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The Effect of Natural-Gas Prices on Power-System Reliability

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Abstract

Purpose of Review Electricity production in United States of America is shifting from coal to natural gas. Much of this shift is driven by decreased natural-gas prices, which are resulting from hydraulic fracturing. Decreased natural-gas prices are causing a price reversal in the merit order between natural-gas- and coal-fired generators. Given that these fuel-price changes are anticipated to pers

the fuel mix is due largely to sustained natural-gas-price decreases. These naturalalso a case with a high penetration of wind generation. We find that wind generation mitigates, but does not eliminate, the reliability impact of fuel prices.

The remainder of our paper is organized as follows. First we provide our literature survey and review. Next we detail case-study methodology, data, and results. This is followed by conclusions.

Literature Survey

A long-standing electricity-industry challenge is ensuring reliable electricity supply. Garver [2] presents a graphical approach to assessing power-system reliabil-

An analysis of the PJM Interconnection system [6] examines power-system reliability given the prevalence of natural-gas-fired generation, increase in renewable resources, and potential future retirements of coal-fired and nuclear units. The analysis finds that these long-run generation-mix changes may result in less fuel assurance but greater flexibility and ramping attributes. A similar analysis of the ISO New England system[3] finds that low natural-gas prices led to increasing use of natural gas as a generating fuel over a 16-year period preceding the study. This shift in the energy mix reduces the use of less efficient oil- and coal-fired units. Contemporaneously, ISO New England contends with fuel assurance as a long-run reliability issue.

A common theme of these works [4–6] is their focus on fuel-price changes impacting the installed mix of resources and the resultant effect on power-system reliability. To a large extent, these works neglect shorter-term reliability impacts, whereby fuel prices change the operation of a fixed mix of resources. One way to address short-term reliability impacts of fuel prices is through the adjustment of operating

$$\sum_{\in} \rho_{,} \geq \eta \;\; \eta \;_{,}; \qquad \forall \in \;; \tag{4}$$

$$\leq ; \qquad \forall \in , \in \;; \tag{5}$$

$$+ \rho_{,} \leq \;^{+} ; \qquad \forall \in , \in \;; \tag{6}$$

$$+ \rho_{,} + \rho \leq \;^{+}; \qquad \forall \in , \in \;; \tag{7}$$

$$0 \leq \rho_{,} \leq \bar{\rho} ; \qquad \forall \in , \in \;; \tag{8}$$

$$0 \leq \rho \leq \bar{\rho}; \qquad \forall \in , \in \;; \tag{9}$$

$$^{-} \leq - _{, -1}; \qquad \forall \in , \in \;; \tag{10}$$

$$- _{, -1} + \rho_{,} + \rho \leq ^{+}; \qquad \forall \in , \in \;; \tag{11}$$

$$\sum_{= - ^{+}} \;_{,} \leq ; \qquad \forall \in , \in \;; \tag{12}$$

$$\sum_{= - ^{-}} \;_{,} \leq 1 - ; \qquad \forall \in , \in \;; \tag{13}$$

$$_{,} - \;_{,} = - _{, -1}; \qquad \forall \in , \in \;; \tag{14}$$

$$, \;_{,}, \;_{,} \in \{0,1\}; \qquad \forall \in , \in \;. \tag{15}$$

Objective function (1) minimizes total generation costs. 5.88993(c)-Tf 3.83984(o)Tj]TJ26153]TJ -320 Tf 3.83984)-1.66393(-18.2003(a)--1 convex piecewise-linear function $\forall \in$, making (1) linear in the decision variables. Constraints ln

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potential output in two ways. The first is that unless a generator has fast start-up capability, it must be online to produce power. Second, a generator's maximum potential time-t output is limited by its time-$(t-1)$ output through its ramping capability.

For all $g \in G, t \in T$, we account for the effect of generator g's online status by making its maximum time-t potential output, $\bar{p}_{g,t}$, dependent on the optimized values of $u^*_{g,t-1}$ and $u^*_{g,t}$, which are determined by the unit-commitment model. We define:

$$\bar{p}_{g,t} = \begin{cases} \min\{K_g^+, p^*_{g,t-1} + \Delta_g^+\}; & \text{if } u^*_{g,t-1} = 1; \\ \max\{K_g^-, \Delta_g^+\}; & \text{if } u^*_{g,t-1} = 0 \text{ and } u^*_{g,t} = 1; \\ \max\{K_g^-, \Delta_g^+\}; & \text{if } u^*_{g,t-1} = 0, u^*_{g,t} = 0, \text{ and } \bar{\rho}_g^{\Delta} > 0; \\ 0; & \text{otherwise;} \end{cases} \tag{16}$$

where the $*$ superscripts in the right-hand side of (16) denote optimized variable values from the unit-commitment model. Equation (16) defines $\bar{p}_{g,t}$ in four cases. The first is if generator g is scheduled to be online during time step $(t-1)$. If so, generator g can remain online at time t (i.e., even if $u^*_{g,t} = 0$ in the unit-commitment solution) and $\bar{p}_{g,t}$ is limited by whichever of its maximum-output and ramping capacities are more restrictive. The second case is if generator g is started-up at time t in the unit-commitment schedule. In this case, $\bar{p}_{g,t}$ is limited by generator g's ramping and minimum-load constraints. The third case is if generator g is offline at time $(t-1)$ and not scheduled to start-up at time t in the unit-commitment solution. If such a generator has fast start-up capability it can be started at time t and its output is governed

ab Summary of supply and demand characteristics of case study

Natural-Gas-Fired Generation	
Number of Units	324
Total Nameplate Capacity (GW)	59.045
Coal-Fired Generation	
Number of Units	28
Total Nameplate Capacity (GW)	16.081
Nuclear Generation	
Number of Units	4
Total Nameplate Capacity (GW)	4.920
Load Summary Statistics (GW)	
Maximum	59.947
Minimum	20.893
Average	34.419

generating capacity is kept online at the end of each day to serve the following day's load [25]. As our model rolls through each day of the year, the starting generation level and commitment status of each generator are updated to

Algorithm Reserve calibration

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Input $\eta$ and $\eta$
$\eta \leftarrow \frac{1}{2}(\eta + \eta)$
repeat
    $(\,^*, \,^*, \,^*, \mu^*, \rho^*) \leftarrow \arg\min$ (1) s.t. (2)–(15)
    compute using (16)
    compute $\pi$ and $\Lambda$ using (17) and (18)
    if $\Lambda > 2.4$ then
        $\eta \leftarrow \eta$
    else if $\Lambda < 2.4$ then
        $\eta \leftarrow \eta$
    end if
    $\eta \leftarrow \frac{1}{2}(\eta + \eta)$

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ab Reserve margin, LOLE, operation cost, and dispatch in base case with different natural-gas prices and operating reserves

Natural-Gas Prices Operating Reserves	Year-2005 Calibrated	$2/MMBTU Uncalibrated	$2/MMBTU Calibrated
η	0.1235	0.1235	0.1378
Λ	2.4	8.2	2.4
Operation Cost ($ billion)	21.7	12.3	12.4
Generation (%)			
Coal	43.28	23.16	22.82
Natural Gas	40.96	61.05	61.38
Capacity Factor (%)			
Coal	92.86	50.02	48.97
Natural Gas	23.92	35.59	35.87

71% of the system’s spinning reserves. This is because the coal-fired fleet has limited reserve capability relative to natural-gas-fired units, which have faster ramping capabilities.

ab Operating reserves provided by coal- and natural-gas-fired units (GW-h) in base case with differerating these units is relatively expensive with year-2005 natural-gas prices, these units tend to be idle in the solution of the unit-commitment model. However, due to their fast-start capability, they contribute to system reliability, insomuch as they have strictly positive [illegible] values. Conversely, with \$2/MMBTU natural-gas prices, these units are dispatched. Although the system maintains the same level of reserves ([illegible]., the value of η is the same in the cases that are reported in the first two columns of Tables 2 and 3), idle natural-gas-fired units with fast-start capability provide ex-

2.4-hour LOLE that is achieved in the base case with these prices. This decreased LOLE is due to wind generators providing energy, which improves system reliability.

ab Reserve margin, LOLE, operation cost, and dispatch with wind generation and different natural-gas prices

Natural-Gas Prices	Year-2005	\$2/MMBTU
η	0.1235	0.1235
Λ	1.1	3.1
Operation Cost (\$ billion)	16.2	9.4
Generation (%)		
Coal	38.26	18.52
Natural Gas	27.08	46.80
Wind	18.9	18.9
Capacity Factor (%)		
Coal	82.09	39.73
Natural Gas	15.82	27.35

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Bullet Annotated References

Very Important References

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PJM Interconnection [6]. Examine power-system reliability given the prevalence of natural-gas-fired generation, increase in renewable resources, and potential future retirements of coal-fired and nuclear units.

Important References

Anstine et al. [7]. Develop a methodology for determination of operating-reserve requirements to achieve a desired level of power-system reliability using a post-processing algorithm that is applied to a unit-commitment solution.
Billinton and Allan [3]. Develop analytic methods to assess power-system reliability and the resource-adequacy contribution of resources.