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POWER QUALITY ENHANCEMENT USING ADVANCED FACTS AND HVDC TECHNOLOGIES

Vikram Singh,*[1] Pradeep Kumar[2]

[1]FoET Khwaja Moinuddin Chishti Language University, Lucknow, India.

[2]Student of Department of CSE (AI & ML), Khwaja Moinuddin Chishti Language University, Lucknow, India.

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***Corresponding Author: Vikram Singh**

FoET Khwaja Moinuddin Chishti Language University, Lucknow, India.

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ABSTRACT

Modern power networks are increasingly affected by power quality degradation due to the extensive deployment of power electronic loads, renewable energy systems, and dynamic industrial consumers. Deviations in voltage magnitude, harmonic distortion, and reactive power imbalance pose serious challenges to grid reliability and operational efficiency. Advanced power electronic solutions such as Flexible AC Transmission Systems (FACTS) and High Voltage Direct Current (HVDC) transmission have demonstrated significant potential in mitigating these disturbances. This paper investigates the fundamental causes of power quality issues and critically examines the role of advanced FACTS and HVDC controllers in improving voltage regulation, harmonic suppression, and system stability. Simulation-based validation using MATLAB/Simulink confirms the effectiveness of these technologies under disturbed operating conditions.

KEYWORDS: Power Quality Improvement, FACTS Controllers, HVDC Transmission, Voltage Stability, Harmonic Reduction.

1. INTRODUCTION

The evolution of electrical power systems toward smart grids and renewable integration has introduced new operational challenges related to power quality. The widespread use of nonlinear loads such as variable-speed drives, inverters, and power converters has intensified harmonic distortion and voltage instability in both transmission and distribution networks.

These disturbances not only affect sensitive consumer equipment but also accelerate aging of power system components.

Conventional compensation methods, including fixed capacitor banks and passive harmonic filters, lack adaptability and fail to provide satisfactory performance during transient conditions. Consequently, power electronic-based controllers such as FACTS and HVDC systems have gained prominence due to their rapid response and precise controllability. This study focuses on the application of these technologies for systematic power quality enhancement.

2. Reframed Power Quality Challenges

Power quality disturbances occur when electrical parameters deviate from prescribed standards. The most prominent issues include:

- Short-duration voltage variations caused by faults and load switching
- Harmonic currents injected by nonlinear electronic devices
- Reactive power imbalance leading to poor power factor
- Voltage flicker due to fluctuating industrial loads
- Phase imbalance in three-phase systems

If left unmitigated, these problems result in increased power losses, malfunction of protection systems, and compromised grid reliability.

3. Advanced FACTS-Based Compensation Techniques

FACTS controllers employ high-speed semiconductor switching to dynamically regulate power system variables.

3.1 Shunt Compensation Devices

STATCOM and SVC are widely used to inject or absorb reactive power at strategic network locations. Compared to SVC, STATCOM offers superior dynamic performance, particularly under low-voltage conditions, making it more effective for voltage stabilization and harmonic reduction.

3.2 Series Compensation Devices

Devices such as TCSC and SSSC regulate line reactance to control power flow and damp power oscillations. Their ability to rapidly adjust transmission parameters improves system stability during disturbances.

3.3 Combined FACTS Controllers

The Unified Power Flow Controller (UPFC) integrates both series and shunt compensation, enabling comprehensive control of voltage magnitude, line impedance, and phase angle. This multifunctionality makes UPFC one of the most powerful tools for power quality improvement in AC networks.

4. HVDC Systems for Power Quality Enhancement

HVDC transmission provides enhanced controllability and isolation between interconnected AC systems.

4.1 Voltage Source Converter HVDC

VSC-HVDC technology enables independent regulation of active and reactive power. This capability allows effective voltage support and harmonic suppression, even in weak or isolated grids.

4.2 Power Quality Advantages

HVDC links:

- Limit harmonic propagation between networks
- Improve transient voltage recovery
- Enhance grid stability during large disturbances
- Facilitate renewable energy integration

These attributes make HVDC systems particularly suitable for modern power networks with high renewable penetration.

5. MATLAB/Simulink Simulation and Results

5.1 Simulation Model Description

To evaluate the performance of FACTS and HVDC systems, a test power network was developed using MATLAB/Simulink. The model consists of:

- A three-phase AC source connected to a nonlinear load
- A STATCOM connected at the point of common coupling (PCC)
- A VSC-HVDC link interfacing two AC systems
- Measurement blocks for voltage, current, and harmonic analysis

The nonlinear load introduces voltage sag and harmonic distortion to emulate realistic operating conditions.

5.2 Simulation Scenarios

The following cases were simulated:

Case 1: System without compensation

Significant voltage sag and total harmonic distortion (THD) were observed at the PCC due to nonlinear loading.

Case 2: System with STATCOM

Reactive power compensation improved voltage profile and reduced THD substantially.

Case 3: System with VSC-HVDC

Independent control of active and reactive power further enhanced voltage stability and minimized harmonic distortion.

5.3 RESULTS AND DISCUSSION

Parameter	Without Compensation	With STATCOM	With HVDC
Voltage Sag (%)	18%	6%	3%
THD (%)	14.2	5.1	3.4
Power Factor	0.78	0.95	0.98
Voltage Stability	Poor	Improved	Excellent

The simulation results confirm that FACTS and HVDC controllers significantly enhance power quality. HVDC systems demonstrated superior performance due to their independent power control capability.

6. CONCLUSION

This paper presented an in-depth analysis of power quality improvement using advanced FACTS and HVDC technologies. Through analytical discussion and simulation-based validation, it was demonstrated that these systems effectively mitigate voltage instability, harmonic distortion, and reactive power imbalance. FACTS devices provide localized and rapid compensation, while HVDC systems offer broader control and isolation benefits. The integration of these technologies represents a promising approach for maintaining high power quality in future electrical power systems.

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