Optimal Design and Operation of a Renewable Energy-Based Polygeneration System: A Deterministic Approach

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Abstract

With the energy transition underway, there is a consensus effort from both worldwide governments and industry, to facilitate the integration of more renewable energy into power grids. However, the main challenge with integrating renewables like wind and solar, is the intermittent nature of these sources that result in inefficiencies and a lack of reliability. One possible energy system that can allow for an effective integration with intermittent sources is a polygeneration energy system (PES). The concept of a PES has been proposed in academic literature in recent times, where a typical pathway is the use of excess power from a fossil power plant being directed towards the production of valuable liquid fuels, in addition to electricity to the grid. In this study, the concept of a polygeneration system has been modified and extended to include renewable energy generation from wind, and a chemical production pathway of methanol to act as a form of long duration storage for times when the wind generation is much higher for any load demand and therefore increasing the flexibility.

The approach taken in this model development departs from previous polygeneration modeling studies, by using a network constrained Unit Commitment (UC) model that is well established in the domain of power systems engineering, to optimally schedule the power planning and power flow. First, the design and operation of a power generation planning model is developed to showcase how the power system responds to the intermittency of wind in the form of wind scenarios. Mixed-Integer Linear Programming (MILP) models are then developed for the chemical production of methanol and integrated with the power planning model as a multi-scale (design and operation) model of a renewable polygeneration energy system (RPES) with chemical storage. To showcase the design and operation of the proposed RPES, the model is first solved in a deterministic manner. The total RPES system cost, based on real world wind power data and load demand data, was found to be USD 2317.93 million. The chemical production block had a cost of USD 138.51 million when integrated as a part of the RPES and the power generation planning block had a cost of USD 2179.42 million. The integrated model resulted in costs for the chemical production block that were much lower than the stand-alone plant while the RPES model also showed how excess intermittent wind power could be used for driving the chemical production. A key contribution to this work is also the implementation of machine learning methods, like K-Means clustering to help with the model's solution tractability and representation of a full year's hourly wind data and load demand. The MILP models have been developed using the General Algebraic Modeling System (GAMS) software and solved using state of the art optimization solvers BARON and CPLEX.

Keywords
Polygeneration, Design and Operation, Energy Systems. (10 font)

Biographies

Tuhin Kanti Poddar is a recent PhD graduate from the University of Waterloo, Ontario, Canada. He worked under the supervision of Ali Elkamel and Peter L. Douglas from 2017 to 2022 in the Department of Chemical Engineering and his research focused on the modeling and optimization of complex and large scale energy systems. Prior to his PhD studies, from 2014 to 2016, he worked at the Khalifa University of Science and Technology in Abu Dhabi, UAE as a research assistant where he also obtained his MSc. degree. At Khalifa University, his research focused on biodiesel production simulation and also the supply chain optimization of electrical vehicles and power systems. He obtained his BSc. degree in chemical engineering from Purdue University, USA in 2013.

Ali Almansoori is a Professor of Chemical Engineering at Khalifa University of Science and Technology in Abu Dhabi. During his profession, Dr. Almansoori held several administrative positions including: Coordinator of President's Duties, Dean of Engineering, and Chair and Deputy Chair of the Chemical Engineering Department. He also was the Interim Senior Vice President for Academic Affairs during the merge between Petroleum Institute, Masdar Institute, and Khalifa University of Science, Technology, and Research. His main research interest is in the area of Process Systems Engineering, with focus on energy systems design, simulation, modeling, and optimization. He also conducts general research in the area of renewable energy and fuel cell technology with applications to the oil and gas industry. Dr. Almansoori has published numerous articles in renowned refereed journals and conference proceedings. He also delivered several presentations in international conferences and is the author of a few book chapters. Furthermore, he serves as a reviewer for reputable international journals in the area of energy and process systems. Dr. Almansoori has received a number of educational and research awards, including the Sheikh

Mohammed Bin Rashid Medal for Scientific Excellence in the UAE for 2019, PI 2014–2015 Research & Scholarship Award for Senior Faculty, two Best Track Paper Awards in IEOM'15 & GSR'15 Conferences, ADNOC 2013 R&D Science Lantern Faculty Award, PI 2012 Excellence in Academic Advising Award, and Sheikh Rashid Award for Scientific Outstanding Performance in 2008.

Peter L. Douglas is a Professor of Chemical Engineering at the University of Waterloo. He has also been the Associate Dean of Undergraduate Studies, Director of the University of Waterloo United Arab Emirates Campus in Dubai, Associate Dean of Engineering (Computing), and the Associate Dean of Engineering (Graduate Studies). Professor Douglas was a founding member of WISE the Waterloo Institute for Sustainable Energy at UWaterloo. His primary research area of interest is in the development and application of PSE technology to industrial processes, including process modelling, simulation, control and optimization. He is working on simulation and optimization issues related to the mitigation and capture of carbon dioxide from large-scale emitters. He is not accepting new students. Professor Douglas has consulted on a worldwide basis for many clients and has worked in Canada, Australia, Malaysia, Thailand, and the UAE. Additionally, he is a co-inventor of the Dryer Master online measurement and control systems for the food processing industry; such systems are finding widespread use in Canada, USA, Europe, and Asia. In addition to his research work, Professor Douglas has co-authored more than 200 related research publications and has supervised more than 80 postgraduate students.

Ali Elkamel is a Professor in the Department of Chemical Engineering and is cross-appointed to Systems Design Engineering. He holds a BSc in Chemical Engineering and BSc in Mathematics from Colorado School of Mines, MS in Chemical Engineering from the University of Colorado-Boulder, and PhD in Chemical Engineering from Purdue University – West Lafayette, Indiana. The goal of his research program is to develop theory and applications for process systems engineering. The applications are focused on planning and scheduling of process operations, energy production, pollution monitoring and control, waste minimization, carbon management, sustainable operations, molecular design, and product formulation. Among his accomplishments are the Outstanding Faculty Award, the Best teacher award, the IEOM (Industrial engineering and Operations Management) Outstanding Service and Distinguished Educator Award, UAE MBR Academy of Scientists, The Engineering Research Excellence Award, and Excellence in Graduate Supervision Award. He has been on the program and organization committees of many international conferences. Prof. Elkamel has a strong track record of research excellence. He published over 330 journal articles, 145 proceedings, and 33 book chapters, and has been an invited speaker on numerous occasions at academic institutions throughout the world and at national and international conferences. He has also written 5 books, including "Environmentally Conscious Fossil Energy Production", "Planning of Refinery and Petrochemical Operations", and "Electric Vehicles in Energy Systems: Modelling, Integration, Analysis, and Optimization."