Power Generation Asset Optimization:
Optimal Generating Strategies in Volatile Markets
(Case Study)

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OPTIMAL GENERATING STRAGIES IN VOLATILE MARKETS
(Including a CCGT Plant Case Study)

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INTRODUCTION

Never has it been as critical for generation asset owners to evaluate the optimum generation strategy that captures the most value from both their asset management and energy trading activities as it is in today's volatile energy markets. It has become increasing important to link the physical asset to trading activities. Deregulation and subsequent competition among wholesale energy providers has caused corporations to rethink their traditional operational methods and decipher the complexity of maximizing their profits in such an environment. This paper will investigate how various operating strategies can impact the bottom line and how analytical methods can be applied to maximize profits for a typical generation company (GenCo) within a power market. We have included a case study that specifically addresses combined cycle gas turbine plants that clearly demonstrates the significance of the opportunity.

Traditionally, GenCo's operated under a cost minimization and reliability objective. Fulfilling native load obligations and minimizing production costs were the primary measures of GenCo operating strategies. Flexible generators were used to balance the variation in load, replace generators that were forced out, and serve peak load obligations.

Today, GenCo's must retool to operate under a profit maximization objective. The convergence of asset operations and energy marketing and trading has created financial opportunities for GenCo's that are subject to energy market volatilities. Fulfilling load obligations and minimizing production costs are still part of the profit maximization equation, however, profits from energy trading can now be added to the equation. When economically viable, GenCo's must be prepared to fulfill obligations from the energy market and shutdown plants; remarket existing fuel contracts; and curtail plants, or bring plants online to backup energy trades. Flexible generators can thus be measured in value by how they can capture on-peak price spikes; replace firm power obligations; and shut down when not profitable.

This paper investigates how GenCo's can select operating strategies to maximize profits. To introduce this concept, this paper presents a detailed case study for combined cycle gas turbine (CCGT) plants with specific focus on the number of starts the plant incurs in a given year; additional sources of value from operations optionality will then be discussed.

For CCGT plants, variable operating and maintenance costs (O&M costs) are highly dependent on the number of online hours and the number of starts that the plant incurs; in fact, many aspects of OEM-provided maintenance programs are based on these variables. The current practice among the major combustion turbine manufacturers is to structure maintenance costs according to formulas, which factor in both starts and operating hours in order to determine when the maintenance is required. Formulas consider a number of factors; in addition to hours of operation and starts, the formulas include when liquid fuels are used, running in peak mode (higher exhaust temperature), hot starts vs. cold starts, or ramping the unit faster than the base recommendation.

While there actually are a number of variables impacting CCGT O&M costs, our analysis will focus on the fundamental tradeoff for CCGT plants: What is the "optimal start strategy" and how does energy market volatility affect this start strategy? The answers to these questions will be based on economics. Obviously, for a specific situation, other, ancillary questions that must be considered include are:

- How to best adopt operations strategies that are consistent with mode of operation – i.e., how to minimize to degree possible impacts on the forced outage rate from aggressive operations.
- Are the aggressive operations within GenCo safety limitations?
- How should a GenCo accommodate the associated risks?

CASE STUDY: ASSUMPTIONS and METHODOLOGY

The primary assumptions for this paper involve the generation asset technology, forward electric power prices/volatilities, forward natural gas prices/volatilities, correlation between energy and fuel markets, and variable O&M costs associated with unit starts and online hours.

The generator evaluated in this study is a natural gas-fired combined cycle combustion turbine set. The configuration for this combined cycle is two combustion turbine generators (CTG) and one steam turbine generator (STG). The plant cannot operate in simple cycle mode but may operate in one on one configuration with one CTG along with the STG. The performance for this plant is measured under ISO conditions. Figure 1 represents the combined cycle heat rate curve used within this case study.

The physical constraints of this plant will be tested to measure flexibility value. The electric energy and fuel price forecasts are typical price forecasts with associated uncertainties applied. For purposes of this case study, off-peak energy price volatility; fuel price volatility; and the correlation between the fuel price and energy price were all set to constant values. The off-peak energy price volatility and fuel price volatility were each set to 25 percent. The energy and fuel market correlation was set to 0.35. The on-peak energy price was set to have a varying volatility that will be used to measure the impact that a volatility forecast may have on operating strategy. Natural gas pricing for this study averages $3.50 per MBtu. Figure 2 shows the energy price profile used in this case study.

Figure 1. Case Study Combined Cycle Average Heat Rate Curve Characteristics

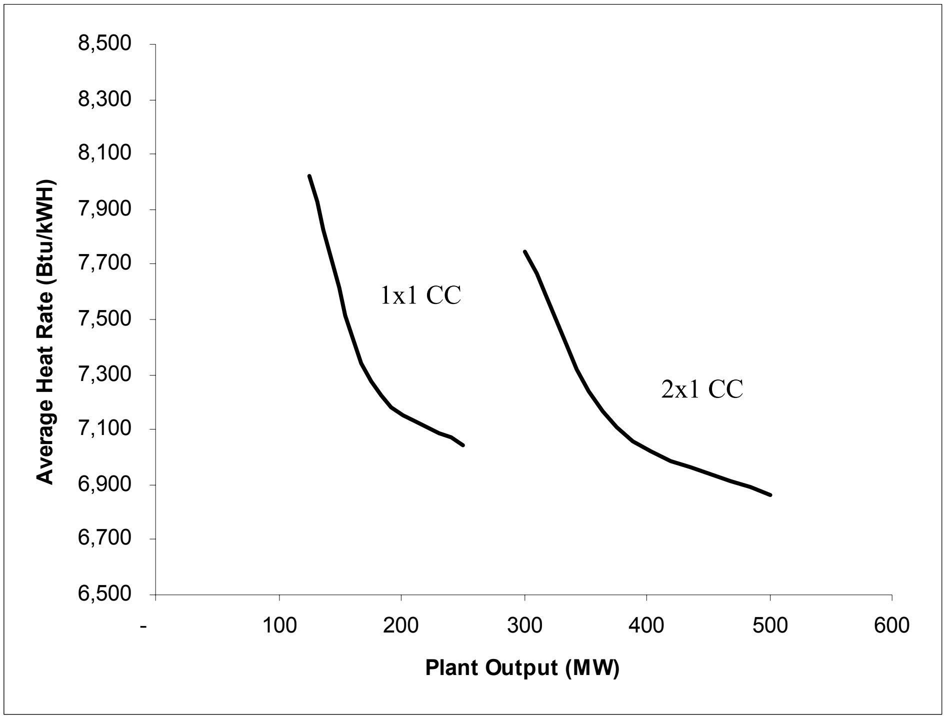
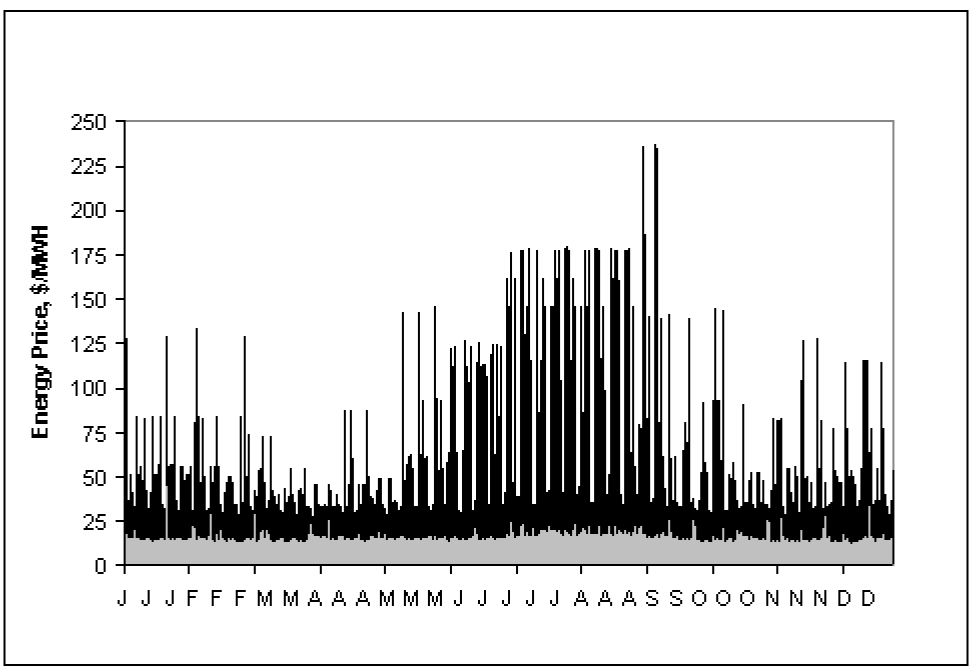


Figure 2. Case Study Annual Hourly Energy Price Detail



Estimated O&M costs for the plant can be calculated based on assumptions about the number of online hours and the number of starts that the plant incurs during the study horizon, based on its expected unit commitment and dispatch in the market. For this example, these costs can be restated in terms of an hourly online hour rate, $/hour-CC. Figure 3 describes the O&M cost for the combined cycle and is dependent on the number of online hours per start. Once the online hours and number of starts are known for a particular scenario, the ratio of number of hours per start is calculated. This calculated ratio is then used to determine the $ per fired hour cost from Figure 3. As shown, the higher the ratio indicates a less aggressive operational strategy and therefore has a lower $ per fired hour cost.

Based on the above assumptions, the following methodology was adopted to arrive at the results.

Numerous scenarios with a 2 on 1 combined cycle plant configuration with the same physical constraints except for their start-up cost profiles were created to establish the foundation for generating the various optimal operating strategies given the constraints. These profiles will essentially "force" the unit to behave differently in the market so that we can see what the resulting economic effects will be for varying the number of starts. Each plant's performance was measured under ISO conditions in a sample energy market. Each scenario was subject to the same energy market with access to the same natural gas market. The simulation for these plants was carried out using Power Costs, Inc.'s **GENTRADER** software. (For more information on **GENTRADER**, visit **www.PowerCosts.com**) The simulation study's time horizon was set to one year.

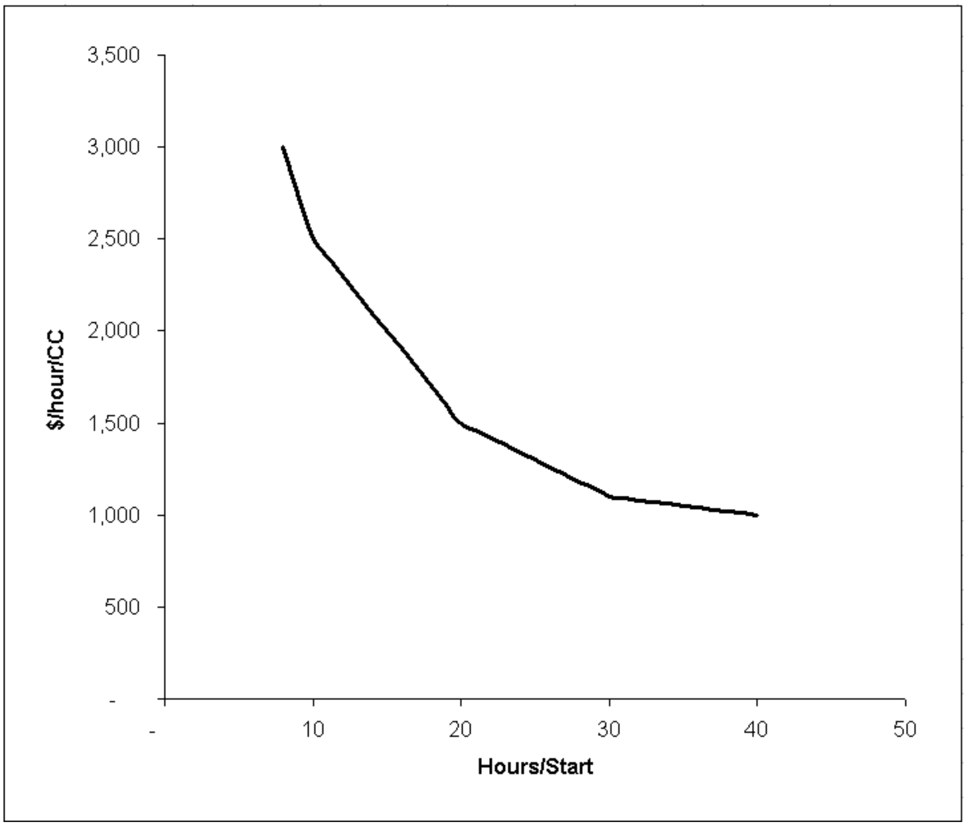
The plant-specific results addressed in this case study include:

- Number of starts in the entire year
- Number of online hours
- Revenue generated by each plant
- Associated fuel costs for each plant.

The plant value is assessed by calculating both the intrinsic and extrinsic value of the generation asset. The intrinsic value is the value at the expected market prices. The extrinsic value considers the market uncertainty together with a cursory model of the generator's optionality – which in this case refers to the ability of the operator to turn off a generator when the prices are too low.

To derive the relationship between plant profitability and its generating strategy, we took the results from **GENTRADER** and deducted fuel costs and O&M costs (which was calculated based on a function of the number of starts and the number of online hours for that plant) from the revenue to arrive at the intrinsic value of each plant. As expected, the results suggested that the lower the start-up costs and therefore the higher flexibility for the plant, the higher is its intrinsic value.

Figure 3. Combined Cycle O&M Costs as a Function of Hours/Start



To factor in the effects of energy price volatility, natural gas price volatility and their correlation on a plant's profitability in true market conditions, **GENTRADER's** Deal Valuation module was used to simulate market price volatility. The simulations were carried out for on-peak energy price volatility that ranged between 50% and 150%. The results obtained were recorded as the plant's extrinsic value at that volatility level. The final step in the process was to sum the intrinsic and extrinsic value of each plant at the various volatility levels.

The results of the analysis are presented in Table 1. As shown, the increasing startup cost constraints limits the number of annual starts and online hours. These operating characteristics are determined based on the most economical unit commitment as determined by **GENTRADER**.

Table 1. Case Study – GENTRADER Results Summary

Case	Cost/Start Constraint	CC Starts	CC Hours	CC Hr/Start	*Margin (Millions)	O&M Rate $/Hr	O&M Cost (Millions)	**Intrinsic Value (Millions)		***Total Value Including Extrinsic 50% Vol. (Millions)	100% Vol. (Millions)	150% Vol. (Millions)
1	$ 4,000	296	4,341	15	$ 32.49	$ 2,100	$ 9.12	$ 23.38		$ 26.69	$ 31.72	$ 37.01
2	$ 6,000	279	4,323	15	$ 32.37	$ 2,000	$ 8.65	$ 23.72		$ 27.22	$ 32.34	$ 37.76
3	$ 8,000	255	4,420	17	$ 32.08	$ 1,800	$ 7.96	$ 24.12		$ 27.81	$ 33.06	$ 38.62
4	$ 10,000	221	4,644	21	$ 31.56	$ 1,460	$ 6.78	$ 24.78		$ 28.77	$ 34.09	$ 39.86
5	$ 12,000	179	5,006	28	$ 30.68	$ 1,220	$ 6.11	$ 24.58		$ 28.88	$ 34.24	$ 40.14
6	$ 14,000	165	5,116	31	$ 30.35	$ 1,090	$ 5.58	$ 24.77		$ 28.97	$ 34.45	$ 40.52
7	$ 16,000	153	5,174	34	$ 30.03	$ 1,070	$ 5.54	$ 24.50		$ 28.85	$ 34.24	$ 40.61
8	$ 18,000	141	5,239	37	$ 29.70	$ 1,030	$ 5.40	$ 24.30		$ 28.61	$ 33.94	$ 40.60
9	$ 20,000	124	5,371	43	$ 29.20	$ 1,000	$ 5.37	$ 23.83		$ 28.05	$ 33.18	$ 40.21
10	$ 22,000	103	5,268	51	$ 28.49	$ 1,000	$ 5.27	$ 23.22		$ 27.40	$ 32.68	$ 39.82
11	$ 36,000	40	4,589	115	$ 25.18	$ 1,000	$ 4.59	$ 20.59		$ 26.88	$ 31.30	$ 38.89
12	$ 50,000	30	3,682	125	$ 23.64	$ 1,000	$ 3.68	$ 19.96		$ 26.51	$ 31.41	$ 39.05

*Margin = Energy Sales – Fuel Purchases
**Intrinsic Value = Margin – O&M Cost
***Total Value = Intrinsic Value + Extrinsic Value

EFFECT OF PHYSICAL CONSTRAINTS ON OPERATING CHARACTERISTICS

The impact of physical constraints on overall profits is evident in Table 1. Constraints invoked by plant managers can be derived from two primary seeds, one is that the plant truly has physical limitations in its ability to cycle, the other is that the plant is artificially being constrained because that is the way it always has been run. Although there are several physical constraints and factors that affect O&M costs, this case study focuses on startup cost constraints only.

Figure 4 shows how startup cost constraints invoked by asset managers can impact the operational characteristics as determined by the most economical unit commitment and dispatch. It should be noted that these characteristics are highly dependent on case study assumptions and the fact that we are isolating startup costs and the impact that the number of starts has on O&M costs. For example in this case, as the startup costs increased, the online hours first rose and then fell. For a market in which the generating asset is on the margin, the increased startup costs eventually caused the asset to start less and remain offline longer. If the particular asset being evaluated were deeper in the money whether by more efficient performance or higher energy prices, the increased startup costs would cause the asset to stay online for more hours and start less often, as shown in Figure 5.

Figure 4. Operating Characteristics as a Function of Startup Cost Constraints

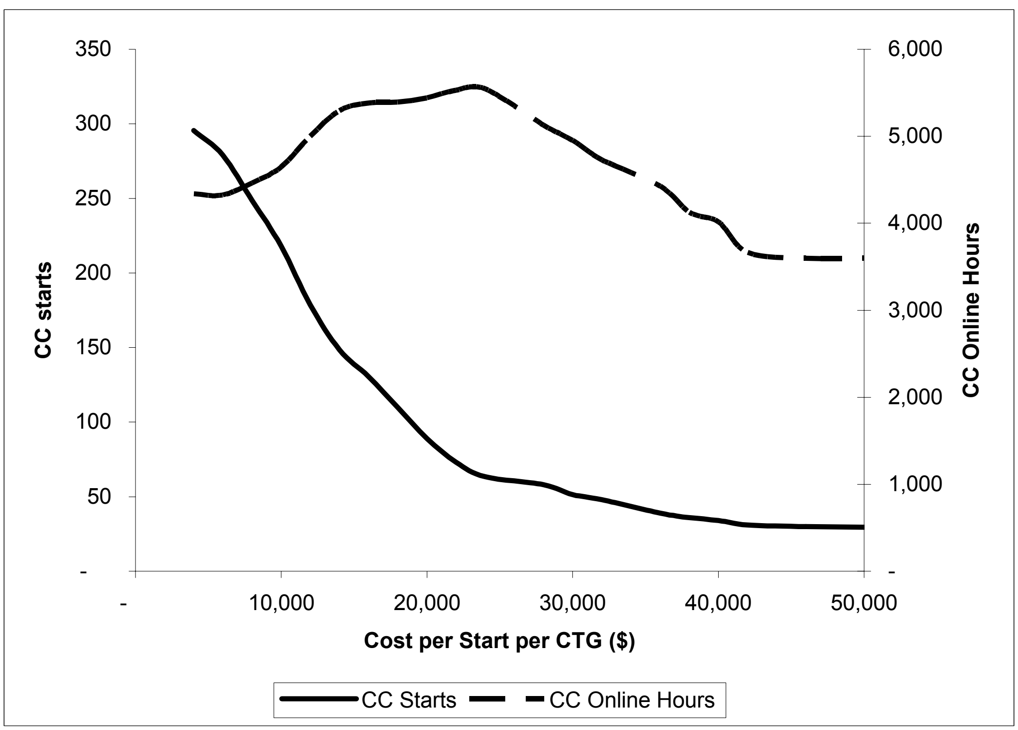


Figure 5. Combined Cycle Online Hours as a Function of Startup Costs and Varying Energy Price Forecasts

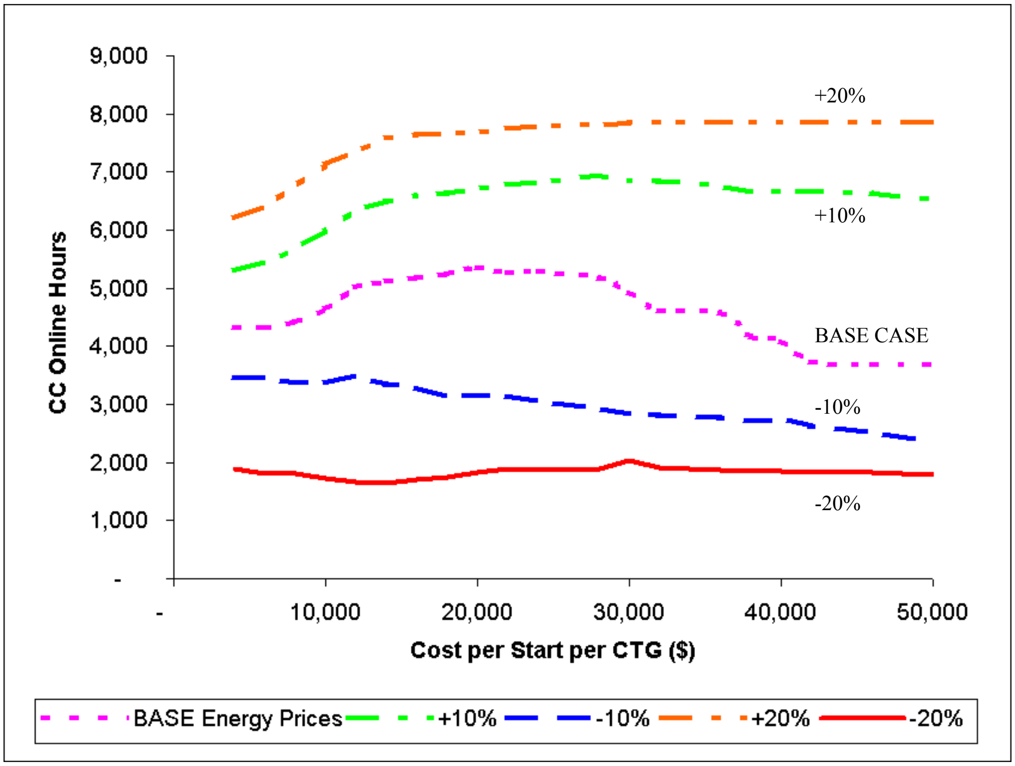
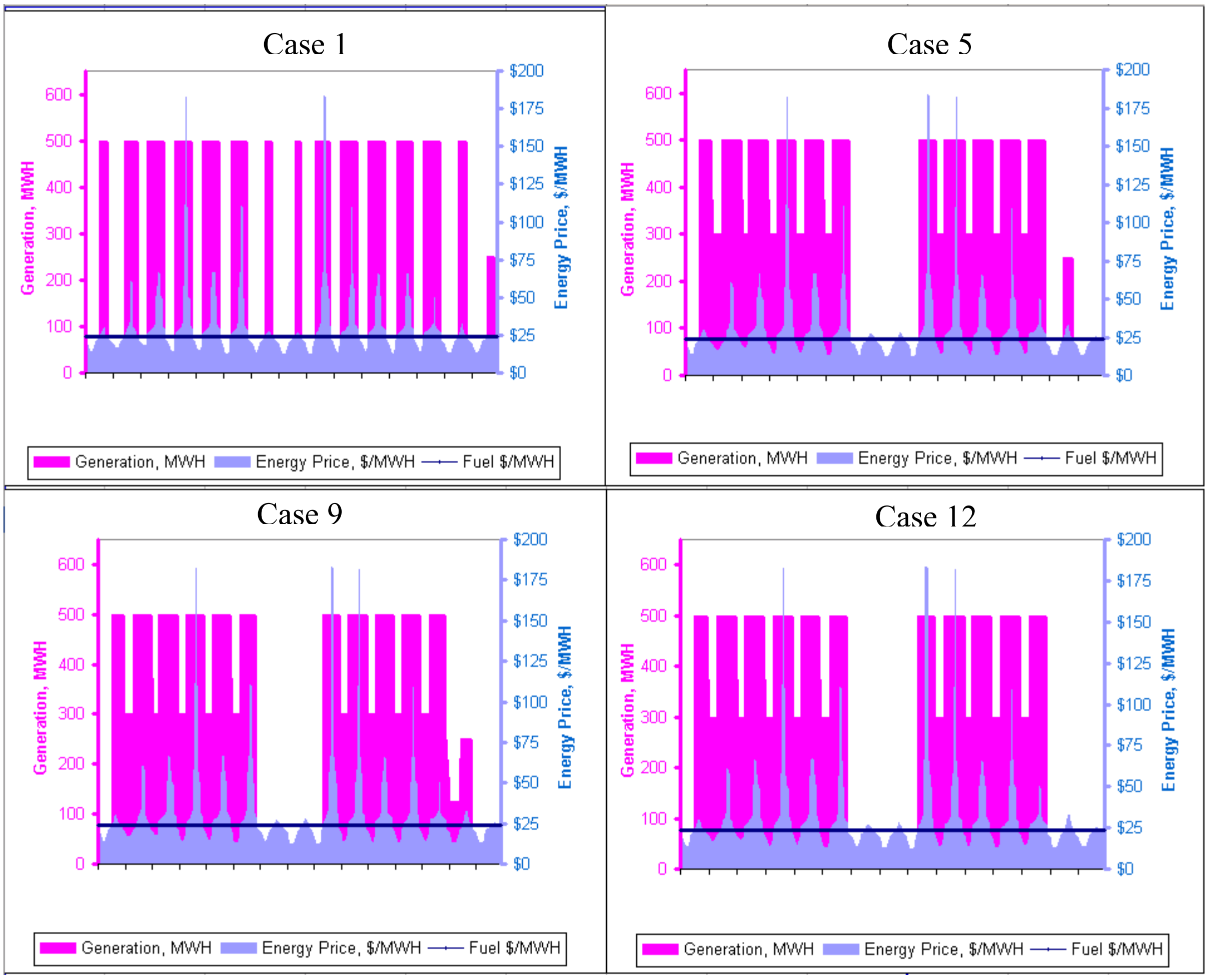


Figure 6 graphically depicts the impact that increasing startup constraints has on the operating profile of the combined cycle plant and it's ability to capture market opportunities. As shown, the most flexible unit (Case 1) can cycle rapidly and cost effectively to capitalize on the energy price spikes. The marginal cost line depicts that at the money position of the generation asset, if the energy price is below the marginal costs, the generation asset is out of the money and if the energy price is above the marginal cost, the generation asset is in the money. The generation asset in Case 1 is capable of turning on when in the money and turn off when out of the money with little constraint. The least flexible unit (Case 12) has to have enough financial justification in the market to overcome the large startup cost ($50,000). The least flexible unit must incur additional market losses since it has less optionality. Constraining minimum up or minimum down times for a generation asset can conclude a similar result.

Figure 6 also shows that the operating strategy can vary between shutting the entire plant (both CTGs), cycling one CTG on and off, or lowering both CTGs to minimum load during the off-peak hours. In all cases the operating profiles are driven by price based optimization to maximize the profits from the plant.

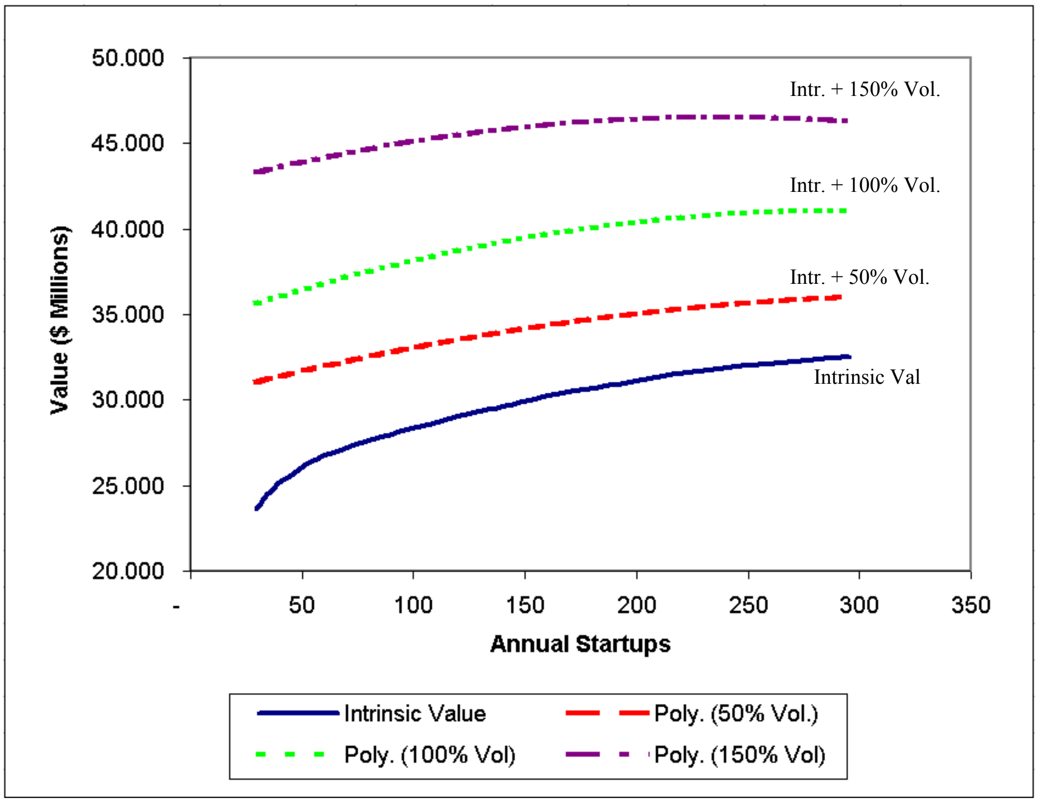
Figure 6. Operating Profiles of Selected Cases



MARKET VALUE – INTRINSIC & EXTRINSIC

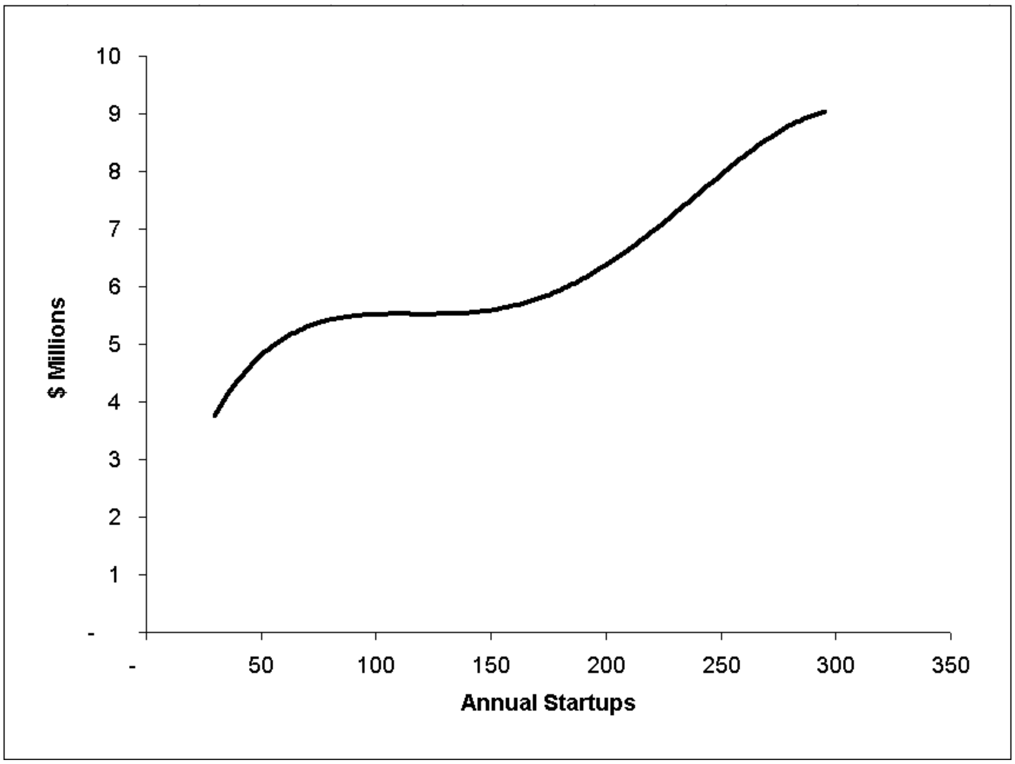
Extrinsic value of a generator is a function of its flexibility and the volatility and correlations in a given market that the generator is operating in. Figure 7 shows that as market volatility increases, the extrinsic value increases for our example combined cycle plant. The difference between any two given points, let us say 200 annual starts and 50 annual starts (~$2,500,000) is the opportunity gained through more flexibility. Depending on your O&M cost profile, a strategic decision can be made regarding operation of the plant.

Figure 7. Case Study Intrinsic/Extrinsic Value as a Function of Starts



Based on the output and the O&M cost describing function, a tailored O&M curve can be built for the generating asset. Figure 8 shows the O&M cost curve as a function of annual startups for the combined cycle in this case study. This curve is derived from Figure 3 and the assumptions used in this case study. As expected the O&M costs increase with increasing annual startups indicative of more aggressive operations.

Figure 8. Case Study – O&M Cost as a Function of Annual Startups



OPTIMAL STRATEGIES AND DECISION TOOLS

The plant characteristics, market conditions, and O&M cost relationships are fundamental inputs required to develop an optimum operating strategy for each given case. In this study, one objective was to determine how many starts an asset owner might consider given that gas turbine combined cycle O&M costs are highly dependent on starts. With the defined conditions in this case study, Figure 9 was developed to show the optimum range to maximize operating profits.

In the case of our representative CCGT plant, many parameters and constraints must be reviewed before an operating strategy can be produced. To summarize this case study, a financial opportunity curve is produced to guide decisions on operating strategy. As shown in Figure 10, our representative CCGT plant has an incremental gain in profit of over two million dollars when operated at its optimal number of starts compared to the least effective startup strategy.

Although annual startups and online hours have a large impact on O&M costs and subsequently GenCo profits, there are several other factors that have to be addressed. On a wider scale, forced outage, safety and employee fatigue must be considered when operating generation assets aggressively. Also as the generating assets become more complex by implementing features such as duct-firing, inlet air chilling, dual fuel capability and other enhancements the operating strategy becomes increasingly complex.

The remainder of this paper expands on the additional complexities and sources of profitability.

Figure 9. Net Annual Profits as a Function of Annual Startups

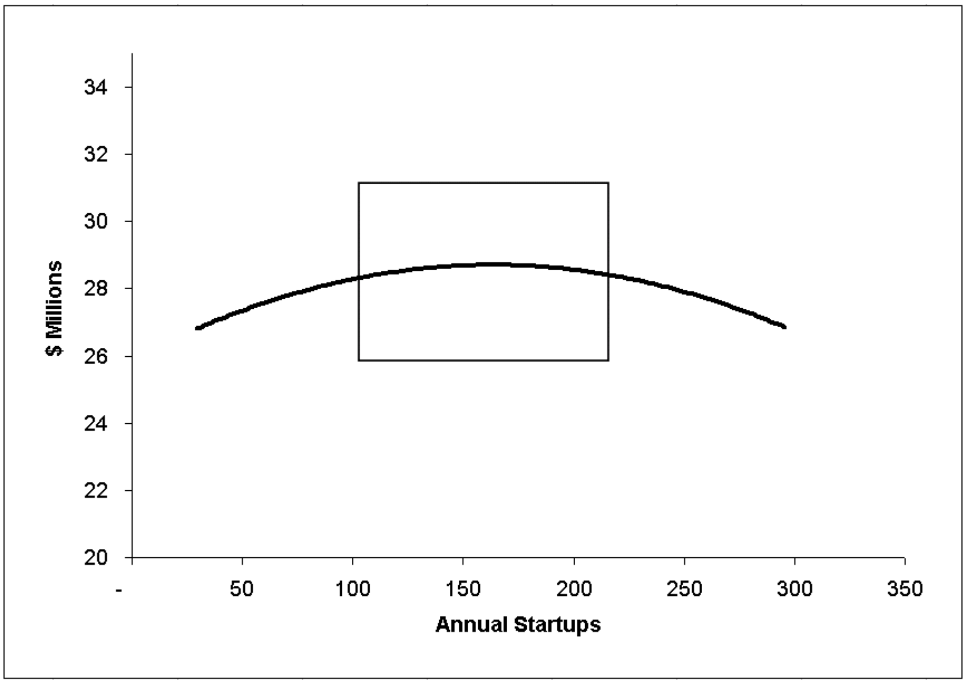
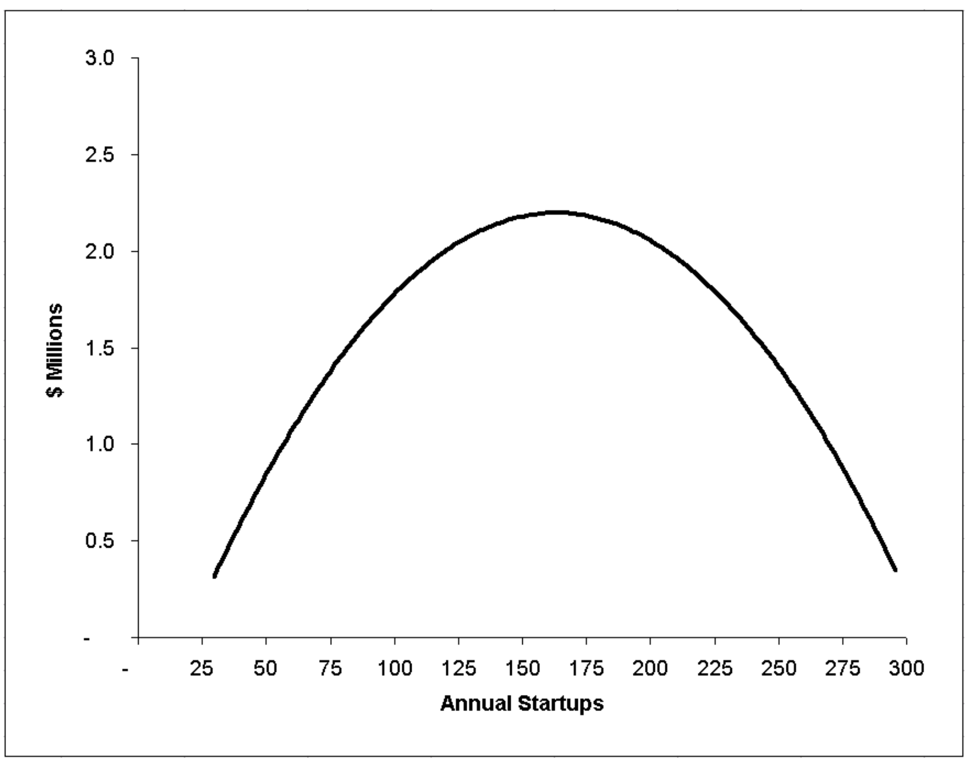


Figure 10. Incremental Financial Opportunity as a Function of Annual Startups



ADDITIONAL SOURCES OF OPTIONALITY AND PROFITABILITY

The case study presented above demonstrated how opportunities for generating greater value from CCGT plants by incorporating the "optimal" number of starts within the dispatch plan; however, a wide range of possible options exists for extracting value of optionality and flexibility within generation facilities.

Fuel switching/Fuel Flexibility

For coal-fired units or dual-fuel units, another common source of optionality and value lies in fuel switching or fuel "flexibility." The capability to switch between fuels offers the generator the capability to better 1) take advantage of fuel market price discontinuities and 2) for coal, substantially alter the "characteristics" of the generation asset. More specifically, the market price for coal is directly related to the inherent "quality" of the coal itself. While there is not sufficient opportunity within this paper to discuss in detail how varying coal quality impacts unit performance characteristics and costs, one can summarize as follows:

- Coal price and quality can vary considerably from source to source
- Coal properties impact the unit heat rate, unit capability (max load), minimum load, ramping rates, reliability, emissions, and O&M costs
- During shoulder periods, it may be more cost-effective to burn cheaper, lower quality coal sacrificing both heat rate and capacity
- During peak periods, it is usually imperative that coal units are supplied with high quality coal to provide best opportunity for reliably meeting load commitments
- In some cases, the installation of coal blending facilities is warranted; this provides the capability to blend lower quality fuels with the main coal supply to better match coal quality burned with that required by the market

Installing Flue Gas Desulfurization Equipment on Phase II Plants

Under the 1990 Clean Air Act, an emissions allowance is required for each ton of SO_2 emitted. This legislation provided for the distribution of annual emissions to cover a portion of plant emissions (typically about equal to emissions from the facility if low-sulfur compliance coal were burned with same annual capacity factor); allowances can be traded and swapped between facilities. Installing FGD systems on plants covered by this legislation offers a distinct trade-off: much greater fuel flexibility versus capital and operating costs of running the FGD system. The imbedded optionality can be characterized as:

- Ability to burn wide range of non-compliant coals.
- Ability to "bank" allowances and/or sell the allowance into the market.
- Ability to transfer the portion of the allowances allocated but not required for the scrubbed unit to other units in the system, thereby increasing the fuel sourcing options for the other units as well.

Installation of Advanced Control Systems

Advanced control systems increase capabilities of the plant to respond to market opportunities – by enhancing operations directly via:

- Faster ramping
- Lower minimum loads
- NOx Mitigation
- Ability to burn wider range of fuels

Additional value may be also recognized if the unit in question also can play a larger role in the context of the overall generation portfolio. Two specific examples of this "value" include:

- Adjusting the ramping and load following capabilities of one unit within a regional portfolio can potentially improve how the portfolio of plants in the region can be dispatched in response to shifts in regional demand or market prices for either energy or ancillary services.
- Ability to diminish NOx obligations for other facilities thereby enhancing these plants' fuel options.

COMMERCIAL AVAILABILITY

Although the focus of this paper and its case study has principally been the illustration of how operating strategies can impact plant value, it is important to recognize how these concepts fit into a larger framework of commercial availability. Simply stated, the concept of "optimal" commercial availability is that a generating unit shall "always" be available when demanded by the market (in the money) but not necessarily available when out of the money.

Clearly, based on the discussion and case study presented in this paper, in volatile markets, the definition of being in the money must be expanded to consider period of operation coincident with the "optimal" operations strategy. This has several implications:

- Costs predicted for O&M and particularly for costs associated with starts, rapid ramping of units, etc. reflected within incremental maintenance costs must fully offset any additional operating risk associated with operating the unit more/less aggressively.
- If the operations strategy is likely to impact the availability of the unit during periods of demand, then these factors need to be explicitly factored into the analysis. If **GENTRADER** were being applied, the expected changes in the Equivalent Forced Outage Rate (EFOR) or Equivalent Availability Factor (EAF) can be directly factored into the analysis; in other cases, it may be necessary to adjust the O&M factors.
- Plant O&M practices should be tuned or tailored to the operations strategy; the frequency of outages and the work performed within the outages should be adjusted as necessary.
- Units can be "in the money" when available to serve either the energy or the ancillary services markets. Hence, the demands on the unit (and associated costs) for keeping the unit commercially available are difficult to quantify and measure.

CONCLUSION

As competitive forces increasingly demand a close knit integration of generation asset operations and energy trading, strategic analysis and tools are needed to manage the complexities. This paper provided a case study that demonstrated the value obtained by optimizing a single plant based upon a subset of operational cost parameters (+$2 million on 500 MW). By optimizing operations based on volatile price signals the profit increases can be significant even on a single asset portfolio. By applying optimization techniques to larger and more complex portfolios the financial opportunities grow substantially if not exponentially.

Once profit maximization objectives are in place, a GenCo must challenge all traditional ways of doing things while considering the financial, reliability, and safety implications. This paper primarily considered the wear and tear costs of aggressive operations on combined cycles and briefly touched on the following:

1. Fuel flexibility/switching
2. Emission controls and constraints
3. Fuel blending
4. Advanced controls
5. Load obligation and forward sale impacts

Yet, we have barely scratched the surface of opportunities in the examples presented in this paper. Opportunities within the market will come in all forms and at varying magnitudes. Yet, each will share the common characteristic – profit opportunity at a reasonable level of risk – and require the right combination of skills and tools to:

- Identify the opportunity
- Assess the value of the opportunity, and potential options for how to address the opportunity
- Understand impacts to the risk profile both current and future implied by options
- Efficiently execute the selected option or strategy.

Opportunities will also exist within different time domains: in the short-term, options will revolve around utilization of current asset and current positions within the market; in the mid-term, options exist as with how outages are managed and scheduled; in the longer term, options exist for changing the fundamentals of plants and portfolios through the combination of new plants, new fuels, or plant capital improvements.

Clearly, the complexity of the problem dictates a sophisticated and integrated solution – finding "success" in terms of maximizing profits is a combination of processes, people, and tools focused on finding and extracting value within the deregulated market.

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