lehmann et al., 2015, arXiv).
[9] Enhancement of Power Quality by an Application of FACTS Devices (Sekhane& Djamel, 2019).
[10] On capability of different FACTS devices to mitigate a range of power quality phenomena – X. Wang et al., IET Gener Trans Distrib (2017).
[11] Liao, H., & Milanović, J. V. (2017). On capability of different FACTS devices to mitigate a range of power quality phenomena. IET Generation, Transmission & Distribution, 11(5), 1202-1211.
[12]Kumar, P. (2015). Enhancement of power quality by an application FACTS device.International Journal of Power Electronics and Drive Systems, 6(1), 10.
[13]Alajrash, B. H., Salem, M., Swadi, M., Senjyu, T., Kamarol, M., &Motahhir, S. (2024). A comprehensive review of FACTS devices in modern power systems: Addressing power quality, optimal placement, and stability with renewable energy penetration. Energy Reports, 11, 5350-5371.
[14] Gandoman, F. H., Ahmadi, A., Sharaf, A. M., Siano, P., Pou, J., Hredzak, B., &Agelidis, V. G. (2018). Review of FACTS technologies and applications for power quality in smart grids with renewable energy systems. Renewable and sustainable energy reviews, 82, 502-514.
[15] Sabo, A., Dabo, A. I., Tureta, K. A., Isah, A. I., Dauda, A. I., Abbah, U., ... & Yusuf, A. FACTS Devices as a Solution to Power Industries Problems: A Review.
[16] Power quality mitigating devices: Review. (n.d.). ResearchGate.
[17]N. G. Hingorani and L. Gyugyi, Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems. New York, NY, USA: IEEE Press, 2000.