Hierarchical Control and Optimization for Microgrids: Balancing Multiple Time Scales with Event-Triggered Mechanisms

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Abstract. Microgrids are dynamic systems that require a coordinated approach to managing multiple time scales across their control layers. This paper proposes a hierarchical control architecture that combines real-time optimization with event-triggered mechanisms to enhance operational efficiency and stability. The architecture is designed to handle both fast transient dynamics and slower, long-term energy management decisions. Simulation results demonstrate how this approach outperforms traditional control strategies in both stability and resource optimization.

Keywords: Hierarchical control, microgrid stability, multi-time scale optimization, event-triggered mechanisms, distributed generation

Introduction:

The increasing complexity of energy systems driven by the integration of renewable energy and distributed generation calls for advanced control strategies capable of managing a wide range of operational time scales. Microgrids, with their inherent flexibility and ability to operate in both grid-connected and islanded modes, provide a promising platform for future energy networks. However, ensuring the stability, efficiency, and reliability of microgrids requires coordinated control strategies that can simultaneously address the needs of fast dynamics (e.g., voltage and frequency regulation) and slower processes (e.g., economic dispatch and load management).

Hierarchical control systems are widely used in microgrids to divide control tasks into layers, each targeting a specific time scale. The challenge lies in integrating these layers in a manner that allows for seamless coordination and optimization across the system. This paper proposes a novel hierarchical control architecture that incorporates real-time optimization algorithms alongside event-triggered mechanisms. The event-triggered layer is designed to detect critical conditions that necessitate control interventions, reducing the frequency of unnecessary actions and enhancing overall system performance.

The proposed architecture is validated through extensive simulation studies, which show that it offers significant improvements in both stability and resource allocation compared to traditional control strategies. The results highlight the effectiveness of combining time-scale separation with event-driven actions to achieve a balanced and efficient microgrid operation.