Thesis Title: Renewable energy support mechanisms for efficient and sustainable power systems

Name: Shilpa Bindal

Entry number: 2019EEZ8371

Abstract:

This thesis addresses the technical and economic issues associated with renewable energy (RE) support mechanisms, which are adopted to promote investments in RE and the generation and consumption of energy from renewable sources. In addition to promoting RE, the design philosophy behind these mechanisms influences the power injection patterns and investment decisions of RE investors. Their actions, driven by these mechanisms, impact power system operation and planning. This research aims to study these impacts comprehensively and suggest improvements. Two types of mechanisms are analyzed: compensation mechanisms for distributed energy resources (DERs) and procurement mechanisms for centralized power plants.

The compensation mechanisms used to incentivize DERs are generation-based and encourage maximum available power injection into the system. With high DER penetration, this practice introduces operational challenges and reinforcement needs. In contrast, encouraging system-aware power injection can offer loss reduction, voltage profile improvement, and reinforcement deferral benefits. To realize these benefits, the design of compensation mechanisms needs to be revisited. New designs should incentivize DERs to coordinate with system operators and dispatch power according to system requirements. This design process involves determining a dispatch schedule, evaluating its benefits, and compensating DERs based on their contributions.

Existing literature offers DER scheduling strategies that address either operational or planning goals but lacks a unified approach that considers both. This thesis addresses that gap by formulating a single scheduling problem incorporating the objectives of different system entities. The developers' goal of reducing asset utilization and the operators' aim of improving system performance are aligned by analyzing the impact of power injection on branch flows. A phase-specific Optimal Power Dispatch (OPD) scheme is proposed, which reduces losses and asset usage. Compared to balanced scheduling, a phase-specific schedule offers additional benefits by controlling unbalance.

Alongside OPD scheduling, utilities must quantify the economic benefits of these actions. While loss reduction and capacity deferral benefits are addressed in existing work, benefits like voltage profile improvement and unbalance reduction are often unquantified. To capture all benefits, this thesis proposes a methodology to measure branch-level advantages from local power injection. Results show that OPD actions yield higher utility benefits than maximum power injection.

Since current compensation mechanisms are generation-based, DERs injecting maximum power are paid more than those providing OPD services, despite the latter's higher system value. To resolve this, a compensation scheme for OPD is proposed. It utilizes the economic benefits of OPD and allocates compensation based on individual DER contributions. As OPD benefits result from cooperative actions, joint-cost allocation is required. The Aumann-Shapley value method is applied for fair benefit allocation, and a compensation plan is developed by aggregating individual components. The scheme is self-sufficient, with payments funded by OPD benefits. Compensation varies with network loading and DER location, creating locational signals. The scheme proves economically viable, especially for DERs near peak loads or on downstream buses. Using batteries to store unscheduled energy has also been beneficial in such locations.

The thesis also analyses procurement mechanisms for centralized power plants, particularly multi-technology auctions used to procure RE capacity. Although intended to reduce support costs and meet capacity targets, actual allocations often deviate from the target mix. Quantity-based support mechanisms attempt to align allocations with the target mix but raise cost concerns. A tier-price-based approach is proposed to address this, analysing how support mechanisms shift capacity and affect procurement cost. The analysis shows that the long-term mix can be achieved without additional cost. Applied in the Indian context, this approach results in significant cost savings while meeting long-term capacity goals.