Cyprus University of Technology
Faculty of Engineering and Technology

Doctoral Dissertation

Mathematical and Bayesian Inference Strategies for Optimal Unit Commitment in Modern Power Systems

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CYPRUS UNIVERSITY OF TECHNOLOGY

FACULTY OF ENGINEERING AND TECHNOLOGY

DEPARTMENT ELECTRICAL ENGINEERING, COMPUTER ENGINEERING AND INFORMATICS

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Approval Form

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This thesis is dedicated to my family for their endless support and love and to the memory of my uncle who’s no longer with us

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Abstract

Global efforts aiming to shift towards de-carbonization give rise to remarkable challenges for power systems and their operators. Modern power systems need to deal with the uncertain and volatile behavior of their components (especially, renewable energy generation); this necessitates the use of increased operating reserves. To ameliorate this expensive requirement, intelligent systems for determining appropriate unit commitment schedules have risen as a promising solution. This is especially the case for weak power systems with low dispatching flexibility and high dependency on imported fossil fuels.

With the fast-paced changing technologies in the context of sustainable development, new approaches and concepts are needed to cope with the variability and uncertainty affecting generation, transmission and load demand. The main challenge remains in developing technologies that can efficiently make use of the available renewable resources. Among them, electrical energy storage constitutes a potential candidate capable of regulating the power generation to match the loads via time-shifting. Optimally planned, such facilities can meet the increasing requirement of reserves to manage the variability and uncertainty of renewable energy sources whilst improving the system operation efficiency and economics.

In this thesis, we present a novel Lagrange Relaxation method with constraints, considering the impact of variable renewable energy sources. Our proposed approach successfully deals with identical generating units found in isolated power systems, enabling the realistic determination of the optimal electricity storage size based on actual data. In addition, we introduce a radically novel paradigm for addressing the optimal unit commitment problem, that is capable of accounting for the largely unaddressed challenge of the uncertain and volatile behavior of modern power systems. Our innovative solution leverages state-of-the-art developments in the field of uncertainty-aware machine learning models, namely Bayesian optimization. This framework enables the effective discovery of the best possible configuration of a volatile system with uncertain and unknown dynamics in the least possible number of trials, and without the need of introducing restrictive prior assumptions.

Developing a deep understanding of the different electricity storage principles and their applications, we develop an innovative model able to distinguish the power-related and energy-related cost components and integrate complex features such as the round-trip efficiency, depth of discharge, self-discharge rate, etc. We evaluate the impact of intermittent renewable energy sources on total production cost, by making use of annual data regarding the isolated power system of the island of Cyprus. Once electrical energy storage is identified as an approach enhancing flexibility and reliability, we formulate and evaluate the selected facilities via a life-cycle cost analysis, based on the most realistic characteristics and cost metrics found in the literature. The derived simulation results showed that improvements exist in profitable return credits when storage was integrated.

Keywords: *renewable energy generation, weak power systems, electrical energy storage, machine learning models, Bayesian optimization, life-cycle cost analysis.*