Chapter 13

Voltage Control in Smart City Low Voltage Distribution Networks Using Artificial Intelligence and Power Electronics

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ABSTRACT

Voltage stability is a critical aspect of ensuring reliable power supply in smart city low voltage (LV) networks, where increasing penetration of renewable energy sources and dynamic demand patterns present operational challenges. This study proposes an AI-enhanced optimal voltage control method implemented using smart

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power converters with real-time monitoring and adjustment capabilities. The control strategy employs the Exhaustive Search Method (ESM) to determine optimal reference voltage set points by evaluating all possible solutions within a defined range. The method is applied to the CIGRE LV residential distribution network under worst-case PV and load conditions. Compared to the base case, the proposed method—using a step size of 0.001—achieves a significant reduction in total voltage deviation, with improvements ranging from 88.05% to 90.78%. The results confirm that the integration of artificial intelligence and power electronics enables effective voltage regulation, making the approach well-suited for smart city applications.

INTRODUCTION

The increasing integration of photovoltaic (PV) systems into low voltage (LV) distribution networks, especially within smart city environments, presents critical challenges stemming from the uncertainty and variability of renewable energy generation. Voltage rise during periods of high PV injection and voltage drops during peak load conditions restrict PV hosting capacity and compromise load support, highlighting the need for robust voltage regulation strategies that comply with grid codes and support high renewable penetration without unnecessary curtailment (Manojkumar et al., 2024).

Smart urban energy systems—characterized by bidirectional power flows, time-varying loads, prosumer activity, and interconnectivity—demand advanced voltage control methods to maintain voltage profiles within statutory limits. High PV penetration often causes voltage rise in residential feeders, while peak demand leads to voltage sags, potentially disrupting sensitive electronic infrastructure and connected smart devices (Rahimi et al., 2025; Ruiz-Romero et al., 2014). Traditional voltage regulation approaches such as on-load tap changers (OLTCs), reactive power control (RPC), battery energy storage systems (BESSs), and active power curtailment (APC) have been extensively explored (Tonkoski et al., 2011). However, OLTCs are not viable at the LV level (11/0.4 kV), RPC becomes less effective in distribution systems with high R/X ratios, BESSs are capital-intensive with substantial maintenance demands, and APC results in reduced solar energy utilization (Masters, 2002).

To overcome these limitations, smart power converters (SPCs) have been proposed as a promising alternative for voltage regulation in LV networks. SPCs offer continuous and dynamic voltage control without relying on mechanical switching or centralized devices like DSTATCOMs (Kumar et al., 2018; Yu et al., 2014). These converters provide fast and localized voltage adjustment, disturbance rejection, and power quality improvement, which are crucial in networks with high levels of distributed generation (Chen et al., 2018; Shah & Crow, 2016). Their modular

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