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Coordinated operation of the electricity and natural gas systems with bi-directional energy conversion

Qing Zeng[a], Baohua Zhang[a], Jiakun Fang[a,*], Zhe Chen[a]

[a]*Department of Energy Technology, Aalborg University, Aalborg 9220, Denmark*

Abstract

A coordinated operation of the natural gas and electricity network with bi-directional energy conversion is expected to accommodate high penetration levels of renewables. This work focuses on the unified optimal operation of the integrated natural gas and electricity system considering the network constraints in both systems. An iterative method is proposed to deal with the nonlinearity in the proposed model. The models of the natural gas and power system are linearized in every iterative step. Simulation results demonstrate the effectiveness of the approach. Applicability of the proposed method is tested in the sample case. Finally, the effect of Power to Gas (P2G) on the daily economic dispatch is also investigated.

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Keywords: Integrated electricity and gas network, coordinated operation, successive linearization, Power to Gas, economic dispatch

1. Introduction

The rapid development of the renewable energy brings sustainability of the energy supply [1], while challenging the power system operators with the intermittent and unpredictable features at the same time. In recent years, research investigations have demonstrated that the integration of energy systems can balance the energy production and consumption in a broader scope, thereby improve the overall efficiency and sustainability of the energy utilization [2].

Among different energy systems such as power, gas, heating, transportation, etc., the natural gas and electrical power systems are the most common options for bulk energy transmission over thousands of kilometers. Moreover, the emerging power-to-gas technology enabling the bi-directional energy conversion further enhances the interaction

* Corresponding author. Tel.: +45 9940 3821.
E-mail address: jfa@et.aau.dk.

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between the gas and power systems [3]. More recent researches are carried out from the market perspective, illustrating that neglecting the gas supply limitations may lead to the energy cost distortion [4] and coordination can help to reduce energy supply cost [5].

The optimal operation of integrated gas and power systems can be formulated as an optimization problem. However, network constraints for both gas and electricity systems are usually presented in nonlinear forms which challenge the tractability of the global optimality. Existing work [6] decouples the optimization into two subproblems representing gas and electricity. However, it may not work for the loop-locked system with bi-directional energy conversion.

To achieve the optimal operation of the integrated gas and electricity system synchronously, this work focuses on the coordinated operation of the integrated gas and power system with bi-directional energy conversion. The objective is to minimize the operation cost for both electricity and gas systems while maximizing the renewable energy accommodation. It is mathematically formulated as a scaled nonlinear optimization problem. An iterative method is proposed to handle its scale and nonlinearity.

2. Integration of the electricity and natural gas systems

The integrated natural gas and power system is composed of a natural gas network and an electricity network as shown Fig. 1. It is a test system which has been used in the steady-state analysis of the combined gas and power system, and the details can be found in [7].

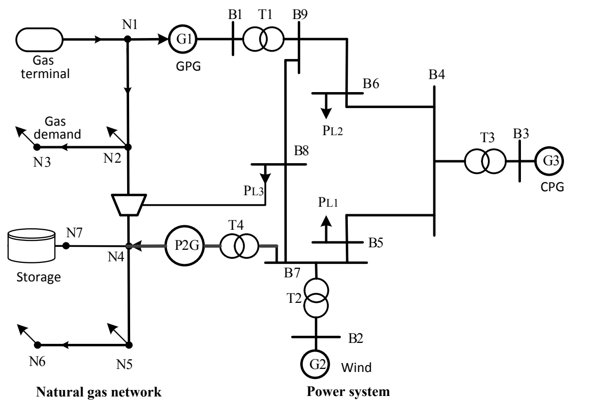

Fig. 1. The test system of a 7-node gas network coupled with IEEE-9 system

The bi-direction energy conversion between the natural gas and electric power systems primarily takes place in the GPG units and P2G. So the integrated natural gas and power system is a loop-locked system. The production and consumption in both networks need to be balanced simultaneously.

To simplify the analysis, the unit of the gas flow rate is converted to power unit as MW and then the per-unit system is used in this paper. The base value of voltage is set as 110kV. The base value of gas pressure is 1MPa. The base value of power is 100MW. Finally, all the related coefficients are adjusted to meet the per-unit system accordingly.

3. Mathematical formulations of the optimization problem

3.1. Objective function