Power Measurements

Conquering Time

Understanding the value of pumped storage.

By Mark Griffith

The key value driver for electric power is time; that is, the exact clock time at which it is produced. Time determines the demand for electricity, the resources competing to supply the power and the state of congestion in the delivery system.

Benjamin Franklin once said that "lost time is never found again." While there is much truth to this, the time value of electric energy can, in a way, be deferred and "found again" by storing energy in some form and then retrieving it later.

This is the key factor in understanding the value of energy storage. Storage allows one to conquer time, as it were, and deliver power when it is needed, not just when it is generated.

Various schemes exist to store energy, with the most common being chemical energy (*e.g.,* batteries) and hydroelectric pumped storage. The concept of pumped storage is deceptively simple. When its value is low during off-peak periods, electricity is used to pump water from a lower reservoir to a higher reservoir *(see Figure 1)*. Later, when the value of the electricity is much greater (on-peak periods), the water is allowed to flow from the upper to lower reservoir, and this movement is used to generate electricity. The pump and generator often constitute the same device, just operating in an opposite direction. Either reservoir can be a natural body of water or a man-made lake.

While pumped-storage projects have been difficult to develop in the past, their economics are improving along with increasing market demand for ancillary services and standby capacity.

Storage Economics

Capital costs for pumped-storage plants vary widely according to local conditions (*e.g.,* is there a pre-existing lake?) and economies of scale, and easily can exceed $2,000/kW. While there is no "fuel" as such, the cost of the output energy depends on the cost of the input energy. The total consumption of energy during the cycle of pumping and generating is called the "round-trip efficiency" and is typically in the range of 70 to 75 percent; that is, 25 to 30 percent of the input energy is consumed by the storage facility. For example, if the "round trip" efficiency is 70 percent, then 1 MWh off-peak = 0.70 MWh on-peak, or 1.43 MWh off-peak = 1 MWh on-peak.

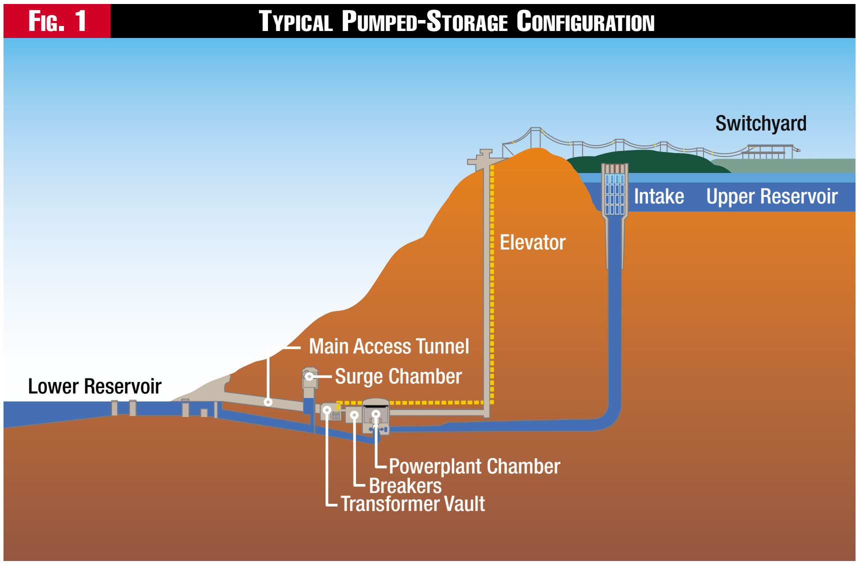
The round-trip efficiency therefore defines the difference—the spread—between off-peak and on-peak prices needed to dispatch economically a pumped-storage facility. For example, focusing on one month in PJM East—September 2005—average on-peak prices were $122.53/MWh, and average off-peak prices were $59.41/MWh. At an assumed 70 percent efficiency, the margin for a pumped-storage asset was [122.53 - (59.41 x 1.43)], or $37.57/MWh (*see Figure 2*).

While this example explains what drives the energy value of pumped storage, those who actually operate such assets likely would cringe at this oversimplification. In a real-time operating environment, pumped-storage calculations constitute very complex problems in optionality, with many complicated and uncertain factors to consider. For example, no one knows with any certainty what power prices will be in the next hour, day or week, so all decisions to pump and generate have market risks associated with them. Additionally, there are many physical limitations to consider, such as the hourly rate at which the plant can pump or generate, the minimum and maximum allowed elevations for the reservoirs, and, in some cases, issues of water requirements for irrigation or fisheries management can come into play.

More Revenue Sources

Pumped storage makes energy available on a dispatchable basis during peak-load

Fig. 1 Typical Pumped-Storage Configuration



Source: TVA

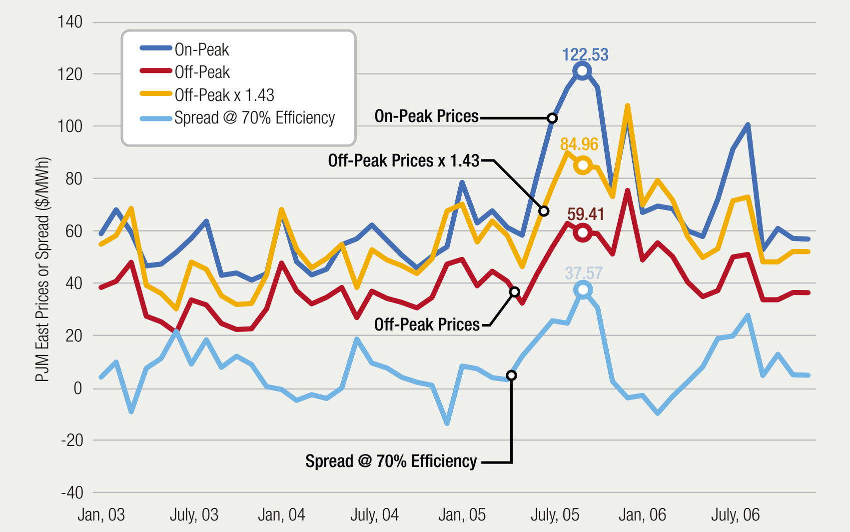
conditions, and that generating capacity counts toward a load-serving entity's capacity responsibility in whatever power pool or independent system operator (ISO) it is operating in. If the asset is located in an ISO with a functioning administrative capacity market (as currently exists in New York, New England and PJM), then it will qualify for that ISO's form of ICAP (installed capacity) payments. In other markets the pumped-storage asset will be able to compete with other generation technologies for capacity payments in bilateral contracts. And in the context of the vertically integrated utility business model, pumped storage is one of many competing technologies to consider in the integrated resource-planning process.

Revenue from capacity payments can make up a significant portion of the total value of a pumped-storage plant. Another significant revenue source can come from payments for ancillary services. The power system requires ancillary services (AS) to provide short-term balancing between load and generation. Without careful balancing, grid frequency and voltage can become unstable, and the entire transmission system risks collapse. Various forms of AS have been developed to reflect that having a quicker response to correct imbalances has greater value to the system, and therefore will generate higher payments. The classic division of AS products follows this pattern:

- **Regulation.** This is a "real-time" service that moves generation via automatic generation controls. It is often further divided into "regulation up" and "regulation down," reflecting that the need to regulate generation in a certain direction tends to depend on the time of day.
- **Spinning Reserves.** Typically, these resources need to respond to imbalances within 10 minutes.
- **Non-spinning Reserves.** These resources are off-line, but can be started and respond to imbalances within 10 minutes.
- **Replacement Reserves.** These resources are off-line, but can be started and respond to imbalances within 60 minutes.
- **Voltage support (VARs) and black-start capability.** While needed to operate a transmission system, generators that provide such services generally aren't compensated for them in wholesale power markets.

There's a temporal relationship between the various AS markets (*see*

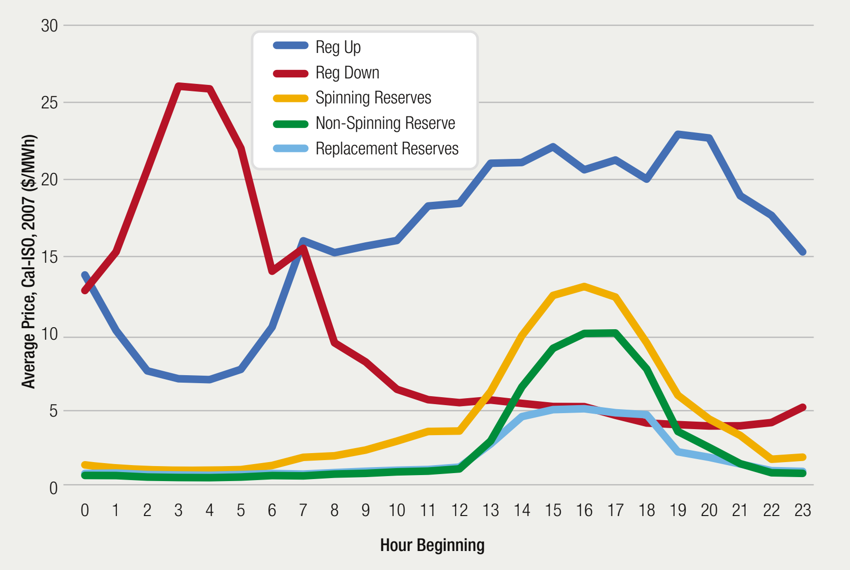
FIG. 2 **PUMPED STORAGE IN PJM**



This figure uses historical monthly average on-peak and off-peak prices for PJM East and an assumed pumped-storage round-trip efficiency of 70 percent. On-peak prices (the blue line) persistently are higher than off-peak prices (the red line). If energy could be stored without losses, it always would be in the money. However, the difference between on-peak and off-peak prices needs to be great enough to overcome the efficiency losses—represented by the yellow line, which increases off-peak prices by a factor of 1.43. The resulting spread, when considering the 70 percent efficiency, is represented by the light blue line, and is positive whenever the value of off-peak generation multiplied by 1.43 is lower than the on-peak price.

Source: PJM and VENTYX

FIG. 3 **ANCILLARY SERVICE PRICES**



Source: Cal-ISO and VENTYX

Figure 3). Using the California ISO as an example, one can see that the value of AS varies dramatically by time of day, and services with quicker response obligations carry higher values. Also, the price levels of the services are quite high, representing a significant potential revenue stream.

Pumped-storage assets are in an excellent position to participate in AS markets. Since there is no "warm-up" period in the starting process, pumped-storage units start quickly and qualify as spinning-reserve services. Pumped-storage units also have very fast ramp rates, and can qualify to provide regulation-up and regulation-down services, potentially in both pumping and generating modes, depending upon their specific designs.

Pumped-storage assets do run the risk of becoming a dominant force in their regional AS markets. For example, in a 50,000-MW peak-demand market, the maximum amount of operating reserves needed (spinning plus non-spinning) may be only 3,000 MW (based on a 6 percent operating reserve criterion). A 1,000-MW pumped-storage facility potentially could provide one-third or more of that market's operating reserves. This creates an issue where the full capability of the asset materially could impact AS prices, so the asset owner would need to develop a dynamic bidding strategy for optimizing revenue from its joint participation in the energy and AS markets.

While it sounds innocuous at first, each ISO sets its own standards for AS product definition, accreditation standards and market-price formation. The whole concept of administratively designed, competitive AS markets is relatively new and is continuing to evolve, making the pumped-storage owner subject to various administrative risks related to future rule changes. Similar administrative risks exist in the ICAP markets.

Valuing Energy, Capacity and Ancillary Services

The valuation of any generation asset, including pumped storage, usually is performed using an income-based approach, which in turn requires the use of forecasted values for the prices of energy, capacity and ancillary services. What's important to understand is how the forecast was prepared, to ensure that the forecast is used in an appropriate context, and that nothing is either "double counted" or "left on the table."

- ❑ **Energy Prices:** The core of the forecast is the energy prices, typically prepared using a market-simulation model. Key questions to address:
  - Does the energy forecast assume all market participants bid at variable costs, or does it include some element of scarcity pricing?
  - Is the energy forecast meant to represent forward prices or future spot market prices?
  - Do forward markets influence the near-term results in any way?
- ❑ **Capacity Prices:** Typically, the capacity-price forecast relates to the energy-price forecast, looking at the revenue shortfall of some proxy unit. Key questions:
  - Is the capacity forecast meant to be the same as future ICAP prices in markets with ICAP mechanisms?
  - What proxy unit is used for comparison? Are revenue shortfalls the same for other likely new-entrant technologies?
- ❑ **Ancillary Services Prices:** It's possible to develop either statistical models or structural models to forecast ancillary services (AS) prices. Key questions:
  - Is the capacity market price forecast already designed to capture AS value?
  - Each ISO has its own approach to AS market design. How does the forecast model capture the specific ISO AS market design?

A rigorous approach to valuation will help avoid double counting of AS and energy revenues.–***MG***

Wind Integration

Pumped storage offers significant value for integrating storage with variable generation sources, including wind and solar power. Renewable portfolio standards established in many states are leading grid operators to become concerned about their ability to integrate wind resources into the balance of the power-delivery system. Wind generation is variable and non-dispatchable, and if no remedial action is taken, this can lead to unstable grid conditions.

Beyond the grid-operations issues, wind-asset owners suffer because wind generation often occurs during lower load periods, when energy prices are lower, thereby reducing their energy revenues. Asset owners also have seen conditions, such as those in West Texas, where the amount of wind generation has led to curtailed output and reduced (or even negative) energy prices, and has resulted in the need for significant new transmission investments.

Storage technologies offer an intriguing answer to address these concerns. A small localized storage technology (such as batteries) could be located at a wind turbine site and be used to transform the time pattern of the generation before it hits the grid. Pumped storage is a more land-intensive alternative and therefore typically would connect at the grid separately from a wind farm. As a result, the variable nature of the wind resource still might require a local transmission investment to avoid negative grid impacts.

That said, pumped storage could provide grid regulation to offset wind-generation variability. It could store energy during lower value periods, prevent wind curtailment and avoid new transmission investments. Pumped-storage capacity could even shape prices by optimizing schedules of wind output and storage.

This last item is particularly noteworthy because—as in the context of ancillary services—a pumped-storage plant commercially integrated with a wind farm could be used to reduce downward pressure on off-peak prices. So in addition to just realizing value for the off-peak, on-peak spread, storage potentially can change the off-peak prices, benefiting other generation assets in a larger portfolio.

But all these benefits come at some cost. Now, instead of just looking at the capital cost for a wind project, the developer of the combined wind-pumped storage complex faces a much higher initial investment. And, as much as a developer might try, one never can avoid the round-trip efficiency issues.

Valuing Storage

Several major value drivers (positive and negative) affect the prospects for building new pumped-storage assets in U.S. markets. The on-peak, off-peak spread is the single biggest value driver. Regional resource scarcity and energy-price volatility typically will improve value. Likewise, market conditions that reduce the price spread by suppressing on-peak prices, such as reduced natural gas prices or high planning-reserve margins, will damage the value of pumped-storage assets.

Operational flexibility is another major value driver. Rapid starting and high ramp rates make it possible to sell various ancillary services. And the ability to move power from off-peak to on-peak periods will allow the asset to generate capacity payments.

> Pumped-storage assets are in an excellent position to participate in ancillary services markets.

Additionally, the potential to integrate with, and increase the value of, wind generation could be a win-win marriage—with the caveat of associated capital costs.

Finally, while pumped storage is ideally suited to provide ancillary services, AS markets easily can become oversupplied. The demand for AS is only a small fraction of the demand for energy, making this revenue stream risky as a primary driver for pumped-storage plants.

Finally, pumped-storage projects continue to face the same operational challenges that have constrained their development in the past. Depending on the site, a pumped-storage project that makes perfect sense for economic reasons might be a non-starter because of environmental opposition, fisheries management regulation or the irrigation needs of the region. Nevertheless, with power capacity and ancillary services becoming more valuable in organized markets—and with a growing fleet of wind turbines—pumped storage does merit new consideration in the U.S. power supply mix.

Mark Griffith is a senior vice president at Ventyx Energy and leader of its asset valuation practice. He can be reached at Mark.R.Griffith@Ventyx.com.

Since the publication of this article Mark Grifith has become a Managing Director at Black & Veatch, and can be reached at GriffithM@BV.com.