CHAPTER 9

OPTIMIZATION OF VOLTAGE STABILITY IN DISTRIBUTION MICROGRID SYSTEM

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9.1 INTRODUCTION

With the evolution of power networks driven by technological developments and greater integration of renewable energy, microgrids have surfaced as a viable alternative for improving grid resilience and energy sustainability. However, maintaining voltage stability in microgrids presents a significant challenge owing to the intermittent nature of renewable generation and the impacts of system disturbance (Satish Kumar & Sharma, 2020). Current approaches lack in addressing dynamic fluctuations, which are seen as a critical gap in optimizing voltage stability in microgrid with renewable energy integration.

Voltage instability may occur during events such as line outages, generator failures, or sudden load variations. This causes cascading failures as well as the loss of generation and loads. An increasing amount of focus is being placed on monitoring the voltage profile and voltage regulation of the system in order to address the challenge of rising power demand. Proposed solutions include expanding generation capacity (Neema, 2020), upgrading infrastructure, and integrating renewable energy sources (RESs) such as solar and wind energies. The integration of RESs into microgrids has become more appealing due to the shift in electricity generation from centralized to distributed generation (DG). However, this introduces new stability challenges including abnormal voltage fluctuations.

To address voltage instability, flexible AC transmission systems (FACTS) devices provide an effective solution by dynamically managing power flow and voltage levels. Their benefits include increasing transmission capacity, regulating power flow, improving transient stability, damping power oscillations, and maintaining voltage stability. Besides, FACTS devices are classified as series, shunt, or a mix of both (Al Ahmad & Sirjani, 2020; Chandak et al., 2019; Wondie et al., 2022). Among shunt devices, static var compensator (SVC) and static synchronous compensator (STATCOM) are the most implemented, with STATCOM being the superior option due to its faster response, linear reactive power control, and stable compensation performance, independent of system voltage.

Existing studies have explored the impact of system disturbances and RESs integration on voltage stability, alongside FACTS-based mitigation. Research indicates that disturbances such as load increases and line outages push stability indices toward critical thresholds, leading to potential collapse (Mokred et al., 2023). Despite the optimal solar PV placement that enhances stability (Olarewaju et al., 2023; Uzun et al., 2022), excessive penetration may cause overvoltage issues, which reduce stability margins (Al-Omary, 2023; Shinde & Mane, 2022). Likewise, while wind power improves stability, reactive power demand may increase due to high penetration, which causes instability (Pelosi et al., 2025). In addition, FACTS devices such as SVC, STATCOM, and TCSC have proven effective in enhancing voltage stability, with shunt-based devices outperforming series alternatives (Abdullah et al., 2022).

In this work, a microgrid is simulated to assess voltage stability under various disturbances using five voltage stability indices (VSIs) such as fast voltage stability index (FVSI), line stability (Lmn) index, line stability factor (LQP), novel line stability index (NLSI), and novel voltage stability index (NVSI). Each index quantifies different voltage stability aspects which enables a comprehensive evaluation of system performance. Subsequently, RESs such as solar PV and wind are integrated into the system to examine the effects of their intermittent nature on voltage profiles. Due to their intermittency, voltage instability becomes a growing concern, especially at high penetration levels (Elkhidir et al., 2022; Talaat et al., 2023).

Hence, this study proposes the application of a STATCOM for its ability to provide fast and efficient reactive power compensation (Paredes et al., 2023). By analyzing the microgrid under multiple scenarios, the study evaluates the effectiveness of STATCOM in enhancing system resilience, regulating voltage profiles, and maintaining overall voltage stability (Saadati Toularoud et al., 2024).

9.2 VOLTAGE STABILITY INDICES

Voltage stability indices (VSIs) are intended to help identify the system's potential voltage collapse or unstable point. Each index possesses a critical value which indicates the stability of the system. To prevent any network instability, the index value must not exceed such point (Saadati Toularoud et al., 2024). Five types of VSIs are listed in Table 9.1, accompanied with their formulas and descriptions.

The table presents a comparative overview of four voltage stability indices commonly used to assess the risk of voltage instability or collapse in power systems. Each index is based on different assumptions and modeling approaches, making them suitable for various system conditions. All aim to detect the critical voltage point (typically set at 1) beyond which the system becomes unstable, and they are essential tools for real-time voltage monitoring and control in microgrids or conventional power networks.