Guest editorial: special section on coordinated planning, operation and control of electricity and natural gas infrastructures

Mohammad SHAHIDEHPOUR[1], Jizhong ZHU[2], Ming NI[3]

We are very pleased to present to you the special section of the Journal of Modern Power Systems and Clean Energy on the coordinated planning, operation, and control of electricity and natural gas infrastructures. This special section aims at addressing the existing challenges in integrated planning, operation and control of natural gas and electric power systems that will enhance the resilience, economics, efficiency, reliability sustainability, and security of both infrastructures. We had invited original submissions from various countries focusing on the computational and technological aspects of the integrated natural gas and electric power systems.

The development of sustainable, affordable, and clean sources of energy is considered a prerequisite for today's global economic strength and will benefit tomorrow's resilient society. Under the impetus of competition in the energy industry, the unbundling of the electricity sector has introduced new technologies for the generation and the delivery of electricity, which signify less pollutant, highly efficient, and less costly ways of supplying the electricity. The large-scale integration of variable and renewable generation units will require an installed generating capacity that can respond quickly in power systems, and the deployment of natural gas-fired generation units will continue to serve this critical mission and play an indispensable role in power system operation and control. It is envisioned that cheap supply of natural gas, abundant quantity of renewable energy, and greater use of smart grid for promoting customer participations in managing the daily electricity load will reshape the global energy profile in upcoming years. However, there are many challenges that require further research and development corresponding to the planning, operation and control of integrated natural gas and electricity infrastructures. New tools are desired to manage the coupling between natural gas and electric power system, and innovative methods are sought to analyze the impact of uncertainty on the integrated energy systems.

This special section includes a total of eleven articles which discuss the above issues, introduce analytical methods for solving the pertinent problems, and present the results in detail in order to introduce the audience with the integration of these two very critical and highly diverse energy infrastructures. We had the honor of serving as the Guest Editors-in-Chief and would like to thank the Guest Editors for the special section who contributed to the review and the

Received: 26 April 2017/Accepted: 28 April 2017

✉ Mohammad SHAHIDEHPOUR
ms@iit.edu
Jizhong ZHU
zhujz@csg.cn
Ming NI
ni-ming@sgepri.sgcc.com.cn
[1] Illinois Institute of Technology, USA
[2] China Southern Power Grid, China
[3] State Grid Electric Power Research Institute, China

selection of the final articles, especially Dr. Xiaping Zhang, Operation Planning, Peak Reliability Inc., USA; and Dr. Lei Wu, Clarkson University, USA.

The eleven articles included in the special section are summarized and categorized into four groups as follows:

1) Planning of integrated natural gas and power systems

The aarticle titled, “Integrated operational planning of hydrothermal power and natural gas systems with large scale storages” presents a modelling and optimization approach to the operational planning of electric power and natural gas systems, taking into account different energy storage facilities, such as water reservoirs, natural gas storages and line packs of pipelines. The proposed model takes advantage of and captures both energy systems synergy and their associated networks. The approach identifies the interactions between the energy storage facilities and their economic impact over their optimal scheduling. The results show the benefits of an integrated operational planning of electric power and natural gas systems, the close interdependency between the energy resources stored in both systems, and the effects of a combined scheduling. The model and the proposed optimization approach allow the assessment of interactions between the energy storage facilities and analyse their economic impact on the optimal system scheduling. The simulation results show the benefits of an integrated operational planning of electric power and natural gas systems and the close interdependency between the energy resources stored in the two energy systems.

In the article titled, “Coordinated expansion co-planning of integrated gas and power systems”, the co-planning process is formulated as a mixed integer nonlinear programming problem to address several challenges including the system reliability evaluation, market time line mismatch, market uncertainties, and demand response. The proposed expansion co-planning (ECP) framework can find the minimum cost as it considers the constrained energy conversion process between gas and electricity in the coupled load center. Comprehensive case studies are applied to validate the performance of proposed approach. The simulation results demonstrate that the proposed minimum-cost planning decisions consider interactions between natural gas and electricity systems as it meets long-term energy demands.

2) Economic operation of integrated natural gas and power systems

The article titled, “Security-constrained model for integrated power and natural-gas system” presents a SCUC with dynamic gas constraints, such as the line pack, that can be employed to study the integrated system reliability by including contingencies of power and gas transmission networks. Contingencies are evaluated by using the Benders decomposition method that is able to cope with large integrated systems and a significant number of contingencies. Case studies demonstrate that the proposal can not only take into account the system security but also estimate the energy adequacy using the gas dynamic (line pack). The proposed models and solution methods can be used to operate the integrated system defensively, preventing cascading events, and ensuring the continuity of supply.

The article titled, “Integration of power-to-hydrogen in day-ahead security constrained unit commitment with high wind penetration” considers power-to-hydrogen (P2H) as a storage option to balance supply and demand in a variable power grid, in which excess wind power is converted into hydrogen via electrolysis and stored for later use. In this study, an energy hub with both a P2H facility (electrolyzer) and a gas-to-power (G2P) facility (hydrogen gas turbine) is proposed to accommodate the variability of wind power. The energy hub is modeled and integrated into a security-constrained unit commitment (SCUC) optimization problem which is solved by a mixed-integer linear programming (MILP) method with the Benders decomposition technique. Case studies are presented to validate the proposed model and elaborate on the technological potential of integrating P2H into a power system with a high level of wind penetration

(HWP).

The article titled, “Many-objective optimization for coordinated operation of integrated electricity and gas network” develops an optimization model considering several objectives for representing the interests of electricity and gas networks as well as distributed district heating and cooling units, which coordinate the benefits of participants in the integrated energy system (IES). The proposed study considers an improved objective reduction (IOR) approach aiming at acquiring the smallest set of objectives. The IOR approach adopts various strategies to reduce the number of objectives gradually and utilizes the Spearman’s rank correlation coefficient to measure the relationship among objectives which is based on the Pareto-optimal front. Simulation studies are conducted on an IES consisting of a modified IEEE 30-bus electricity network and a 15-node gas network. The results show that the many-objective optimization problem is transformed into a bi-objective formulation by the IOR. The proposed approach improves the overall dispatch solution and offers a concise decision making process.

In the article titled, “Linearized model for optimization of coupled electricity and natural gas systems”, the coupled optimization of electricity and natural gas systems of Greece is investigated. The extended incremental method as well as the outer approximation method is applied in this work for the linearization of the nonlinear equations that govern the physics of gas transport and for representing the coupling constraint of the two energy systems. This work is intended to act as a basis for further investigation into the modeling and the computation of the coupled electricity and natural gas system optimization.

The article titled, “Robust coordination of interdependent electricity and natural gas systems in day-ahead scheduling for facilitating volatile renewable generations via power-to-gas technology.” proposes a robust day-ahead scheduling model for the optimal coordinated operation of integrated energy systems while considering key uncertainties of the power system and natural gas system operation cost. Energy hub, with collocated gas-fired units, Power-to-Gas (PtG) facilities, and natural gas storages, is considered to store or convert one type of energy (i.e., electricity or natural gas) into the other form, which could analogously function as large-scale electrical energy storages. The column-and-constraint generation (C&CG) is adopted to solve the proposed integrated robust model, in which nonlinear natural gas network constraints are reformulated via a set of linear constraints. Numerical results signify the effectiveness of the proposed model for handling volatile electrical loads and renewable generations via the coordinated scheduling of electricity and natural gas systems.

The article titled, “Energy hub modeling to minimize residential energy costs considering solar energy and BESS” aims to optimize total energy costs in an operational energy hub model for residential areas. This work applies a new energy hub model considering load characteristics in residential areas. The proposed energy hub model exploits the applications of Photovoltaic (PV) and Solar Heat Exchanger (SHE), while taking into account the use of battery energy storage system (BESS) in the distribution grid. The article also minimizes the total energy cost in the energy hub. The optimization results show that the constrained energy hub with PV, SHE and BESS can reduce the total energy cost while meeting the demand.

3) Network analyses of integrated natural gas and power systems

In the article titled, “Unified probabilistic gas and power flow”, a unified probabilistic gas and power flow calculation method is proposed to analyze the effect of random factors on coupled natural gas and electricity systems. The case study demonstrates that random factors have a more significant impact on nearby state variables. Also a higher fluctuation of random factors will lead to larger variations in state variables with a more difficult curve fitting process in the proposed method. The proposed method applied to the calculation of probabilistic flows in the coupled system would result in desired-level precisions which are attained faster than the Monte Carlo simulation. The proposed piecewise linearization method is effective to deal with large scale random factors, making the proposed method more applicable to the optimization of energy infrastructures. The proposed method can provide quantitative safety assessments in the planning and the operation of couples natural gas and electricity systems.

The article titled, “Multi-period integrated natural gas and electric power system probabilistic optimal power flow incorporating power-to-gas units” proposes a multi-period integrated natural gas and electric power system probabilistic optimal power flow (M-GEPOPF) model, which includes dynamic gas flow models. To address the uncertainties originating from wind power and load forecasting, a probabilistic optimal power flow model based on a three-point estimate method is adopted in this work. Moreover, power-to-gas units are employed to avoid wind power curtailment which enables flexible bi-directional energy flows between the coupled energy systems. An integrated IEEE RTS 24-bus electric power system and Belgium 20-node natural gas system are employed as a test case to verify the applicability of the proposed M-GEPOPF model, and to demonstrate the potential economic benefits of power-to-gas units.

4) Market issues for integrated natural gas and power systems

The article titled, “Impact of increased renewables on natural gas markets in eastern United States” explores the market structures for natural gas and electricity as well as the interdependence of natural gas prices and electricity bids with increasing reliance on natural gas in order to complement uncertainties as the penetration of renewable energy resources increases. In particular, the article attempts to answer the following two questions: What could the generation mix look like in 2030 with a renewable-rich generation landscape and how could this impact gas prices? How will gas-fired generation volatility, their prices, and their bids for gas change between 2015 and 2030 with increased penetration of renewables? In order to answer these questions, computational models are derived using forecasting and regression analysis tools and an auction model. The main results of this article are that with increasing variable wind/solar penetration, ① volatility in gas generation increases, ② gas prices go up on average, with a significant increase in the summer months and a slight decrease in the winter months, and ③ volatility in gas bids increases.

Guest Editors-in-Chief

Mohammad SHAHIDEHPOUR
Illinois Institute of Technology, USA

Jizhong ZHU
China Southern Power Grid, China

Ming NI
State Grid Electric Power Research Institute, China

Guest Editors

Richard TABORS
Utility of the Future Project, Massachusetts Institute of Technology (MIT), USA

Cong LIU
Market Operation, ERCOT, USA

Göran ANDERSSON
Swiss Federal Institute of Technology (ETH Zurich), Switzerland

Xiaping ZHANG
Operation Planning, Peak Reliability Inc., USA

James MAREAN
Senior Program Manager, Gas Technology Institute, USA

Mark MCGRANAGHAN
Vice President, Electric Power Research Institute (EPRI), USA

Lei WU
Clarkson University, USA