

# 論文の要旨

## **Optimal Voltage Control for Active Distribution Systems Using Multi-Agents** (マルチエージェントを用いた配電システムの最適電圧制御)

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The rapid increase in the installation of distributed generations (DGs), particularly solar photovoltaic (PV) associated with unbalanced features of distribution systems (DS), disturbs the classic control strategy of voltage regulation devices. The classic control strategies of the traditional voltage regulation devices, such as the on-load tap changer (OLTC), switchable capacitors (SC) and step voltage regulators (SVRs), are designed based on the unidirectionally power flow scheme from the substation to the loads. The DG installation changes the characteristic of the DS from passive to active, which can mislead such classic control strategies and causes tap oscillations and increase the voltage violation problems, i.e., voltage rise, voltage fluctuation and voltage imbalance because of the intermittent and unbalanced outputs of DGs.

The main objective of this work is to develop effective voltage control schemes for DS with high DG penetration. For this purpose, three strategies for voltage control are proposed in this work based on a multi-agent system (MAS) architecture. An advantageous feature of using the MAS scheme is a robust control performance in a flexible and reliable manner, even in the case of agent failure.

Firstly, an effective voltage control strategy for voltage regulators in the unbalanced DS (UDS) is proposed based on voltage/tap sensitivity and the MAS architecture. The features of the UDS with DGs and different types and configurations of voltage regulators are considered in the proposed strategy. The novelty of the proposed method lies in realizing both the control optimality of minimizing voltage violations and the flexibility to accommodate changes in the DS topology using a MAS scheme. Simulation studies have been conducted using the IEEE 34-node and 123-node distribution test feeders considering high PV penetration and different sun profiles. The results show that the proposed voltage control strategy can optimally and effectively manage the voltage regulators in the UDS, which decreases their operation stresses and minimize the overall voltage deviation.

Secondly, a simple and efficient method is proposed for voltage regulation by managing the reactive power of the DG sources. The proposed control strategy is formulated based on voltage/reactive power sensitivity analysis using the MAS architecture. Comprehensive case studies on IEEE 33 test feeders are carried out to demonstrate the effectiveness of the control strategy. The numerical results show that the proposed strategy can significantly mitigate voltage violation problems in a simple manner.

Finally, a novel method for management the output active and reactive powers of the DG sources in order to realize an optimal operation of the DS. The objective of the proposed method is to control the

reactive power outputs of DGs for maximizing the total output power while improving the voltage profiles of the DS. The proposed method resolves all those problems. In order to mitigate the voltage violation, the proposed method performs an optimal power flow (OPF) calculation and compute the nodal prices of active and reactive powers based on the MAS approach. Then dynamic pricing is carried out on-line using locational marginal pricing (LMP) for real and reactive powers of PVs in DS. The simulation results confirm that the proposed method can successfully deal with the voltage violations in DS and minimize the curtailment of PV power.

The thesis consists of six chapters. The research topics are mainly distributing among the chapters as follows:

**Chapter 1:** presents the introduction to the active DSs, research objectives, scope of the research, and organization of the thesis.

**Chapter 2:** provides a comprehensive review of DS, impact of DGs on feeder voltage regulation, voltage control techniques, and MAS.

**Chapter 3:** presents an optimal voltage control strategy for voltage regulators in active UDS using MAS architecture. The proposed method is tested considering high PV penetration and compared with a conventional method. The simulation results demonstrate that the proposed strategy can effectively adjust the tap operations to minimize the voltage deviation with no tap oscillations under different sun profiles (sunny or cloudy).

**Chapter 4:** provides an effective control strategy for DGs reactive power based on MAS and voltage/reactive power sensitivity analysis. The proposed strategy utilizes the reactive power capability of the DG sources to reduce the overall system voltage deviation. The numerical results show that the proposed strategy can significantly mitigate voltage violation problems.

**Chapter 5:** provides a novel method for controlling photovoltaic (PV) power outputs for optimal operation of DS. The proposed method maximizes the total power of PVs in the DS by controlling their reactive power outputs while improving the voltage profiles. The results demonstrate that the proposed method is effective to mitigate the voltage violation problem and maximize the total PV power generations.

**Chapter 6:** provides a conclusion part, where contributions of the study are discussed. In addition, some recommendations for further research in the future are presented.