The present decade has seen significant growth in renewable energy sources-based generators (RESs) due to growing concerns for sustainable development. However, as clean as they are, RESs have a major drawback of variability. In addition, these generators are interfaced to the grid via power electronic converters, which have a low short circuit ratio (SCR), leading to reduced system strength and grid support participation. To this end, various solutions are being proposed, ranging from deploying energy storage systems (ESSs) to legacy system upgrades involving retrofitting and software modifications. A retrofitting or ESS deployment would incur additional costs, while a software upgrade involves resource-intensive design changes.

To provide an immediate solution to maximize the grid support contribution of legacy wind RES systems, this work explores techniques involving optimized control references to unlock their full potential in grid support without design changes. The research involves a case study of a legacy GE1.5 commercial-scale Doubly-Fed Induction Generator (DFIG)--based Wind Farm (WF). DFIG-based WFs (DFWFs) are popular in onshore systems due to their low capital cost. The first part of the work identifies the support capability of a legacy DFWF by considering system and regulatory constraints. These limits are quantified, and the generator operating set points are determined under various operating conditions.

The Wake Effect (inter-turbine wind interference) in the WF necessitates a Farm-Level Optimization (FLO) to ascertain these set points. Considering this, the support limits are optimized to achieve the objectives with minimal control transition effort to increase the equipment's lifetime. The proposed optimization is time-independent, offline, and a one-time procedure for a given WF geometry. Next, the support performance is tested in low and high-voltage ride-through (L/HVRT) modes to validate its efficacy, adding significant value over the prior art, where a comprehensive solution with quantified support limits was lacking. This solution package is termed the Systematic Enhanced Optimization and Grid Support (SEOGS) algorithm.

Next, the research extends to tap into the full support potential of the DFWF by integrating the Grid Side Converter (GSC) into the SEOGS framework. By harnessing the reactive power headroom of the GSC, the reactive power burden on the DFIG is reduced, enabling an even higher active power ramping limit. The new package is called the Modified SEOGS (M-SEOGS) algorithm. On a larger scale, the proposed solutions are expected to enhance the support performance of legacy DFWFs without altering the system design, utilizing optimized lookup references.

Overall, the thesis introduces strategies for optimizing farm-level operations by enhancing spinning reserves, minimizing blade wear, and establishing clear grid support limits while ensuring compatibility with legacy systems. The findings shall contribute to higher operational efficiency, reliability, and profits (with appropriate policies), empowering operators to enhance grid stability as RES penetration increases. Ultimately, this study promotes the effective integration/utilization of wind energy in power systems, supporting their present transition to a cleaner and sustainable future.