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Dissertation Title: TSO–DSO Coordination: Distributed Frameworks for Harnessing DER Flexibility in Power System Operational Planning

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Abstract or Public Summary: Electric power systems are undergoing a profound transformation driven by the large-scale integration of Renewable Energy Sources (RES) and Distributed Energy Resources(DER). Increasing shares of generation are now connected at the Distribution Network (DN) level, accompanied by the widespread deployment of Energy Storage Systems (ESS), Electric Vehicles (EV), and flexible demand. While these developments introduce significant new sources of flexibility, they also challenge traditional operating paradigms that rely on limited interaction between Transmission System Operators (TSOs) and Distribution System Operators (DSOs). Fully exploiting distribution-level flexibility therefore requires a fundamental rethinking of how TSO and DSOs interact, together with the establishment of

effective coordination mechanisms.

This thesis proposes a comprehensive set of tools for the coordinated operation and planning of transmission and distribution systems. Central to the proposed approach is a distributed TSO–DSO coordination framework that enables the joint exploitation of DER-based flexibility while respecting institutional separation, data privacy, and regulatory requirements. A key novelty is the introduction of shared resources installed at transmission–distribution interface nodes, which can be jointly managed by TSO and DSOs to improve coordination efficiency and overall system performance. To operationalize this framework, the thesis develops a suite of optimization-based tools spanning multiple time scales, including a TSO–DSO coordinated operational planning tool and a bi-level planning framework for the optimal siting and sizing of shared resources. Distributed optimization methods are employed throughout to ensure scalability and preserve data confidentiality among participating agents.

The proposed methodologies are validated through extensive numerical studies on standard IEEE test systems and real-world network data, as well as experimental Hardware-In-the-Loop (HIL) testing for real-time operation. The results demonstrate that coordinated TSO–DSO operation significantly improves system efficiency, enhances renewable energy integration, and mitigates network constraints through the effective utilization of DER flexibility. Overall, this work shows that distributed TSO-DSO

coordination constitutes a viable and practical pathway toward the secure, efficient, and sustainable operation of future power systems.

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