

Modern energy conversion systems are designed by tightly integrating power electronic converters, digital control platforms, and communication infrastructures to enable efficient transformation of electrical energy. The rapid proliferation of inverter-based resources has significantly improved system flexibility, efficiency, and scalability. However, the inherent discreteness of semiconductor switching devices introduces quantized input constraints that fundamentally alter closed-loop dynamics. The mismatch between continuous-time control design and discrete switching implementation creates performance degradation, increased ripple, and stability challenges, particularly in high-performance systems and grid-interactive applications.

While appreciable progress has been made in nonlinear control, adaptive regulation, and model predictive control of energy conversion systems, a unified theoretical framework that explicitly incorporates quantized control inputs into stability and performance design remains an open problem. This deficiency leads to limitations in robustness, computational scalability, and constraint handling, particularly in IBRs-dominated or inverter-interfaced power systems.

Model predictive control is a popular control method in the IBR-dominated energy conversion systems because it provides control, accommodates constraints and nonlinearities. However, the computational burden posed by the accuracy associated with longer horizon when the converter switching dynamics are considered is a big issue in its implementation. Thus, FCS-MPC has been adopted to restrict the control design to a single horizon and eliminate PWM requirement for power converters, which comes with a lot of ripples and high harmonic content. To bridge continuous nonlinear designs and discrete switching realization, a projection-based control scheme is developed, providing Lyapunov stability guarantees under bounded quantization error.

The proposed framework demonstrates that properly incorporating quantized input constraints into control synthesis significantly improves steady-state performance, robustness, and computational efficiency compared to conventional continuous MPC algorithms in converter-tied systems. By unifying nonlinear control theory and finite-set predictive optimization, this dissertation establishes a rigorous foundation for resilient control of energy conversion systems operating under discrete input constraints. This method is an improvement on the contemporary finite-control-set predictive methods because converters are switched directly without PWM and variable frequency issue is curtailed along with smoothness guarantees in the regulation results.