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Assessing production assurance in a natural gas network by using scenario generation and optimization

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Abstract

We discuss how an optimization model can be used together with a scenario generation procedure to provide valuable analysis for companies operating in a natural gas value chain. The solution time of the optimization model can be considerable for some model specifications, so a large scale sampling from the distribution of the uncertain parameters would lead to intractable solution times. By using a scenario generation procedure we can, however, drastically reduce the required amount of analyses necessary to run. We discuss two different procedures in this paper: moment-matching and copulas. We also demonstrate the application on a gas transportation network similar to the one on the Norwegian Continental Shelf. The data used in the analysis are synthetic, but with realistic values.

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1. Introduction

One of the most important tasks of a Transportation System Operator (TSO) is to make sure there is a high production assurance (equivalent to security of supply) in the network. In our setting, this is defined as the actual delivery in the markets as a fraction of the agreed delivery. In a natural gas network the production assurance is limited by events in the network that reduce the transportation capacity when they occur. These possible events must

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be taken into account when the expected production assurance is calculated and when routing plans are made for the network.

The pressure-flow relationship in natural gas networks makes the operation of pipelines dependent on each other. This means that increasing the flow in one pipeline in the system may lead to a larger decrease in another part of the system. We refer to these effects as system effects (see [1]). The existence of these effects makes the analysis of the natural gas transportation networks challenging. When pressure levels in the natural gas transportation network are changed, the gas flow will have a transient nature. Models of such transient gas flows are presented in [2]. Often, a steady-state assumption is used when modelling the relationship between pressure and flow in the network. In [3] and [4], such a steady-state representation of gas network pressures and flows is used to optimize the network.

Natural gas is not a uniform commodity. Each production field has a distinct gas composition (different concentration of components such as methane, ethane, and CO_2), which also varies with time. The multi-commodity flow makes the problem difficult to solve and gives rise to even more severe system effects. Given blending opportunities in the network with possibilities to deliver to different markets with quality constraints in the markets, we need to handle the resulting pooling problem in the solution process. The pooling problem is known to exhibit multiple local optima since [5], and was recently shown to be strongly NP-hard by [6]. [7] provides a good review of different approaches to the pooling problem. Gas quality issues are discussed and modelled in [8], [9] and [10]. In the optimization tool used in this paper, we assume a steady-state representation of the pressure-flow relationship, in line with the formulation in [3]. The model also has a flexible set-up such that cases both with and without multi-commodity flows can be handled.

The Monte Carlo method is a numerical technique based on random sampling, used at least as early as in the 1950s. The accuracy and computational efficiency of Monte Carlo methods can be improved by using deterministic selection of values rather than truly random sampling. We propose using scenario generation techniques based on moment matching and copulas in a quasi-Monte Carlo framework. For an overview of Monte Carlo and quasi-Monte Carlo methods, see [11]. The copula-based method for scenario generation we use here is described in [12].

The main contribution of this paper is a discussion of various ways to utilize a scenario analysis approach combined with an optimization tool for natural gas networks. We investigate the suitability and usability of such an analysis and provide a small numerical example to illustrate the procedure.

In the next section, we give a brief introduction of the optimization tool. In Section 3, we discuss scenario generation techniques and the linking of event and price / demand scenarios. We demonstrate the use of scenario analysis in the context of a natural gas transportation network in Section 4, before a numerical example is given in Section 5. We conclude in Section 6.

2. The optimization model

In this paper we use an optimization tool, GasOpt, that has been developed for and used by Statoil and Gassco (TSO on the Norwegian Continental Shelf) to assess capacity in the transportation network. The tool uses a single period steady-state, deterministic flow optimization model. It includes modelling of pressure-flow relationships in pipelines, flexible production capacity and use of compressor units. It is also possible to run GasOpt in multi-commodity mode, where the gas quality is tracked throughout the network and quality constraints may be imposed at various points in the network. A model of processing facilities where some gas components are extracted may also be invoked. GasOpt has an interactive interface for specification of the transport network and its properties, and defining specific deviations from normal operation in terms of events is straightforward. The model can be run for a single period or as batches of multiple runs such as Monte Carlo simulations with variations in production capacity, quality attributes, demand or prices. For more details on the GasOpt modelling framework, see [13].