From Siloed Operations to Co-Designed Energy Systems: Scheduling, Control, and Flexibility

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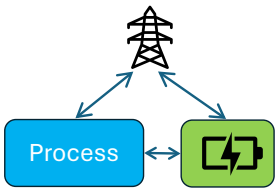
With the accelerating energy transition, dependencies between power grids and process systems are intensifying. Optimizing such coupled energy systems is best treated as a joint problem of scheduling and control (Baldea and Harjunkoski, 2014), with demand-side management and process flexibility at the core. Scheduling allocates resources and commitments over longer horizons using forecasts and constraints; control executes these plans in real time while adapting to disturbances. The key is co-designing their interface so that flexible demand – adjustable production rates, shiftable tasks, thermal or material buffers, and storage-like inventories – can be reliably mobilized. Both domains contain plannable elements essential for cost-efficient operation and fast dynamics that demand short-term actions. As the share of non-dispatchable renewables grows, stabilizing the power grid must get increased attention.



Effective solutions use hierarchical architectures that translate high-level objectives and constraints into actionable setpoints and aggregate feasible responses back up. Model predictive control (Rawlings et al., 2017) links multi-period planning with feedback; stochastic and robust formulations hedge uncertainty across horizons. Decomposition methods (Conejo et al., 2006) enable tractable coordination among subsystems, while surrogate modeling and learning enhance forecasts and decisions without sacrificing transparency. The palette of methodologies becomes complex and the success depends on co-design: aligning objectives, constraints, and information flows; defining clear interfaces and ensuring verifiable performance under uncertainty. Across diverse settings, integrated scheduling-with-control consistently outperforms siloed approaches on cost, reliability, and sustainability, pointing to uncertainty-aware, interoperable, and auditable architectures as the path forward.

For energy systems that span slow and fast dynamics in both power grids and production processes, the main challenge is integration. Priorities include actionable demand signals, clear flexibility metrics (ramp rate, duration, recovery), and safeguards for product quality and safety. Evidence from process industries shows that embedding demand-side actions into scheduling-with-control reduces costs and emissions, improves resilience to variability, and unlocks value streams, e.g. load shifting, peak shaving, ancillary flexibility, often without new hardware. When energy storage and market participation (e.g., electricity bidding) enter the picture, coordination becomes even more complex. Should power systems and industrial processes remain separate, or should the automation pyramid be integrated so both collaborate across levels? Answering this requires a clear assessment of the flexibility and dynamic capabilities of industrial loads.

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