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A Distribution-class Locational Marginal Price (DLMP) Index for Enhanced Distribution Systems

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Abstract
The smart grid initiative is the impetus behind changes that are expected to culminate into an enhanced distribution system with the communication and control infrastructure to support advanced distribution system applications such as distributed generation, energy storage systems and price responsive loads. This thesis proposes a distribution-class analog of the transmission LMP (DLMP) as an enabler of the advanced applications of the enhanced distribution system. The DLMP is proposed to be an efficient control signal that can incentivize price-sensitive distribution system resources to behave optimally in a manner that benefits economic efficiency and system reliability.

In order to reduce the computational complexity that could result from solving a unit commitment or an economic dispatch problem for a single model that includes details of both the transmission and the distribution systems, the DLMP’s calculation problem is decomposed into a transmission and a distribution system OPF problem. It is proposed to iterate between the two problems until convergence, defined in terms of the distribution system proxy LMPs in successive iterations, is reached. The iterative approach provides a
means to accurately represent the price-sensitive resources in a distribution system for the transmission system OPF and vice versa and it optimally couples the transmission and the distribution systems. The approach and its attendant convergence problems are discussed.

As part of the DLMP’s calculation framework, a DCOPF formulation that endogenously captures the effect of real power losses is discussed extensively. The formulation uses piecewise linear functions to approximate real power losses. The methodology could produce incorrect solutions with the occurrence of non-positive DLMPs/LMPs. The breakdown and its impact on DLMPs/LMPs are theoretically proven and an alternate mixed integer linear programming based formulation is presented.

The DLMP is numerically illustrated for a traditional and an enhanced distribution system. The superiority of the DLMP to contemporary pricing signals is also demonstrated through the incentivized actions of price-responsive loads. Results show that as flexible resources increase, the impact of the inaccuracy of contemporary pricing signals becomes significant. At high price elasticity of demand, the aggregate consumption incentivized by a flat and a time-of-use rate deviated from the optimal consumption incentivized by the DLMP by approximately 40 and 45 percent respectively in certain periods. The individual load consumption incentivized by a real-time price deviated by as much as 25 percent. The superiority of the DLMP is more significant when important distribution network conditions are not reflected by contemporary prices. The individual load consumption incentivized by the real-time price in a congested distribution network deviated by approximately 90 percent in certain periods. While the DLMP internalizes congestion management, the consumption incentivized by the real-time-price caused line overloads.