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Shale-gas scheduling for natural-gas supply in electric power production

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A B S T R A C T

This paper describes a novel integration of shale-gas supply in geographical proximity to natural-gas power production. Shale-gas reservoirs hold special properties that make them particularly suited for intermittent shut-in based production schemes. The proposed scheme argues that shale-gas reservoirs can be used to shift storage of gas used for meeting varying demands, from separate underground storage units operated by local distribution companies to the gas producers themselves. Based on this property, we present an economical attractive option for generating companies to increase their use of firm gas—supply contracts to the natural-gas power plants in order to secure a sufficient gas supply. The shale-well scheduling is formulated as profit-maximization model for well operators, in which we seek to include their main operational challenges, while preserving an economic incentive for the operators to adopt the proposed scheme. The resulting large-scale mixed integer linear program is solved by a Lagrangian relaxation scheme, with a receding horizon strategy implemented to handle operational uncertainties. We present the proposed optimization framework by illustrative case studies. The numerical results show a significant economic potential for the shale-well operators, and a viable approach for generating companies to secure a firm gas supply for meeting varying seasonal electricity demands.

1. Introduction

The use of natural gas for energy production in the US has increased significantly over the last decade. Natural gas constituted 30% of the total electricity generation in the US in 2012 [20], from which the use of NGPPs (natural-gas power plants) has increased by 35% from 2005 to 2012. One of the main factors for this increase has been the access to large volumes of “new” gas recovered from unconventional resources such as shale (ultra-tight) and other tight-gas formations [17]. About 45 GW of natural gas-fired generation capacity is expected to be developed over the next ten years [54], while the US EIA (energy information administration) projects the share of natural gas in total electricity generation to reach 35% by 2040 [20]. This continued increase in use of natural-gas for electric power generation in the US is both related to the displacement of coal-fired power plants to meet CO_2 reduction targets [48], and a sustainable future supply from giant shale-gas recoverable reserves (2.1×10^{10} m^3 [17]).

The remarkable speed and scale of the US shale-gas developments has reduced the country's dependency on gas import, and thereby improved its security of supply. This development has however resulted in an abundance of natural gas in the domestic US market [17,50], and consequently caused a substantial decrease in natural-gas price. The combination of low fuel prices, high efficiencies of modern combined-cycle power plants [37] and significantly lower emission levels compared to coal-fired power plants [50] has favored natural gas for electricity generation, both for serving baseloads and for satisfying demands during peak periods [11]. The gas demand in the electric power sector is very sensitive to the relative price difference between gas and coal; after a consistent increase until 2012, the total gas consumption by the electric power sector was reduced in 2013 compared to 2012, mainly caused by an increase in gas price [20]. The dependency of power-plant gas usage on gas price is mutual for producers and consumers: While continued low gas price is essential for making natural gas a preferred fuel in electric power generation, it has also dramatically reduced the profitability of many dry-gas fields [32,35,50]. Shale-gas operators' interest in dry-gas fields have been on a decline, causing a significant reduction in the rig-count for many dry-gas fields [47], and a shift in focus to condensate-rich

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shale-gas fields. Wells that do not return the required capital expenditure within the first two-three years are often considered unprofitable and thus abandoned. In some situations, operators also choose to shut-in wells to wait for higher gas prices [30,63], or to postpone the start-up of completed wells [62] as the initial peak rate yields a major and decisive part of the profit of shale-gas wells. As such, there is a mutual interest both from the US shale-gas industry and from the electric power sector to explore ways of better utilizing the abundance of dry natural-gas caused by the shale-gas revolution.

Natural gas is normally contracted and sold directly from producers to LDCs (local distribution companies) as illustrated in Fig. 1, paying a transportation fee to a shipper or a gas pipeline company [4]. The LDC distributes the gas to end-users in the different sectors, including electric power generation, residential and commercial heating, transportation and a variety of other industrial customers. Natural gas is traded between producers and LDCs, which may be located in the proximity of each other or distanced far apart; in the latter case increasing the compression cost for the pipeline company and hence the transportation fee. The seasonal demand for gas in the aforementioned sectors varies and depends on factors such as the price for gas compared to alternative fuels, temperature variations, and economy in the industrial and residential sectors [21,28]. However, comparing in Fig. 2 the year-to-year seasonal demands, the different sectors exhibit a relatively predictable trend in natural-gas demand. As an example, NGPPs tend to consume more natural gas during the summer months to meet air conditioning loads [21]. To facilitate these varying gas demands, the LDCs exploit extensively underground storage using salt caverns and depleted reservoirs. The end users pay additional fees to the LDCs for this storage service, a fee which includes: transportation to and from the storage facility, injection well compression, withdrawal and capacity charges [4,21], and losses of injected gas.

Power plants and industrial customers may contract their gas supply directly with the producer to save costs, in particular the storage fees paid to the LDCs [4,21,46]. The entry of shale-gas in the US natural-gas value chain both changes and increases the possibility for direct contracting and distribution of gas between producers and large end-users. As shale-gas is a land-based resource and often located much closer to end-users in the industrial and electric power sector than conventional natural-gas resources and LNG (Liquefied Natural Gas) terminals, it may reduce the distance gas needs to be transported. This lowers fuel consumption by the midstream gas compressors, eventually leading to lower transportation fees for the end-users. A further special property of shale and other fractured tight-formation gas—wells is that they can be

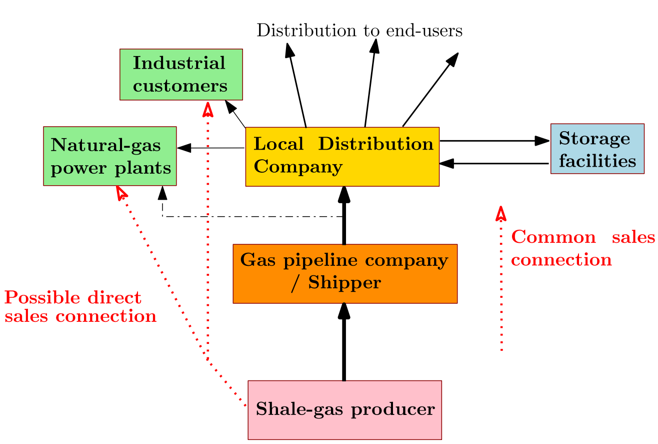

Fig. 1. Participants in the value chain between gas producers and natural-gas power plants.

shut-in for short periods with a minimal loss of recovery [39,71]. This property implies that shale-gas reservoirs may essentially be utilized for storing natural gas, with the same purpose as LDCs make use of separate storage facilities, to meet varying prices and demands. Using shale-gas wells directly for scheduling natural-gas production and supply with respect to varying seasonal demands means that the storage in Fig. 1 is moved from the LDC connection back to the origin of the producer. Large shale-gas fields, consisting of many wells, are as such particularly well suited for supplying large natural-gas end-users as NGPPs. We elaborate on this in Section 2.1.

EUCs (electric utility companies) or GENCOs (generating companies) that own and operates one or more NGPPs need to ensure contract portfolios with low-cost fuel supplies to be competitive in the electricity generation market. Contracts are generally distinguished as *firm* or *interruptible* [4,21]. EUCs and GENCOs have traditionally preferred to use interruptible contracts with gas suppliers [34,46], providing the power plant with inexpensive gas which can be interrupted by both parties at short notice. The preference of interruptible contracts is also related to predominant use of natural gas for satisfying peak demands [11]. In contrast, a *firm* contract entitles the customer with a high priority in which the gas is to be supplied with no interruptions. NGPPs holding only interruptible contracts will thus be susceptible to gas curtailment during periods of peak demand, pipeline congestion, or in the event of a gas-producer reaching its maximum recovery rates [33]. In contrast, customers holding firm supply contracts, together with customers in the non-electrical sectors will retain the highest priority of the available gas supply [28,51]. Note that both firm and interruptible contracts are also applied for the transportation service provided by the shipper [4,21]. The increased use of natural-gas in electricity generation leads to challenges and new requirements for securing the gas supply to power plants [34,50]. Several places in the US, the infrastructure of the natural-gas value chain has not yet been developed to support the high volumes of natural gas produced from the vast shale resources [54], causing low excess capacity in the transmission and distribution pipelines and hence creating a higher risk of interruptions in the supply to customers holding non-firm contracts. This poses a significant challenge in the context of replacing coal-fired power plants with NGPPs as coal, in contrast to natural gas, can be stored on-site at power plants. Moreover, this is an important element for overall system reliability with the increased use of intermittent renewable energy sources [50].

The reliability and security of natural-gas supplies to NGPPs may be improved by increasing the use of *firm* contracts [34], both for the transportation service, and for the supply of gas from the producer to the LDCs or directly to end-users. This will further increase the reliability of natural-gas based electricity generation. Increasing the share of firm contracts for gas supply to NGPPs is, however, clearly a cost-benefit question as well as a security issue, and is related to the security-constrained thermal UC (unit commitment) problem [24,45,46,56], as well as optimization of the natural-gas supply mix for EUCs/GENCOs and LDCs [4,11,28]. To render an attractive opportunity for increasing the use of direct firm supply and transportation contracts between shale-gas producers and NGPPs, it is necessary to create an economic incentive for shale-gas operators to increase their requisite scheduling efforts to meet the firm demand rates. Furthermore, pricing of the firm contracts has to be at a level below the average firm contract option provided by LDCs.

In this paper, we propose a novel scheme for scheduling shale-gas wells that may enable NGPPs to establish firm contracts directly with shale-gas producers, thereby circumventing LDC firm contracts. This is achieved by exploiting shale-gas wells and their near