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Turbine System Economics and Reliability, Availability & Maintainability (RAM)

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5.0-1 Introduction

With the varied and fast changing global power market, the complexity of turbine system economics has increased dramatically. In the past, power plants were primarily government regulated and base loaded. Dispatch and electricity pricing was relatively predictable. In today's market, with IPPs, there are endless variations in the way power is produced, provided, regulated, and purchased. OEMs and power producers need to understand methods to quantify and compare parameters, and to understand the drivers and uncertainties to properly evaluate decisions and their potential for profitability in this constantly changing marketplace.

5.0-2 The Power Market Drivers

To understand the power market, one must keep in mind the key differences between this market and others:

Electric power can not be economically stored.

Unlike other commodities, electric power cannot be easily or economically stored. For the most part, it must be produced on demand. While there are some efforts to retain energy generated during off peak hours using technologies such as pumped storage, flywheels, and/or superconductors, the cost is high and the efficiency and reliability of these methods is low.

The demand for electric power is constantly fluctuating.

The fluctuating demand for electric power is clear. Demand varies during the day, with a morning and evening peak and varies over the year with a winter and summer peak. Some of this fluctuation can be predicted based on historical information, such as the typical change in consumption over a day, and the typical seasonal variations, but the fluctuations can shift significantly from the norm due to uncontrollable events like periods of severe weather.

Utilities have a high capital investment cost.

The initial required investment for a power plant varies based on the type of power plant. Typically, utilities have very high fixed costs, spending almost five times the initial investment per dollar than other manufacturing endeavors[1]. These fixed costs, which are typically between \$475/kW and \$1430/kW[2], include equipment for generation, transmission, distribution, and permitting.

Power plants have a relatively long life cycle.

Power plants do require significant initial investment, but they compensate with very long life. Power plants operate for decades, with units operating 30 years or more.

Fuel prices are subject to negotiation and electricity prices are constantly varying.

These factors impact the ability to compete effectively in the deregulated market.

There is an unflinching expectation that required electric power is always and immediately available.

Electricity has become a critical and integral part of the economy and there is no tolerance for an inadequate supply no matter what the circumstances. This is reflected in the fact that electric consumption is generally accepted as one of the lead economic indicators.

These unique features of the power market create a complex situation to evaluate and choose effective strategies for power generation.

Power Market Solutions

The nature of this constantly fluctuating demand for a commodity that must be essentially produced on demand drives a varied supplier base, which can be broken into three basic types of operating modes – base loaded plants, intermediate loaded plants, and peakers.

Base load plants operate continuously for long periods of time. They are typically large plants (> 200MW), which are economical and reliable to operate. These plants often do not have the ability to change load quickly and take advantage of spot market peak pricing. These units operate year round and all day with an overall economy, which allows them to compete and operate profitably, even at low demand times. Base load plants provide the core of the power grid, and act to regulate and maintain the grid frequency.

Intermediate load supplier includes plants that operate to meet normal fluctuating demands in the morning and evening hours and typically operate for 10 to 14 hours per day.

Peak load suppliers include plants which can start up quickly and supply power to meet high demands during periods of high or low temperature when the combined base and intermediate load capacity is not adequate. These plants are typically more expensive to operate, but offer operational flexibility. Electricity supplied during a peak demand is sold at a premium, making this the most profitable time to generate.

5.0-3 The Economics of Making Electricity

The US market is currently a hybrid market consisting of regulated market regions and deregulated market regions, with each having different economic drivers. The regulated markets have contracts that are cost based. Rates are negotiated, fixed, and renegotiated allowing for a set return on investment for the power producer. The deregulated market is an auction market, with suppliers bidding into the market, offering power to the grid. A controller ranks the bids and purchases power as needed from the lowest cost supplier on up in price until the demand is met.

The traditional power market is regulated to meet local demand for power. In this scenario, the cost of electricity is typically locked in by regulation and varies little. A network of base load units and expensive peakers is put in place to enable the supply to meet the fluctuating demand for power. Profits are based on a cost plus regulated model. For a power producer, when choosing an OEM (Original Equipment Manufacturer) or AE (Architect Engineer), the primary economic variables to consider are first time plant cost, service costs, fuel costs, and plant availability and reliability. Fuel costs far outweigh the other factors and the driver in this case for the OEM industry is efficiency.

The power market has changed significantly with deregulation and different variables must be considered to appropriately assess the potential from a customer and supplier point of view. In the deregulated market power prices fluctuate drastically over time. In different areas and different countries, the rules vary, but it is common to have power generators bidding to supply to the grid and in some cases, there are penalties for promising power and then not being able to deliver. This market, which seems as harried and volatile as the stock exchange floor, bids the operation of units which vary in their ability to come up to full power, to sustain partial load and to assure delivery of power at a precise time.

RAM and Economics

When a power plant is off line for maintenance, there is no income stream. When power is offered on the spot market and the plant does not start, there may be penalties. These scenarios drive a need to consider RAM. RAM is an acronym for Reliability, Availability, and Maintainability.

Reliability is used to express and quantify the unplanned maintenance needs of a power plant. Reliability is a measure of how often a plant is available in comparison to the total number of hours the plant would be available with no unexpected maintenance. An ideal power plant has a reliability is 100%.

$$\mathrm{Re}liability = \left(1 - \frac{hours\_unavailable\_caused\_by\_unscheduled\_outages}{total\_hours}\right) \times 100\%$$

Availability is a measure of how often a unit is capable of providing service. The availability can be quantified as the ratio of the total number of hours the unit is actually available in comparison to the total number of hours. Availability considers both scheduled and unscheduled maintenance and compares that to an ideal situation with no maintenance outages at all. An ideal power plant has an availability that is less than 100%. Units with less frequent and shorter maintenance intervals have higher availabilities.

$$Availability = \frac{available\_hours + operating\_hours}{total\_hours}$$

Maintainability is used to express the cost of maintenance. This includes the cost for parts, and the cost of the servicing. Maintainability can be used to compare plants that require frequent, lower cost servicing, with plants that require less frequent, higher cost servicing.

Combining these considerations, RAM looks at how often you can use the equipment and how much it costs to keep it in operating condition. The concept of RAM is used to consider the trade off between higher technology immature technologies, and less advanced, but more reliable operation.

Modern Power Plant Economics

Throughout the US market exists a hybrid market in which the trend has been to move towards deregulation. The change from regulation to deregulation changed the motivation and strategy of power producers. The old descriptions of the power industry as stable and constant were traded in for adjectives like competitive, flexible, dynamic – even risky. This volatile market favors plants that are highly fuel efficient for base load and plants with quick, "push button" starting capability to meet daily peak demands. As a power producer, the ideal situation is to be efficient enough to compete in the base loaded market or flexible enough to change load quickly to compete in the peak market. For an OEM to have access to the largest market share, this means providing engines that can do both. This need to "have it all" has driven the technology of power plants. Equipment manufacturers are competing to deliver plants with the highest efficiency and the most flexibility. This demand for more performance results in pushing the technology envelope.

There have been positive and negative consequences to this change in the industry. The driver for the change was to increase competition in the marketplace, and consequently to reduce utility bills. A discussion of the result in that regard is out of the scope of this paper, but significant secondary consequences occurred which are relevant. The technology of gas turbines has advanced very quickly in this market. Efficiencies have increased and emissions have reduced. The introduction of new technologies has increased in volume and scope, resulting in issues in reliability and availability for less mature engines. A power producer must decide between buying the most advanced technology with the highest efficiency, or buying a model that is more mature, and more reliable, but not as efficient.

Utilities are businesses. Regulated utilities are mainly concerned with maintaining the lowest life cycle costs for their units. For deregulated enterprises profitability is what is important. Prior to deregulation, sound economic decisions were important, and with regulation, these calculations were fairly simple and reliable. Subsequent to deregulation, sound economic decisions became absolutely critical to survival, while becoming far more complex. Utilities must understand how to make appropriate purchasing decisions, and OEMs must understand how these choices are made to compete effectively. The economics and the technology are intimately tied together. While it may be clear which technical decision advances technology the fastest, it is not always as clear which technical decision makes the best business case. Power plant economics explores the cost of a decision over time.

Basic Power Plant Economics

Economic evaluation of a power plant can be explored in a number of ways. All methods account for the cost of a decision over time. There are several accepted methods to examine cost over time. A common approach is to evaluate net present value (NPV).

The net present value method looks at the value of the project over time by converting all income and expenditures into equivalent values at the current time and subtracting the initial investment. To do this, the future interest rate and the rate of inflation must be estimated and expressed as a discount rate, r. While these estimates are somewhat inaccurate, the sensitivity to the assumption can be explored to understand the implication of one choice over another.

$$NPV = \sum_{1}^{T}\left(\frac{CashFlow}{(1+r)^{t}}\right) - In$$

Where;
In: initial investment
r: discount rate or weighted average capitol cost for a given company
t: time
CashFlow: Income – expenses

The basic rule of thumb is that the NPV should be greater than zero for an investment, though most investors will strive to get a hurdle rate that is higher.

To calculate the NPV of a power plant, the following parameters are needed:

1) capital investments,
2) projected price of electricity,
3) size of the plant,
4) capacity factors (how many hours the plant will operate in a given year),
5) dispatch payments
6) projected fuel costs,
7) operating and maintenance costs,
8) start up time and costs,
9) regulating costs, and
10) the discount rate (the cost of money).

For a power producer, the initial investment is the cost of the plant and initial costs for support equipment and hiring staff.

The income is calculated per annum, and is income from the electricity sold to the grid. This is the price of electricity ($/MWh) multiplied by number of hours the facility is producing power (MWh) in a typical year. In a deregulated market, the price of electricity is determined by the market and for calculation, should be evaluated based on historical data and forecasted fuel and electricity prices. In some markets, dispatch payments are another source of income. Dispatch payments are fees paid to producers that are capable of providing power to the grid with a very short lead time, typically in the range of 10 minutes from demand to supply (spinning and non-spinning reserve). These payments are for the assurance of capability and are paid regardless of whether the capability is leveraged. This provides incentive to suppliers to develop and maintain a fast start supply, so the grid can adequately respond to unplanned peak needs.

Expenses are determined on a per annum basis and include the cost of fuel, and operating and maintenance costs. The fuel cost is a variable cost and must be estimated. For the calculation, fuel cost must be converted to annual cost in dollars by multiplying the fuel price times cumulative fuel consumed per annum. The operating and maintenance costs include personnel costs, and the costs for scheduled and unscheduled maintenance. Operating and maintenance costs are impacted directly by the mode of operation of a plant. The frequency of maintenance is influenced by both operating hours and number of starts. A single start for a combined cycle facility can result in a significant incremental increase in maintenance costs, with one producer estimating $20,000 in incremental costs for one combined cycle start[3].

Expenses may also include regulating costs. Regulating costs are government instituted economic consequence to encourage industry to make decisions that have been determined to be for the good of the people. These costs include taxes and the cost of complying with government regulations. Taxes may be implemented to influence companies to choose preferred technologies or to impact the local job market. Technologies may be politically preferable due to environmental or safety issues as viewed by the regulating government. Certain fuel sources may be preferred to enhance energy independence or to promote local industry and employment. Regulating costs also include costs for adhering to regulations that are put in place to assure the safety of a facility, such as OSHA requirements. Regulations and taxes are dependent on the current political climate and are subject to frequent changes, often resulting in the changing position of a certain facility in the market place. An example of this kind of influence is environmental regulations where emissions credits are traded. Over time a facility built to meet a certain regulation may become covered by a regulation with a more aggressive limit. This may mean that additional operating costs are incurrent to purchase additional emissions credits, thus influencing the economics of the power producer.

The calculation complexity increases further when looking over the life of the power plant. Power plants have a long life and many changes occur over the life of the plant. Some of these risks can be hedged by investing in futures to fix the future price of commodities such as fuels, or to insure against adverse business conditions, such as long periods of mild weather.

Some gas turbines have the capability to operate on alternate fuels. Some units are purchased with the flexibility to switch between gas and oil, and various qualities of oil can be considered. As the price for oils and gases fluctuate, a plant with this capability can be more competitive, but at a price. This option requires more capital investment, both in the unit and in the supporting auxiliaries, and potentially in licensing and permitting fees.

Units desire to remain competitive over time by being highly efficient and as a result of this are also driven to increase capital investment over time. New technology is regularly introduced and can be purchased as upgrades to improve efficiency. To develop a symbiotic relationship with customers, some OEMs offer access to upgrades to customers who purchase long term service agreements, thereby integrating the need for consistent high quality service with the need for continually competitive technology.

To understand the drivers for profitability, and the importance of RAM, the sensitivity of the calculation can be explored to further understand the uncertainty of the calculation. The variables can be examined in terms of controllable variable and uncontrollable variables.

5.0-4 Operating Strategies and Options

For a base loaded plant, low margins are compensated by long operating times. Long, uninterrupted operating times are supported by reliability and maintainability. Gas turbine technology has been in service for many decades, and most units have reliabilities of greater than 95%. However, the base line efficiency of a competitive unit is constantly increasing. The old robust engine with learned out technology is simply not efficient enough.

At the other end of the operating spectrum are peakers that are looking to leverage the high costs of electricity during peak needs. In June 25 of 1998, the price per megawatt-hour of electricity in parts of the Midwest soared briefly from $40 to $7000[4]. Though the higher end of this scale is the exception and not the norm, the implication is clear that the investment costs and fuel costs pale in the face of this return and the only significant factor is how much the plant can generate. In this market the goal is to be ready to run when the prices increase. Here again RAM is the driver since for the most part, a window of high potential for peak need can be identified, and so owners can schedule planned maintenance outside these windows. However, availability and reliability are extremely important because if an owner pushes the start button and does not get power, a competitor will quickly jump in and take over that share of the market. If a plant is inoperable due to unplanned maintenance (low reliability) then the opportunity to compete during this need will not even be possible.

Operators in the intermediate load business are balancing all of these needs. They want to be chosen for operation, so efficiency is important, and they need to ready to operate. Reliability, availability, and maintainability are all equally important.

Gas Turbines in the Power Market

Gas turbines operate in all three operating regimes. Simple cycle gas turbines are installed to meet peak demands. They are extremely flexible, relatively low in initial investment cost, and quick to install. While internal machine efficiencies are quite high, gas turbine simple cycles exhaust at roughly 1000°F, wasting a significant amount of energy and resulting in a rather low cycle efficiency, and limiting the application to peak markets.

For intermediate and base load applications, gas turbines are used in combined cycles. In this arrangement, the gas turbine waste heat is used in a heat recovery steam generator to power a bottoming steam cycle. The combined efficiency of such power plants are quite competitive (> 55%), easily fitting into the intermediate load market, and capable of competing as a base loaded units.

In both scenarios there are economic complexities. The base loaded plants must maintain very low costs. The business cases are based on low margins and high volume. Large plants with high availability and low maintenance needs have the advantage in this market. The business cases for load following plants are based on a low volume high profit model, which requires them to be available when the need is present. The economics improve when an unexpected peak in demand occurs. Those who can meet these peaks quickly and reliably can reap the benefit of selling when the market is at its highest. For these reason, RAM – reliability, availability and maintainability become significant driving factors in the power market.

Controlling RAM While Increasing Technology Level

To maintain competitiveness, OEMs are aware that new technology must be introduced at a lower risk level. Steps are taken to control risk during design, prior to implementation, and during operation. During design, risk analysis and management methods are used which allow a quantified assessment of the probability of a particular failure and the consequences. Results of these analyses are used to mitigate risks by either changing the design, or altering the consequential impact. Prior to implementation, new technologies are being tested more thoroughly. In the past, most of the testing was done with similar technologies in small engines, or aircraft engine test beds. These approaches are similar, but not the same as the IGT (Industrial Gas Turbine) application. To further reduce risk, some OEMs such as Siemens, have built IGT test beds, so fully scaled new technology can be fully instrumented and tested in a controlled environment. For further reaching changes, an entire test site is constructed through cooperation between an OEM and a power producer to validate a new design. In some cases, new technologies are introduced to a single customer site with an agreement to test out the technology prior to release to a larger fleet. Subsequent to implementation, engines can be fitted with improved monitors and sensors, condition monitoring, and better controls. OEMs are now offering producers the option to purchase a monitoring contract, where the OEM constantly monitors plant operation. Monitoring a fleet of engines allows the OEM to develop probabilistic indicators of potential failures. When symptoms occurs, the owner is informed, and corrective actions can be taken in a controlled manner, at a convenient time, greatly reducing the likelihood of unexpected failure during a peak need. All of these features combine to reduce the risk of increased RAM costs.

5.0-5 Conclusion

Since deregulation the focus on efficiency so over shadowed other needs that the technical envelope was pushed very hard, very fast. The result was an improvement in the efficiency of gas turbines, but there was a partnering risk when leveraging immature technologies. Using RAM in business models allows appropriate evaluation of the benefit and risk of immature technologies and allows user to apply these technologies intelligently. Today, OEMs and operators are both cognizant of the need to make sound economic evaluations of technology options and to consider technology maturity and the resultant RAM into their calculations. Additional actions (further testing) are taken and additional products (such as online monitoring) are being offered to reduce and control RAM. With these considerations, good choices can be made by power producers that will provide for profit for the company and reliable power for the communities served.

5.0-6 Notes

1. Bonbright, Danielson and Kamerschen, Principles of Public Utility Rates, Arlington, Virginia, Public Utility Reports, Inc., 1988.
2. "Cost Comparison IGCC and Advanced Coal," by Stu Dalton, Director Fossil, Emission Control and Distributed Energy Resources, EPRI. Presented at EPRI Roundtable on Deploying Advanced Coal July 29, 2004.
3. Panel of Combined Cycle Users Group & Gas Turbine Users Group, Electric Power Conference, Chicago, April 5-7, 2005.
4. "Exploiting Uncertainty, The "real options revolution in decision-making," by Peter Coy, Published in Business Week, June 7, 1999.

BIOGRAPHY

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