INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI
SHORT ABSTRACT OF THESIS

Name of the Student	:	Mudaser Rahman Dar
Roll Number	:	206102102
Programme of Study	:	Ph.D.

Thesis Title: Voltage Control of Active Distribution Networks with EV Charging Stations using Multi-Time Scale Model Predictive Control

Name of Thesis Supervisor	:	Dr. Sanjib Ganguly
Thesis Submitted to the Department/ Center	:	Department of Electronics and Electrical Engineering (EEE)
Date of completion of Thesis Viva-Voce Exam	:	28-November-2025
Key words for description of Thesis Work	:	Active Distribution networks, Voltage control, Distributed control, Electric Vehicles, Distributed Generation, Model Predictive Control.

SHORT ABSTRACT

The rapid proliferation of photovoltaic (PV) units and controllable loads, notably electric vehicles (EVs), has significantly altered the operational dynamics of active distribution networks (ADNs), causing various issues. Their large-scale integration and uncertain behaviour induce frequent and severe voltage violations, thereby challenging traditional voltage regulation mechanisms, which involve localized control of on-load tap changers (OLTCs), static voltage regulators (SVRs), etc. For this purpose, coordinated voltage control (CVC) schemes have been developed, wherein the control capabilities of fast-acting devices, such as PV inverters and EV charger inverters, storage devices, and other power electronic interfaced devices, are utilized for voltage regulation and loss minimization. A multi-time scale model predictive control (MPC) based real-time receding horizon control mechanism, enabling coordination of diverse resources including OLTC, PV, and EV charging station (EVCS) inverters, and distribution static synchronous compensators (DSTATCOMs), lies at the core of this thesis. The multi-time scale design allows OLTC operation on a slower time scale, and coordinated operation of inverter-driven control devices (IDCDs) on a faster time scale.

Taking into consideration the need for extensive measurement infrastructure and communication overhead, in centralized control frameworks, an MPC-based centralized control framework has been developed. To avoid the need for a fully observable network, a reduced-order control framework has been developed, with reduced measurement and communication infrastructure requirements, mitigating cost and computational complexity, while enhancing scalability. Based on a novel ranking index, a minimum set of available control resources is identified and employed for voltage regulation and energy loss minimization. The performance of the reduced model framework is comparable to that of the full-order model, with a mean and standard deviation in the difference between the voltage profiles at the critical bus of 0.0036 pu. and 0.0029 pu., respectively.

To effectively address the uncertainties associated with nodal power injections, due to PVs, EVs, and conventional loads, a chance-constrained model predictive control (CC-MPC) based centralized control framework has been developed to contain uncertainties with known probability distributions. A scenario-based solution approach has been developed to solve the chance-constrained (CC) problem, ensuring predefined solution accuracy within the network security constraints, while enhancing computational efficiency using the backward scenario reduction technique. The CC-MPC framework eliminates all the violations as compared to the deterministic MPC, with an increase in energy loss and reactive power exchange by around 20\% and 3\%, respectively. In addition, a distributionally robust chance-constrained formulation is introduced to consider the uncertainties in nodal power injections and real-time measurements with unknown distributions, but with partially available information. Unlike the scenario-based approach to the CC problem, a tractable solution approach has been utilized by modifying the upper and lower limits of CCs with a dynamically adjusted safety margin, based on available information about uncertainties. A local rapid-response control mechanism is also integrated to mitigate fast voltage violations and act as a backup layer for the central controller.

To enhance scalability and preserve data privacy, a centralized-distributed hybrid hierarchical control architecture has been developed for large networks, while considering the demerits of centralized control. The IDCDs are controlled using MPC with distributed coordination among network clusters, and OLTC employs centralized control requiring sparse communication. An improved modularity metric is introduced, incorporating cluster diameter, in addition to voltage sensitivities and device regulation capacities, for optimal partitioning of the network, for distributed coordination. Within these partitions, distributed coordination among IDCDs is achieved using the alternating direction method of multipliers (ADMM), which enables local decision-making with limited communication overhead. Furthermore, a scenario-based chance-constrained MPC framework has been developed to incorporate the nodal power uncertainties in the centralized-distributed hybrid control paradigm. It is seen that the distributed coordination of IDCDs provides a near-optimal solution, with 0.0024 pu. mean deviation in the voltage profile at the critical bus as compared to centralized optimal coordination.

The proposed control strategies are extensively validated on standard test networks, such as the 33-bus distribution network and the modified IEEE 123-bus distribution network, under high PV and EV penetration levels. All the time domain simulations in this thesis have been carried out using the Power System Analysis (PSAT) toolbox in MATLAB, and the optimizations are carried out using IBM ILOG CPLEX with the MATLAB interface.