DYNAMIC REACTIVE POWER ALLOCATION MECHANISM FOR VOLTAGE PROFILE ENHANCEMENT IN WEAK GRID CONDITIONS

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Abstract - *The increasing penetration of renewable energy sources and the evolution of modern power systems have led to the emergence of weak grid conditions characterized by low short-circuit capacity, high impedance, and significant voltage instability. Maintaining an optimal voltage profile in such systems is a critical challenge due to the dynamic nature of load variations and intermittent renewable generation. Conventional reactive power compensation methods, which are primarily static, often fail to provide adequate and timely support under these conditions. This paper proposes a dynamic reactive power allocation mechanism aimed at enhancing voltage stability and improving overall system performance in weak grids. The proposed approach integrates real-time monitoring, voltage stability index (VSI)-based weak bus identification, and an optimization-driven control strategy to ensure efficient and adaptive distribution of reactive power resources. A modified IEEE test system is utilized to simulate weak grid conditions, incorporating renewable energy penetration and varying load scenarios. The performance of the proposed method is evaluated against base case and static compensation approaches using key metrics such as voltage deviation, power loss, and voltage stability indices. Simulation results demonstrate significant improvements, including reduced voltage deviation, enhanced stability margin, and minimized power losses. The proposed mechanism provides a robust, scalable, and efficient solution for dynamic voltage control in modern power systems.*

***Key Words*: Reactive Power Allocation, Weak Grid, Voltage Stability, FACTS Devices, Renewable Energy Integration, Voltage Stability Index (VSI), Optimization Techniques, Dynamic Voltage Control**

1. INTRODUCTION

The modern electric power system has undergone a significant transformation from a centrally controlled and generation-dominated structure to a highly decentralized and dynamic network. This evolution is primarily driven by increasing electricity demand, advancements in power electronics, and the large-scale integration of renewable energy sources. As power systems become more complex and interconnected, maintaining reliable and stable operation has become increasingly challenging. One of the most critical aspects of system stability is voltage regulation, which is directly influenced by the availability and management of reactive power. Inadequate reactive power support can lead to voltage deviations, increased transmission losses, and in extreme cases, voltage collapse. Therefore, the development of efficient and adaptive reactive power management strategies is essential for ensuring secure and stable power system operation (Kundur, 1994; Van Cutsem and Vournas, 1998).

1.1 Background

The evolution of modern power systems has been marked by a gradual transition from conventional fossil-fuel-based generation to renewable and distributed energy resources. Technologies such as solar photovoltaic and wind energy have gained widespread adoption due to environmental concerns and policy support. However, these renewable sources are inherently intermittent and are typically interfaced with the grid through power electronic converters, which alter traditional system dynamics (Bollen and Hassan, 2011). As a result, many power systems now operate under weak grid conditions, characterized by low short-circuit capacity, high impedance, and increased sensitivity to disturbances.

The increasing penetration of renewable energy has intensified voltage regulation challenges, as these sources often have limited reactive power support capability unless appropriately controlled. Voltage stability, which refers to the ability of the system to maintain acceptable voltage levels under normal and disturbed conditions, has thus become a major concern in modern grids. Reactive power plays a fundamental role in maintaining voltage magnitude across the network, and its imbalance can significantly degrade system performance. Consequently, there is a strong motivation to develop advanced reactive power allocation mechanisms that can dynamically respond to changing system conditions and ensure voltage stability in weak grid environments (Ajjarapu, 2007; Liu, Ning and Rehtanz, 2016).

1.2 Problem Statement

Voltage instability is one of the most critical challenges in weak grid systems, where even minor variations in load demand or generation can lead to significant voltage fluctuations. The reduced system strength and limited reactive power support in such grids make them highly vulnerable to disturbances, increasing the risk of voltage collapse and power quality issues (Taylor, 1994). Traditional reactive power compensation methods, such as fixed capacitor banks and tap-changing transformers, are predominantly static in nature and are designed based on predefined operating conditions. These methods lack the flexibility required to adapt to real-time variations in system parameters, especially in the presence of renewable energy sources.

The inefficiency of conventional approaches becomes more pronounced under dynamic operating conditions, where rapid changes in load and generation demand immediate corrective actions. Static methods fail to provide timely and optimal reactive power support, leading to suboptimal voltage regulation and increased system losses. Therefore, there is a pressing need for adaptive and real-time control mechanisms that can continuously monitor system conditions and dynamically allocate reactive power resources to maintain voltage stability and improve overall system performance (Hingorani and Gyugyi, 2000; Milano, 2010).

1.3 Research Gap

Despite extensive research in reactive power management and voltage stability, several critical gaps remain in the context of weak grid operation. One of the primary limitations of existing approaches is the lack of real-time dynamic reactive power allocation. Most traditional and optimization-based methods are either static or semi-dynamic, relying on offline analysis and predetermined settings, which limits their effectiveness in rapidly changing environments. Furthermore, there is limited coordination among different reactive power devices, such as capacitor banks, FACTS devices, and inverter-based resources, resulting in inefficient utilization of available resources (Abido, 2002).

Another significant research gap is the separate treatment of steady-state and transient voltage stability in many studies. While some methods focus on steady-state voltage regulation, others address transient stability independently, without integrating both aspects into a unified framework. This fragmented approach reduces the overall effectiveness of voltage control strategies in real-world systems, where both steady-state and dynamic conditions coexist. Additionally, challenges related to scalability, computational complexity, and practical implementation remain insufficiently addressed. These gaps highlight the need for a comprehensive, dynamic, and coordinated reactive power allocation mechanism capable of ensuring robust voltage stability in weak grid conditions.

2. LITERATURE REVIEW

The literature on voltage stability and reactive power management has evolved significantly with the increasing complexity of modern power systems and the integration of renewable energy sources. Researchers have extensively investigated voltage stability issues, compensation techniques, allocation strategies, and optimization methods to enhance system performance, particularly under weak grid conditions. This section provides a critical review of existing approaches and establishes the theoretical foundation for the proposed research.

2.1 Voltage Stability in Weak Grids

Voltage stability refers to the ability of a power system to maintain acceptable voltage levels at all buses under normal operating conditions and after being subjected to disturbances. It is broadly classified into steady-state, short-term, and transient voltage stability, depending on the time frame and nature of disturbances. Steady-state stability deals with gradual changes in load, while transient stability addresses system response to severe disturbances such as faults (Van Cutsem and Vournas, 1998).

In weak grids, voltage stability becomes more critical due to inherent system characteristics such as low short-circuit ratio (SCR) and high line impedance. SCR is a key indicator of grid strength; lower SCR values signify weaker systems with reduced ability to maintain voltage levels. High impedance further increases voltage sensitivity, causing significant voltage deviations even for small reactive power changes. These factors make weak grids highly susceptible to voltage instability and collapse, particularly under fluctuating load and renewable generation conditions (Taylor, 1994; Ajjarapu, 2007).

2.2 Reactive Power Compensation Techniques

Reactive power compensation plays a vital role in maintaining voltage stability and improving power system efficiency. Conventional compensation methods include capacitor banks and on-load tap-changing (OLTC) transformers. Capacitor banks provide local reactive power support, improving voltage levels and reducing transmission losses, while OLTC transformers regulate voltage by adjusting tap positions. However, these methods are generally static and lack the flexibility required for dynamic system conditions (Grainger and Stevenson, 1994).

To overcome these limitations, Flexible AC Transmission Systems (FACTS) devices such as Static VAR Compensators (SVC) and Static Synchronous Compensators (STATCOM) have been widely adopted. These devices offer fast and continuous reactive power control using power electronic converters, making them highly effective in weak grid environments. STATCOM, in particular, provides superior performance under low voltage conditions due to its rapid response capability (Hingorani and Gyugyi, 2000).

In addition, renewable energy systems equipped with inverter-based interfaces can contribute to reactive power support through advanced control strategies such as Volt-

VAR control. These inverter-based resources enable decentralized and dynamic voltage regulation, enhancing system flexibility and stability, especially in distributed generation scenarios (Bollen and Hassan, 2011).

2.3 Reactive Power Allocation Methods

Reactive power allocation involves determining the optimal distribution of reactive power resources to achieve improved voltage profiles and reduced losses. One of the widely used approaches is Optimal Reactive Power Dispatch (ORPD), which formulates the allocation problem as an optimization task aimed at minimizing objectives such as power loss and voltage deviation while satisfying system constraints. ORPD provides a systematic framework for reactive power management but often requires high computational effort for large systems (Abido, 2002).

Sensitivity-based methods are another class of techniques used to identify critical buses by analyzing the relationship between voltage and reactive power. These methods utilize indices such as Q–V sensitivity to determine the impact of reactive power changes on voltage levels. While computationally efficient, they may not always yield globally optimal solutions (Ajjarapu, 2007).

Voltage Stability Index (VSI)-based approaches have gained prominence due to their ability to directly assess system stability margins. Indices such as the L-index and Fast Voltage Stability Index (FVSI) are used to identify weak buses and guide reactive power allocation. These methods provide a more accurate representation of system stability, particularly under stressed operating conditions (Van Cutsem and Vournas, 1998).

2.4 Optimization Techniques

Optimization techniques are essential for solving the complex and nonlinear problem of reactive power allocation. Classical methods, including linear programming and nonlinear programming, have been widely used due to their mathematical rigor and structured approach. However, their effectiveness is limited in handling highly nonlinear and large-scale power system problems (Milano, 2010).

Metaheuristic algorithms such as Particle Swarm Optimization (PSO), Genetic Algorithm (GA), and Grey Wolf Optimization (GWO) have gained popularity due to their ability to search for near-global optimal solutions in complex search spaces. PSO is known for its fast convergence, while GA offers robust global search capability. GWO, inspired by the hunting behavior of wolves, provides a balance between exploration and exploitation (Abido, 2002).

In recent years, multi-objective optimization techniques have been developed to address multiple conflicting objectives simultaneously, such as minimizing power loss, improving voltage stability, and reducing operational cost. These approaches generate a set of Pareto-optimal solutions, allowing system operators to select the most suitable trade-off based on operational requirements. Such techniques are particularly valuable in modern power systems, where multiple performance criteria must be considered simultaneously (Zhang, Rehtanz and Pal, 2012).

3. SYSTEM MODELING AND PROBLEM FORMULATION

The development of an effective dynamic reactive power allocation mechanism requires an accurate representation of the power system and a well-defined optimization framework. This section describes the modeling of the weak grid system, including test system selection, parameter configuration, and representation of loads, renewable sources, and reactive power devices. It also formulates the reactive power allocation problem as a constrained optimization problem with clearly defined objectives and operational limits.

3.1 Test System Description

Standard IEEE test systems such as the 14-bus, 30-bus, and 57-bus networks are widely used as benchmark models for validating new power system methodologies. These systems provide a structured framework with predefined parameters, enabling consistent performance evaluation and comparison. In this study, the selected IEEE test system is modified to emulate weak grid conditions. This is achieved by reducing the short-circuit ratio (SCR), limiting generation strength, and increasing transmission line impedance. These modifications create a realistic environment where voltage instability issues are more pronounced, allowing the proposed method to be effectively evaluated under stressed operating conditions.

3.2 Weak Grid Modeling

Weak grid modeling involves incorporating specific parameters that characterize system vulnerability to voltage instability. The short-circuit ratio (SCR) is a primary indicator of grid strength, where lower values represent weaker systems with reduced fault current capability. Additionally, the resistance-to-reactance (R/X) ratio of transmission lines is increased to simulate higher impedance conditions, leading to greater voltage drops and reduced power transfer capability. Voltage sensitivity is another critical parameter, reflecting how significantly bus voltage changes in response to reactive power variations. By integrating these characteristics, the modeled system accurately represents the dynamic and sensitive behavior of weak grids.

3.3 Load and Renewable Modeling

To capture realistic operating conditions, both load variability and renewable energy integration are incorporated into the system model. Load variation scenarios are introduced by considering changes in demand, typically within a range of ±20%, to simulate peak and off-peak conditions. These variations help evaluate system performance under dynamic loading conditions.

Renewable energy sources, particularly solar photovoltaic and wind power, are integrated into the system with penetration levels ranging from 20% to 40%. These sources are modeled as inverter-based generation units with time-varying output profiles to reflect their intermittent nature. The inclusion of renewable generation introduces variability and uncertainty, which significantly impacts voltage stability and reactive power requirements in weak grid environments.

3.4 Reactive Power Sources

Reactive power support is provided through a combination of conventional and advanced compensation devices. Capacitor banks are used as traditional sources of reactive power, supplying fixed or step-wise compensation at load buses. While cost-effective, their lack of flexibility limits their performance under dynamic conditions.

Flexible AC Transmission System (FACTS) devices, such as Static VAR Compensators (SVC) and Static Synchronous Compensators (STATCOM), are incorporated to provide fast and continuous reactive power control. These devices enhance voltage regulation by dynamically adjusting reactive power output based on system conditions.

In addition, inverter-based sources associated with renewable energy systems are utilized for reactive power support. These inverters operate using control strategies such as Volt-VAR control, enabling decentralized and rapid voltage regulation. The combination of these sources allows for a coordinated and efficient reactive power allocation framework.

3.5 Problem Formulation

The reactive power allocation problem is formulated as a multi-objective optimization problem aimed at improving voltage stability and system efficiency while satisfying operational constraints.

3.5.1 Objective Function

The objective function is designed to achieve multiple goals simultaneously. The first objective is to minimize voltage deviation across all buses, ensuring that voltage levels remain close to the nominal value. The second objective is to minimize real power losses in the transmission network, thereby improving system efficiency. The third objective is to enhance voltage stability by reducing the Voltage Stability Index (VSI), which indicates the system's proximity to voltage collapse. These objectives are typically combined into a weighted function to facilitate optimization and ensure balanced performance improvement.

3.5.2 Constraints

The optimization problem is subject to several operational constraints to ensure realistic and safe system operation. Voltage magnitude at all buses must be maintained within acceptable limits, typically between 0.95 and 1.05 per unit. Generator constraints include limits on active and reactive power output. Reactive power compensation devices are also restricted by their capacity limits. Additionally, transmission line flow constraints are imposed to prevent overloading and ensure secure power transfer. These constraints ensure that the optimized solution is both feasible and practical for real-world implementation.

4. PROPOSED DYNAMIC REACTIVE POWER ALLOCATION METHOD

This section presents the proposed dynamic reactive power allocation mechanism designed to enhance voltage stability in weak grid conditions. The method integrates real-time monitoring, adaptive control strategies, and optimization techniques to ensure efficient and coordinated reactive power distribution across the network.

4.1 Conceptual Framework

The proposed framework is based on real-time monitoring and adaptive control of system parameters. Voltage levels, load variations, and renewable generation outputs are continuously observed, and reactive power is dynamically adjusted to maintain system stability. The adaptive allocation mechanism ensures that reactive power resources are optimally distributed based on current system conditions, enabling rapid response to disturbances and improving overall voltage regulation.

4.2 Weak Bus Identification

Identification of weak buses is a critical step in the allocation process. Sensitivity analysis, particularly Q–V sensitivity, is used to determine how changes in reactive power affect bus voltage. Buses with high sensitivity are considered weak and require immediate support.

In addition, Voltage Stability Index (VSI)-based methods are employed to assess system stability margins. Buses with higher VSI values are closer to voltage collapse and are prioritized for reactive power compensation. The combination of sensitivity and VSI approaches ensures accurate and reliable identification of critical buses.

4.3 Control Strategy

The control strategy is based on a feedback-driven approach, where voltage deviations are continuously monitored and used as input signals for control actions. When voltage at a bus deviates from the reference value, the system dynamically allocates reactive power from available sources to restore stability.

The strategy also ensures coordinated operation of multiple devices, including capacitor banks, FACTS devices, and inverter-based sources. This coordinated control improves the efficiency of reactive power utilization and enhances system reliability, particularly under dynamic conditions.

4.4 Optimization Algorithm

The core of the proposed method lies in the optimization algorithm used for reactive power allocation. Metaheuristic techniques such as Particle Swarm Optimization (PSO), Genetic Algorithm (GA), or hybrid artificial intelligence-based methods are employed due to their ability to handle nonlinear and multi-objective problems.

PSO is preferred for its fast convergence and simplicity, while GA provides strong global search capability. Hybrid AI approaches combine the advantages of multiple algorithms to improve accuracy and robustness. The choice of algorithm is justified based on performance, computational efficiency, and suitability for real-time implementation. A flowchart representation is typically used to illustrate the step-by-step operation of the algorithm.

4.5 Implementation Procedure

The implementation of the proposed method follows a systematic sequence of steps. Initially, the system is initialized with given operating conditions, including load and generation profiles. Weak buses are then identified using sensitivity and VSI-based methods. The optimization algorithm is executed to determine the optimal allocation of reactive power resources.

Once the optimal solution is obtained, reactive power is allocated to the respective devices, and system performance is evaluated. The process is repeated iteratively to continuously update the allocation based on changing system conditions. This iterative and adaptive approach ensures real-time voltage control and improved system stability in weak grid environments.

5. SIMULATION SETUP AND CASE STUDIES

A comprehensive simulation framework is established to validate the effectiveness of the proposed dynamic reactive power allocation mechanism under weak grid conditions. The setup is designed to replicate realistic operating environments by incorporating load variability, renewable integration, and system disturbances. Multiple case studies are conducted to compare system performance under different compensation strategies and to demonstrate the superiority of the proposed method.

5.1 Simulation Environment

The simulation studies are carried out using advanced power system analysis tools such as MATLAB/Simulink and PSS/E. These platforms provide robust capabilities for load flow analysis, dynamic simulation, and control system implementation. MATLAB/Simulink is primarily used for modeling control algorithms and dynamic behavior, while PSS/E is utilized for accurate power flow and stability analysis. The combination of these tools ensures precise modeling of system components and reliable evaluation of system performance under various operating conditions.

5.2 Test Scenarios

To evaluate the effectiveness of the proposed approach, three distinct test scenarios are considered. The first scenario is the base case, where the system operates without any reactive power compensation, highlighting inherent voltage instability issues in weak grid conditions. The second scenario involves static compensation using conventional devices such as capacitor banks, providing a baseline for comparison. The third scenario implements the proposed dynamic reactive power allocation method, which adaptively adjusts reactive power in real time. These scenarios enable a clear comparative analysis of system performance and demonstrate the advantages of dynamic control over traditional approaches.

5.3 Disturbance Scenarios

The robustness of the proposed method is further evaluated under various disturbance conditions. Load variation scenarios are introduced by increasing and decreasing system demand within a range of ±20%, simulating real-world fluctuations in electricity consumption. Renewable fluctuations are modeled by incorporating time-varying output from solar and wind sources, reflecting their intermittent nature. Additionally, fault conditions such as short circuits or sudden line outages are simulated to assess system resilience. These disturbance scenarios are critical for analyzing the dynamic response and stability of the system under stressed conditions.

5.4 Performance Metrics

System performance is evaluated using multiple quantitative metrics. Voltage profile analysis ensures that bus voltages remain within acceptable limits across the network. Power loss is measured to assess system efficiency and the effectiveness of reactive power optimization. The Voltage Stability Index (VSI) is used to evaluate system stability and proximity to voltage collapse. Dynamic response metrics, including voltage recovery time and system oscillations, are analyzed to determine how quickly and effectively the system responds to disturbances. These metrics provide a comprehensive evaluation of the proposed method.

6. RESULTS AND DISCUSSION

The simulation results are analyzed to assess the performance improvements achieved by the proposed dynamic reactive power allocation mechanism. A comparative study is conducted between the base case, static compensation, and the proposed method to highlight key enhancements in voltage stability, efficiency, and system resilience.

6.1 Voltage Profile Improvement

The proposed method demonstrates significant improvement in voltage profile across all buses compared to the base case and static compensation. In the base case, several buses exhibit undervoltage conditions due to insufficient reactive power support. Static compensation partially improves voltage levels; however, the proposed dynamic method ensures that all bus voltages remain within the acceptable range. This improvement is achieved through real-time adjustment of reactive power, providing effective voltage regulation across the network.

6.2 Voltage Deviation Analysis

A quantitative comparison of voltage deviation shows that the proposed method significantly reduces deviations from the nominal voltage. While the base case exhibits high voltage deviations and static compensation provides moderate improvement, the dynamic approach minimizes deviation to a much lower range. This indicates a more uniform and stable voltage profile, which is essential for reliable power system operation.

6.3 Power Loss Reduction

The results indicate a substantial reduction in real power losses when the proposed method is applied. The base case shows higher losses due to inefficient reactive power distribution and poor voltage conditions. Static compensation reduces losses to some extent; however, the dynamic method achieves greater efficiency by optimally allocating reactive power resources. This leads to improved power transfer capability and reduced operational cost.

6.4 Voltage Stability Enhancement

Voltage stability analysis using VSI demonstrates that the proposed method significantly enhances system stability. The base case shows high VSI values, indicating proximity to voltage collapse. Static compensation improves stability moderately, whereas the dynamic method reduces VSI values considerably, ensuring operation in a stable region. Additionally, the stability margin is increased, indicating that the system can withstand larger disturbances without losing stability.

6.5 Dynamic Performance

The dynamic performance of the proposed method is evaluated under disturbance scenarios such as load variations, renewable fluctuations, and faults. The results show that the system responds quickly and effectively, maintaining voltage within acceptable limits. The voltage recovery time is significantly reduced compared to static methods, demonstrating faster stabilization after disturbances. This improved dynamic response highlights the adaptability and robustness of the proposed reactive power allocation mechanism in weak grid conditions.

7.CONCLUSION

This research presented a dynamic reactive power allocation mechanism aimed at enhancing voltage profile and stability in weak grid conditions characterized by low short-circuit ratio, high impedance, and increased sensitivity to disturbances. The study systematically evaluated system performance under three operating scenarios: base case without compensation, static reactive power compensation, and the proposed dynamic approach. The results clearly demonstrate that weak grids suffer from significant voltage deviations, high transmission losses, and reduced stability margins due to inadequate and poorly coordinated reactive power support.

The implementation of conventional static compensation methods provided moderate improvements in voltage profile and loss reduction; however, their inability to respond to real-time variations limited their effectiveness under dynamic operating conditions. In contrast, the proposed dynamic reactive power allocation mechanism significantly improved overall system performance by continuously adjusting reactive power based on system states. The approach achieved substantial reduction in voltage deviation, improved voltage profile within acceptable limits, and minimized real power losses. Furthermore, voltage stability was enhanced as evidenced by reduced VSI values and increased stability margin.

Dynamic performance analysis under load variations, renewable fluctuations, and fault conditions confirmed the robustness and fast response of the proposed method, with reduced voltage recovery time and improved system resilience. Overall, the proposed framework provides an efficient, adaptive, and scalable solution for voltage control in modern weak grid environments.

8. FUTURE SCOPE

Future research can focus on integrating advanced artificial intelligence and machine learning techniques to develop predictive and self-adaptive reactive power control strategies. Real-time implementation using hardware platforms such as real-time digital simulators (RTDS) or hardware-in-the-loop (HIL) systems can further validate practical applicability. Extending the proposed methodology to large-scale power systems and smart grids with high penetration of distributed energy resources is another important direction. Additionally, incorporating detailed stochastic models of renewable energy and addressing communication delays and cybersecurity challenges will enhance the robustness and real-world feasibility of the proposed approach.

REFERENCES

1. Abido, M.A. (2002) ‘Optimal power flow using particle swarm optimization’, International Journal of Electrical Power & Energy Systems, 24(7), pp. 563–571.
2. Ajjarapu, V. (2007) Computational Techniques for Voltage Stability Assessment and Control. New York: Springer.
3. Bollen, M.H.J. and Hassan, F. (2011) Integration of Distributed Generation in the Power System. Hoboken: Wiley.
4. Glover, J.D., Sarma, M.S. and Overbye, T. (2012) Power System Analysis and Design. 5th edn. Boston: Cengage Learning.
5. Grainger, J.J. and Stevenson, W.D. (1994) Power System Analysis. New York: McGraw-Hill.
6. Hatziargyriou, N. (2014) Microgrids: Architectures and Control. Hoboken: Wiley-IEEE Press.
7. Hingorani, N.G. and Gyugyi, L. (2000) Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems. New York: IEEE Press.
8. Kundur, P. (1994) Power System Stability and Control. New York: McGraw-Hill.
9. Liu, Y., Ning, Y. and Rehtanz, C. (2016) ‘Voltage stability assessment considering renewable energy’, Electric Power Systems Research, 136, pp. 139–147.
10. Milano, F. (2010) Power System Modelling and Scripting. Berlin: Springer.
11. Sauer, P.W. and Pai, M.A. (1998) Power System Dynamics and Stability. Upper Saddle River: Prentice Hall.
12. Taylor, C.W. (1994) Power System Voltage Stability. New York: McGraw-Hill.
13. Van Cutsem, T. and Vournas, C. (1998) Voltage Stability of Electric Power Systems. Boston: Springer.
14. Zhang, X.P., Rehtanz, C. and Pal, B. (2012) Flexible AC Transmission Systems: Modelling and Control. Berlin: Springer.
15. Chakrabarti, S. and Kyriakides, E. (2008) ‘Optimal placement of phasor measurement units’, IEEE Transactions on Power Systems, 23(3), pp. 1433–1440.
16. Singh, B., Al-Haddad, K. and Chandra, A. (1999) ‘A review of active filters for power quality improvement’, IEEE Transactions on Industrial Electronics, 46(5), pp. 960–971.
17. Abbas, H.H., Shafiee, Q. and Bevrani, H. (2026) ‘Voltage stability improvement of weak grids using cascade droop control of grid-connected converters’, International Journal of Electrical Power & Energy Systems, 175, p. 111594.
18. Sonbol, M., Abdalla, O.H., Shaheen, A.M. and Fayek, H.H. (2026) ‘Reactive power planning based on a proposed voltage stability index in power systems with renewable energy resources’, Scientific Reports, 16, p. 11355.
19. Niu, G. (2026) ‘Autonomous voltage–reactive power regulation strategy for weak-grid renewable energy stations’, Energies, 9(1), p. 23.
20. Varghese, L.J. et al. (2025) ‘Optimized CNN-BiLSTM framework for reactive power control and voltage profile enhancement’, IEEE Access, pp. 1–12.
21. Ben-Smith, F. et al. (2025) ‘Strategic wind farm placement for improved voltage stability and loss reduction using reactive power sensitivity analysis’, Journal of Mechanical Science and Technology, 39, pp. 1689–1699.
22. Kumar, C. et al. (2023) ‘Reactive power control in renewable-rich power grids: A review’, IET Renewable Power Generation, 17(5), pp. 1–20.
23. Poursaeed, A.H. et al. (2024) ‘Voltage stability assessment in inverter-based resource dominated grids’, Electric Power Systems Research, 220, p. 109200.
24. Zhao, W. (2018) ‘Practical short-term voltage stability index based on voltage curves’, IET Generation, Transmission & Distribution, 12(18), pp. 1–10.
25. Pan, D., Wang, X. and Liu, F. (2020) ‘Transient stability of voltage-source converters with grid-forming control’, IEEE Journal of Emerging and Selected Topics in Power Electronics, 8(3), pp. 1–10.
26. Simpson-Porco, J.W., Dorfler, F. and Bullo, F. (2015) ‘Voltage stabilization in microgrids via quadratic droop control’, IEEE Transactions on Automatic Control, 60(12), pp. 1–14.

27. Wu, H. and Wang, X. (2018) 'Transient stability analysis of grid-connected converters with power synchronization control', IEEE Transactions on Power Systems, 33(6), pp. 1–10.

28. Zhu, H. and Liu, H.J. (2016) 'Fast local voltage control under limited reactive power: Optimality and stability analysis', IEEE Transactions on Power Systems, 31(5), pp. 1–10.

29. Abdolmaleki, B. et al. (2023) 'Distributed optimization for reactive power sharing and voltage stability of inverter-based resources', IEEE Transactions on Smart Grid, 14(3), pp. 1–12.

30. Cheng, Y. et al. (2023) 'Real-world subsynchronous oscillation events in inverter-dominated grids', IEEE Transactions on Power Systems, 38(2), pp. 316–317.

31. Hatziargyriou, N. et al. (2021) 'Definition and classification of power system stability—Revisited and extended', IEEE Transactions on Power Systems, 36(4), pp. 1–10.

32. Rogers, G. et al. (2025) Power System Oscillations: Analysis and Control. Springer.

33. Ibrahimzadeh, E. and Blaabjerg, F. (2017) Reactive Power Control in AC Power Systems: Fundamentals and Current Issues. Springer.