

# **Trigger rules optimization for adaptable investment in distribution substation capacity under uncertainty: Untapping the value of flexibility**

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## **Abstract-**

The rise of intermittent renewable generation and the electrification of demand are causing grid congestion and connection delays in some countries, a trend expected to expand as the energy transition progresses. At the same time, distribution system operators face high uncertainty in forecasting peak loads due to the unpredictable adoption pace of technologies such as electric vehicles, distributed generation, and industrial electrification. This paper presents a stochastic optimization model to determine the optimal timing of substation capacity investments combined with flexibility solutions under uncertainty. The model builds on the real options framework and employs triggers as decision rules (e.g., investing in a transformer once peak load exceeds a threshold), resulting in adaptable strategies, in which future investment decisions are contingent on unfolding information rather than fixed planning schedules. The model optimizes these triggers and reveals strong synergies with flexibility solutions, achieving 15.1% expected savings and 64.9% expected reduction in reserved flexibility compared to the traditional approach in our case study. Adaptable strategies may lead to anticipatory investment in some scenarios and deferral in others compared to the traditional planning approach, striking a balance between faster connections and cost-efficiency. This adaptability is particularly valuable given the current high-uncertainty context. The case study shows that these benefits grow as available flexibility increases. From a regulatory standpoint, these trigger rules can support conditional approval of anticipatory grid investments, contingent on confirmation of the investment need (e.g., peak load exceeding a set threshold), thereby limiting the risk of such investments becoming stranded assets.

**Index Terms-** Distribution network; Real options; Flexibility; Investment under uncertainty; Anticipatory investment

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