Duality in Profit Maximizing Grid-Scale Storage Optimization for AC Networks

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We investigate the relationship between nodal price signals and the optimal operation of distributed energy storage systems (ESS) in alternating current (AC) power networks. We carry out the analysis using a multi-period alternating current optimal power flow (ACOPF) problem with charge and discharge dynamics for ESS collocated with load and/or generation. We analyze the resulting ACOPF with ESS problem by first applying a convex relaxation to obtain a semidefinite program (SDP). We then derive the storage subproblem from the Lagrangian dual in order to investigate the relationship between the storage variables and the locational marginal prices (LMPs), which are the dual variables associated with the nodal active power flow balance. We illustrate that negative LMPs can lead to simultaneous charging and discharging, which can be avoided by modifying the ACOPF. Our theoretical results prove that LMPs drive charging and discharging dynamics, and that storage is allocated and operated to maximize the storage operator's profits. Thus, profit maximization of the storage operator is dual to cost minimization of the system operator in a purely competitive market. We illustrate these theoretical relationships using case studies based on IEEE benchmark systems.