The Duck Curve and More

New Challenges in Utility Planning and Operations

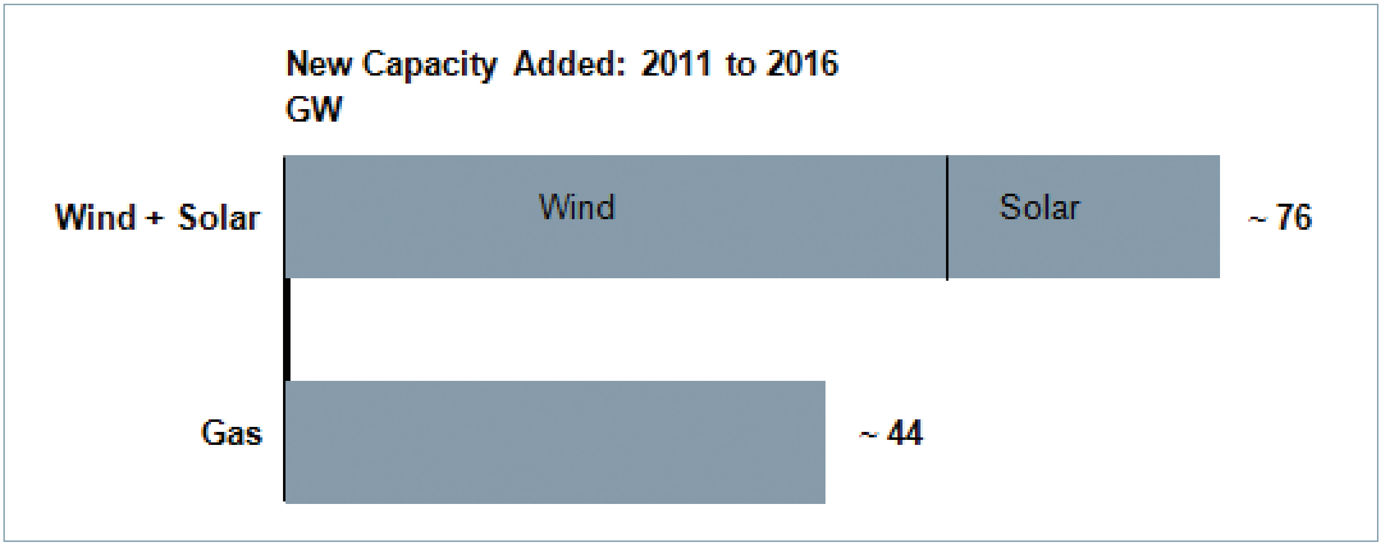
The penetration of intermittent, non-dispatchable resources will result in new challenges for utility planning and operations. To address these new challenges, traditional tools will need to be complemented with new modules such as Pace Global's Sub-Hourly Intermittent Reserve Evaluation (SHIRE) module discussed here. Storage, in particular, offers multiple value streams to the electric system including, importantly, the flexibility to provide reserves to address the challenges posed by intermittency. With expected technological innovation, storage will grow in importance, making it imperative for planners to properly integrate storage with its multiple value streams into future generation portfolios. In addition, the industry will need a new planning architecture that includes modules such as SHIRE, as well as a common framework to bring together today's separate generation, transmission, and distribution planning tools. Pace Global's in-house research and client work is focused on this new frontier.

Intermittent and non-dispatchable resources – mainly wind and solar - have experienced rapid growth over the last decade. The driving forces behind this growth include technological innovation and customer preference for clean energy as well as state and federal policies and tax incentives. As the penetration of intermittent and non-dispatchable generation on the system increases it creates planning and operational challenges for the electric system. From a planning perspective, these intermittent resources present two challenges: the sharp hourly variability in output during a 24 hour cycle, as well as the inability to count on them to deliver a known level of energy in a specific hour due to such events as cloud cover. As a result, new methods and tools are needed to complement the current suite of planning tools. From an operational perspective, the system will need more flexible resources such as regulation and spinning reserves to deal with the characteristics of intermittent resources. Storage, in particular, offers multiple value streams to the electric system including, importantly, the flexibility to provide reserves to address the challenges posed by intermittency. With widely expected technological improvements, storage will only grow in importance. The ability of storage to provide readily deployable reserves is but one part of its value. The larger question for planners will be to properly integrate storage with its multiple value streams into future generation portfolios, and is the subject of other Pace Global efforts. The focus is here is on one element of that value: the ability to use storage to provide reserves.

The Context

The last decade has witnessed increasing penetration by renewable wind and solar resources into the U.S. electric system. Even as these technologies contribute to fulfilling various environmental stewardship objectives, they are approaching and, in some cases, already have attained grid parity. They have dominated new builds in recent years and are expected to maintain their advantage going forward (Exhibit 1).

Exhibit 1: Solar and Wind have Dominated New Builds

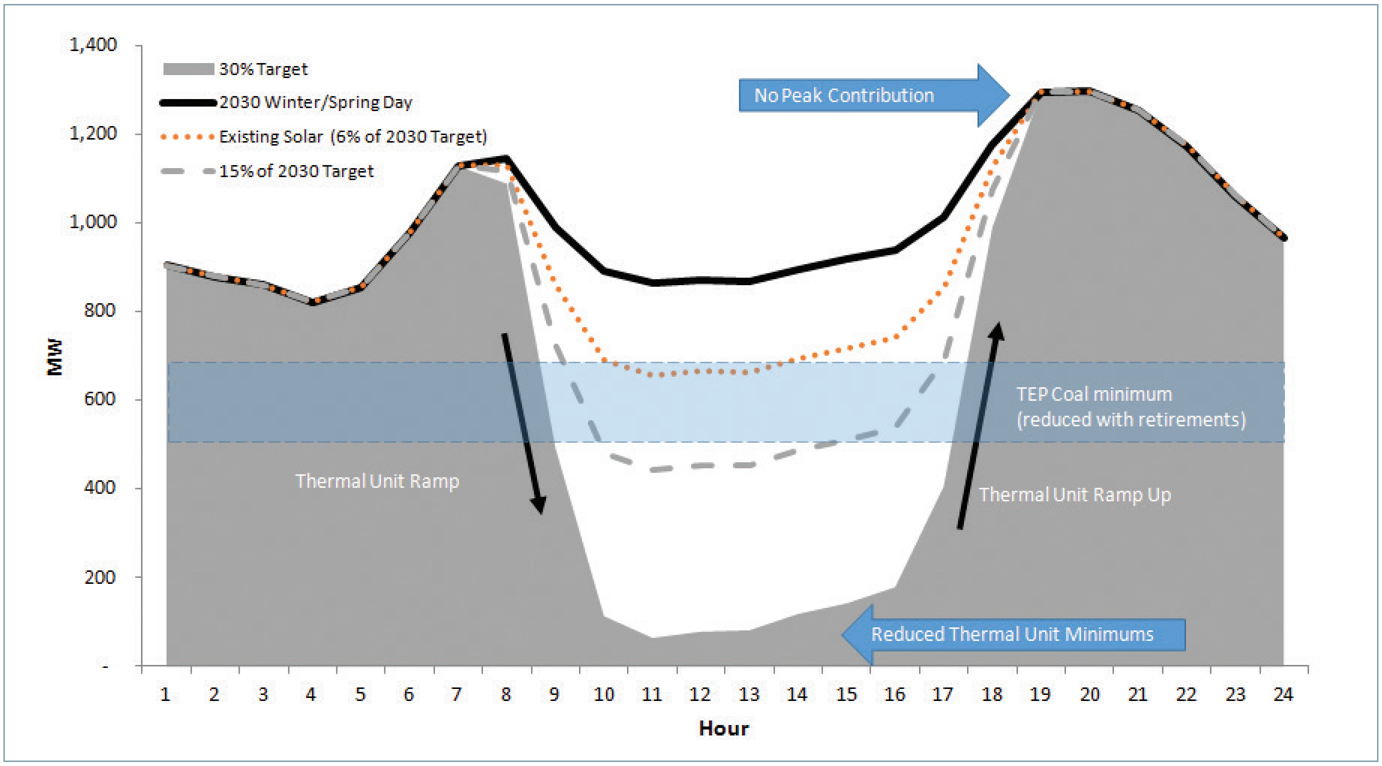


Source: Energy Velocity; Pace Global analysis

Markets such as California and Arizona possess advantageous conditions for the penetration of solar and other renewables – e.g., abundant sunshine, favorable economics, and strong policy support. In these markets the penetration of renewables has been dramatic, leading to a drastically changed daily residual load shape that must be met by conventional generation. In simple terms, these markets have seen high levels of solar generation during the day that have severely depressed the residual demand that must be met by conventional generation. As a result the highest demand to be met with conventional generation has shifted from the middle of the day, when both the actual total load and total solar output are each at their highest, to early evening, when actual total load remains high but solar output tails off. The shape of the increase in the demand that must be met by conventional generation during early evening is said to resemble the shape of a duck's neck, hence the phenomenon has been dubbed the "duck curve". As solar penetration continues to increase, this trend will get even more pronounced. Tucson Electric Power (TEP) represents one striking example of the duck curve phenomenon, especially during that utility's winter/spring seasons (Exhibit 2):

- With 6% of its 2030 renewable target, it already has day time loads that will make it hard to live with its coal unit minimums
- With 15% of its 2030 renewable target, it will clearly not be able to live with its coal unit minimums
- And, at the 2030 target, solar will meet over 80% of its mid-day load, which will mean that conventional thermal units will face a completely different operating cycle.

Exhibit 2: Operational Challenge: Case of Tucson Electric Power



Source: Tucson Electric & Pace Global presentation at EEI

Because of the non-dispatchable and intermittent nature of solar generation, displacing conventional generation with solar creates substantially different challenges than those that have to be overcome when coal generation is displaced by gas generation or generation from biomass. In particular, the output from a solar plant exhibits variability and uncertainty, each of which makes hourly generation from the resource hard to predict. Variability refers to changes in output as the sun changes position throughout the day and over seasons. Variability can shift solar generation from a single installation by more than 10% over a 15 minute period. Uncertainty is change in output caused by factors such as variable cloud cover. Uncertainty from a passing cloud can lead to changes in solar output of as much as 50% or more in seconds. The operation of these phenomena means that the observed output from solar installations can vary dramatically both in a time scale of seconds to minutes as well as a time scale of tens of minutes. In turn, this adds a sub-hourly dimension to the challenge utilities already face when dealing with the (hourly) duck curve phenomenon of Exhibit 2. With solar, therefore, the system has to be ready to deal with significant swings up and down in output at the sub-hourly level (Exhibit 3). To deal with the imbalances between load and generation created by such swings – i.e., to maintain reliable system operations even with these swings – there will be an increasing need for reserves, particularly regulation reserves, which allow the system to respond in the seconds to minutes time frame[1]. This means:

- From a planning perspective, there is a need to create new methods and tools to examine the adequacy and cost of obtaining such reserves
- In terms of operations, the system must have resources that can provide such reserves. Given the progress of storage technology, storage is of particular interest to potentially meet this increasing need for reserves.

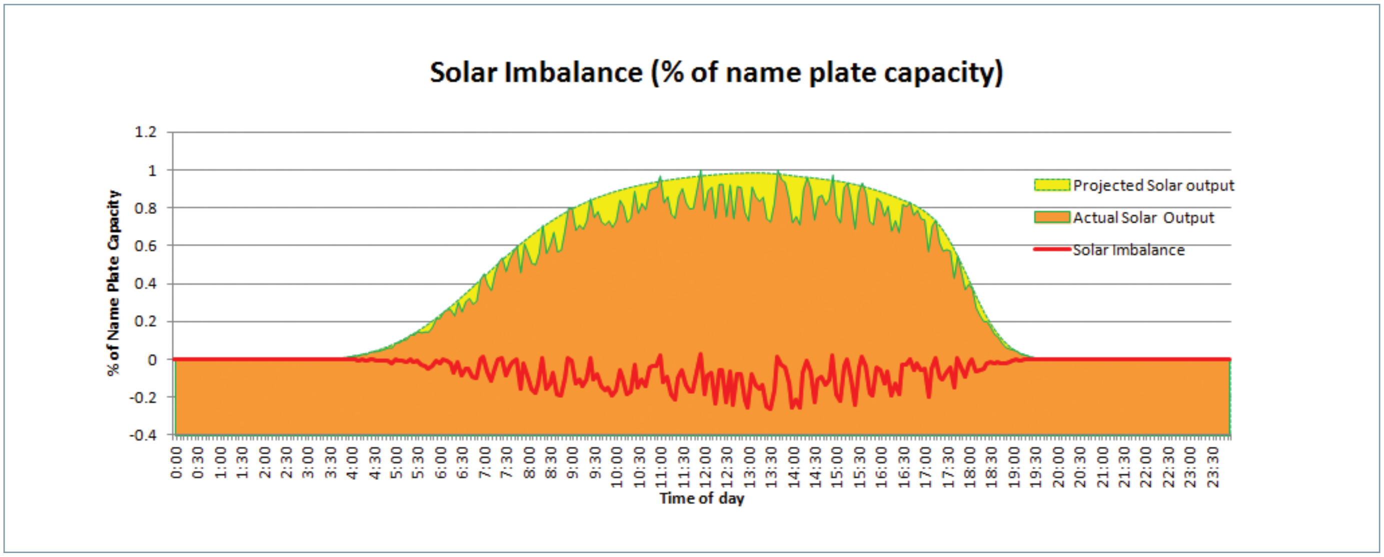
New Methods and Tools

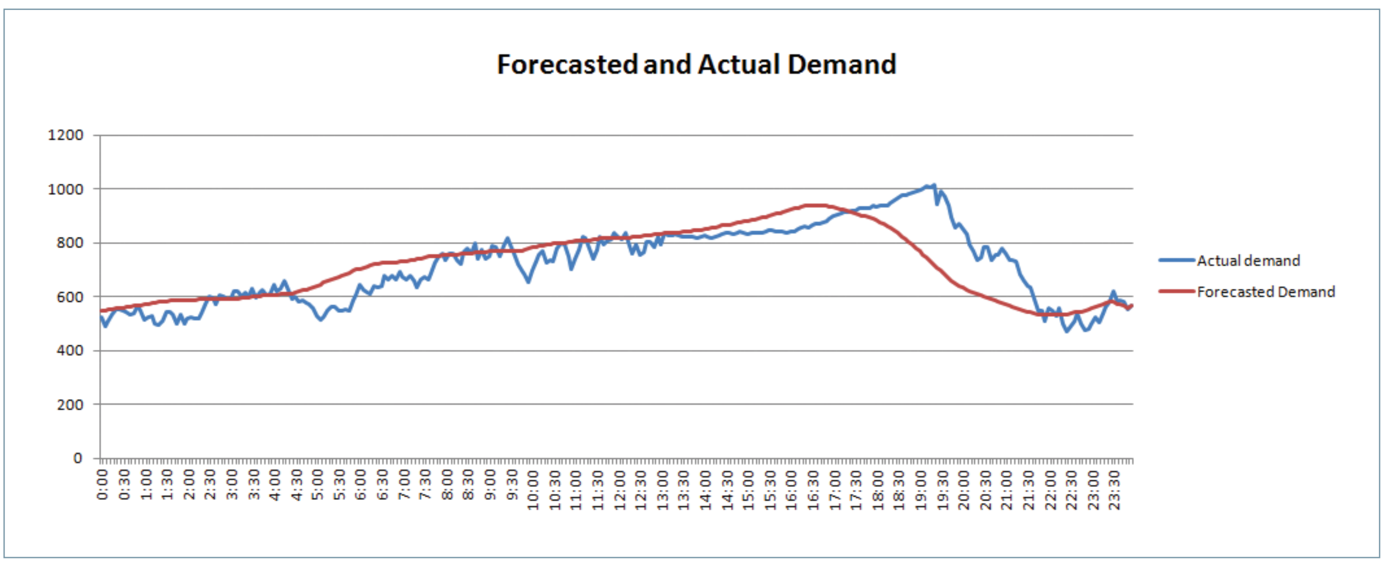
Traditional utility planning tools (e.g., production cost models such as PROMOD, AURORA, Plexos) generally use hourly demand forecasts and make a single security constrained commitment/dispatch decision for each hour. In their hourly commitment/dispatch logic, these tools are generally able to achieve cost minimization while withholding energy from a known (pre-specified) level of reserves to provide spinning reserves or regulation reserves as needed to meet system reliability requirements[2,3]. Our experience suggests that these tools generally start with a known (pre-specified) level of reserves as an input, and are generally not equipped to evaluate whether that pre-specified level of reserves is truly sufficient to meet actual system variabilities caused by the duck curve and renewable intermittency. Specifically, they *do not*:

- Address the adequacy of a specified level of reserves to reliably deal with intra-hour fluctuations, and
- Consider the ability of storage resources to provide reserves, but rather deploy these resources to optimize energy value over an operating cycle.

Pace Global has developed a proprietary tool – the Sub-Hourly Iterative Reserve Evaluation ("SHIRE") module – which can complement traditional planning tools such as AURORA to evaluate the adequacy of given level of

Exhibit 3: Imbalances at the Sub-hourly Level will Increase with Increased Solar Penetration

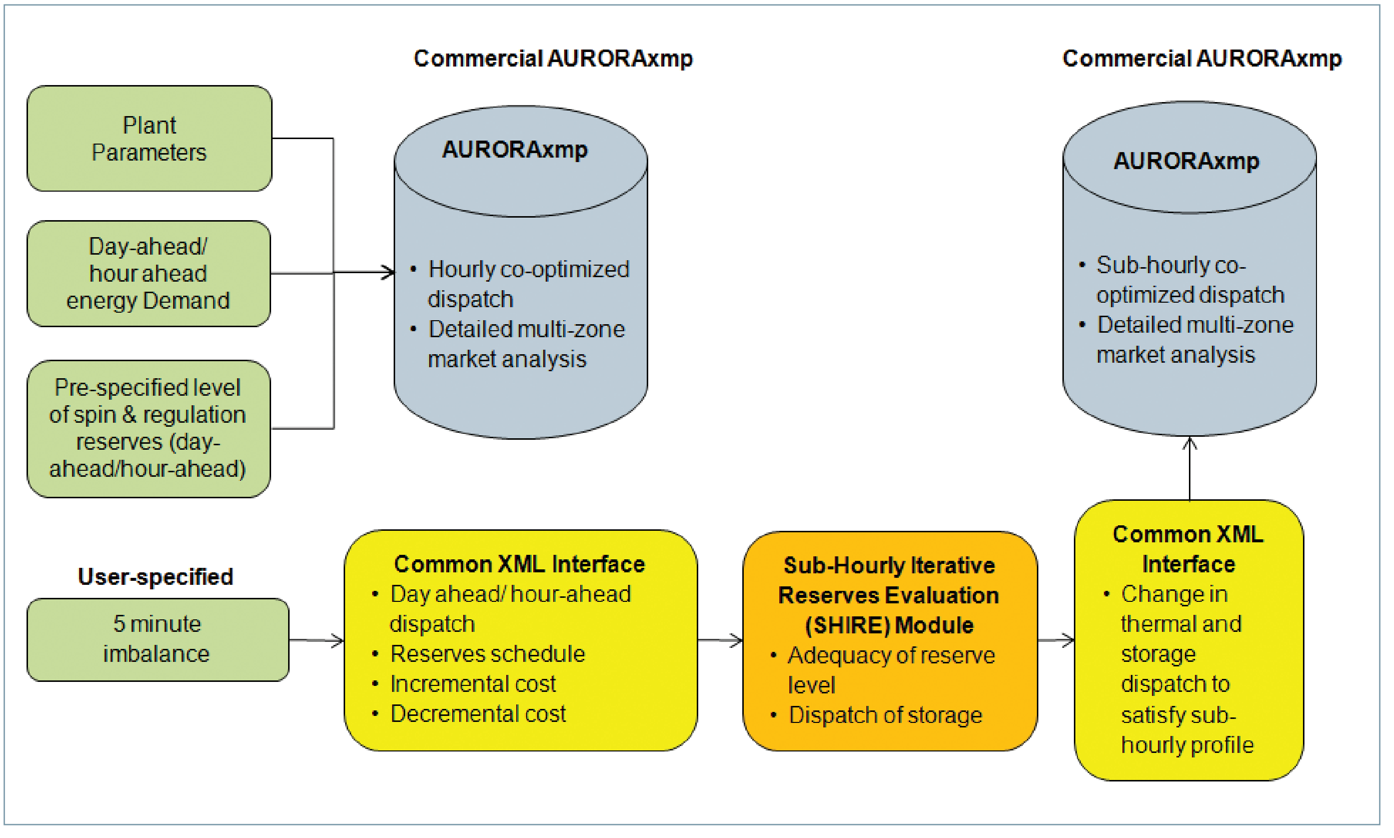




reserve requirement in meeting the imbalances caused by intermittency. The essential elements underlying Pace Global's approach are as follows (Exhibit 4, 5):

- **Step 1:** Generate from an initial AURORA run the hourly load shape, the co-optimized hourly commitment/ dispatch of resources including the withholding of resources to provide the pre-specified input level of reserves
- **Step 2:** Superimpose on the hourly load shape and hourly dispatch profile from the prior step a set of granular intra-hourly fluctuations (from 5 minute to 15 minute intervals, depending on data availability) capturing output intermittency, deviations in demand, and deviations in generation caused by unplanned outages,
- **Step 3:** Using Pace Global's SHIRE module assess how the imbalance can be met at a sub-hourly level by using resources capable of providing reserves to address the imbalance
- **Step 4:** Through an iterative process, converge on an adequate level and an economic mix of reserves needed to meet the sub-hourly imbalance, using SHIRE
- **Step 5:** Re-run AURORA by setting the required level of reserves to the "adequate level and economic mix" – i.e., the Step 4 level – and report the correct production cost by zone

Exhibit 4: Dealing with Sub-hourly Phenomenon with Sub-Hourly Iterative Reserve Evaluation (SHIRE) and AURORAxmp

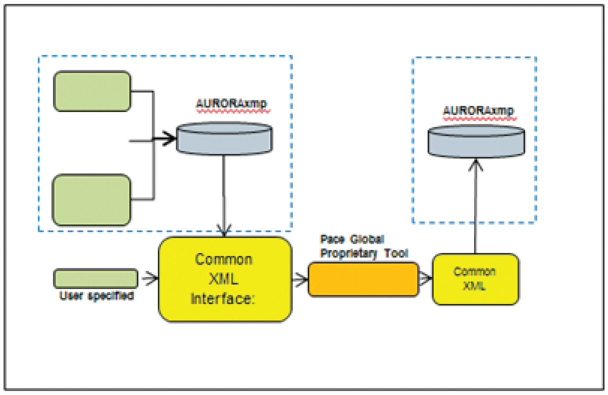


[1] The reserves that matter for this discussion are spinning reserves and regulation reserves. The electric system needs ancillary services other than spinning reserves and regulation reserves, but these other ancillary services are not relevant here.

[2] Version 12.1 and later of AURORA performs co-optimization of energy and reserves for hourly day-ahead dispatch

[3] In general, regulation reserves can be thought of as resources that are fully available to meet load within 10 minutes or less. Spinning reserves, which are thought of as a subset of this class, represent resources that are already synchronized with the gird and available almost instantaneously.

Exhibit 5: Using SHIRE to Estimate Adequate Level and Economic Mix of Reserves



Step 1

- Generate from initial AURORA run using a pre-specified level of reserves:
  - hourly load shape
  - the co-optimized hourly commitment/dispatch of resources
  - withheld resources to provide the pre-specified input level of reserves

Step 2

- Superimpose on the hourly load shape and hourly dispatch profile sub-hourly fluctuations (e.g., 5 min interval data)

Step 3

- Derive sub-hourly imbalances relative to Step 1 hourly assumption
- Using Pace Global's SHIRE module to assess adequacy of reserves to meet sub-hourly imbalances

Step 4,5

- Through iterative process, converge on adequate and economic level of reserves needed to meet the sub-hourly imbalance
- Report cost of providing adequate level of reserves

Deploying Storage Effectively

Storage technologies – well-established pumped storage, as well as newer battery technologies – can provide multiple value streams to the system, including the flexibility to deal operationally with sub-hourly variability created by renewable intermittency. Because traditional tools operate on an hourly basis, they can neither fully account for storage resources' ability to react to intra-hour system imbalance, nor the opportunity cost of utilizing finite storage capacity for short-term system balancing instead of longer term arbitrage. However, by interacting with more traditional tools like AURORA, SHIRE offers a way to account for the ability of storage to be dispatched up or down within an hour, while assessing whether or not it can lower production costs as well. To do this, Pace Global's approach operates in tandem with AURORA as follows:

- Step 1: Use an AURORA dispatch (conducted on an hourly basis) to create a baseline for operation of the storage resource as well as the level of stored energy at the start and the end of the storage cycle
- Step 2: Include storage as an available resource to meet sub-hourly imbalances within SHIRE
- Step 3: Dispatch the storage (within SHIRE) as an available resource to meet the sub-hourly imbalance, while remaining as close as possible to the level of stored energy at the start and the end of the storage cycle
- Step 4: Re-run AURORA incorporating the Step 3 dispatch of the storage resource to yield a production cost estimate. This can be compared to a "no use of storage for reserves case" to assess the cost-effectiveness of storage as a resource for reserves.

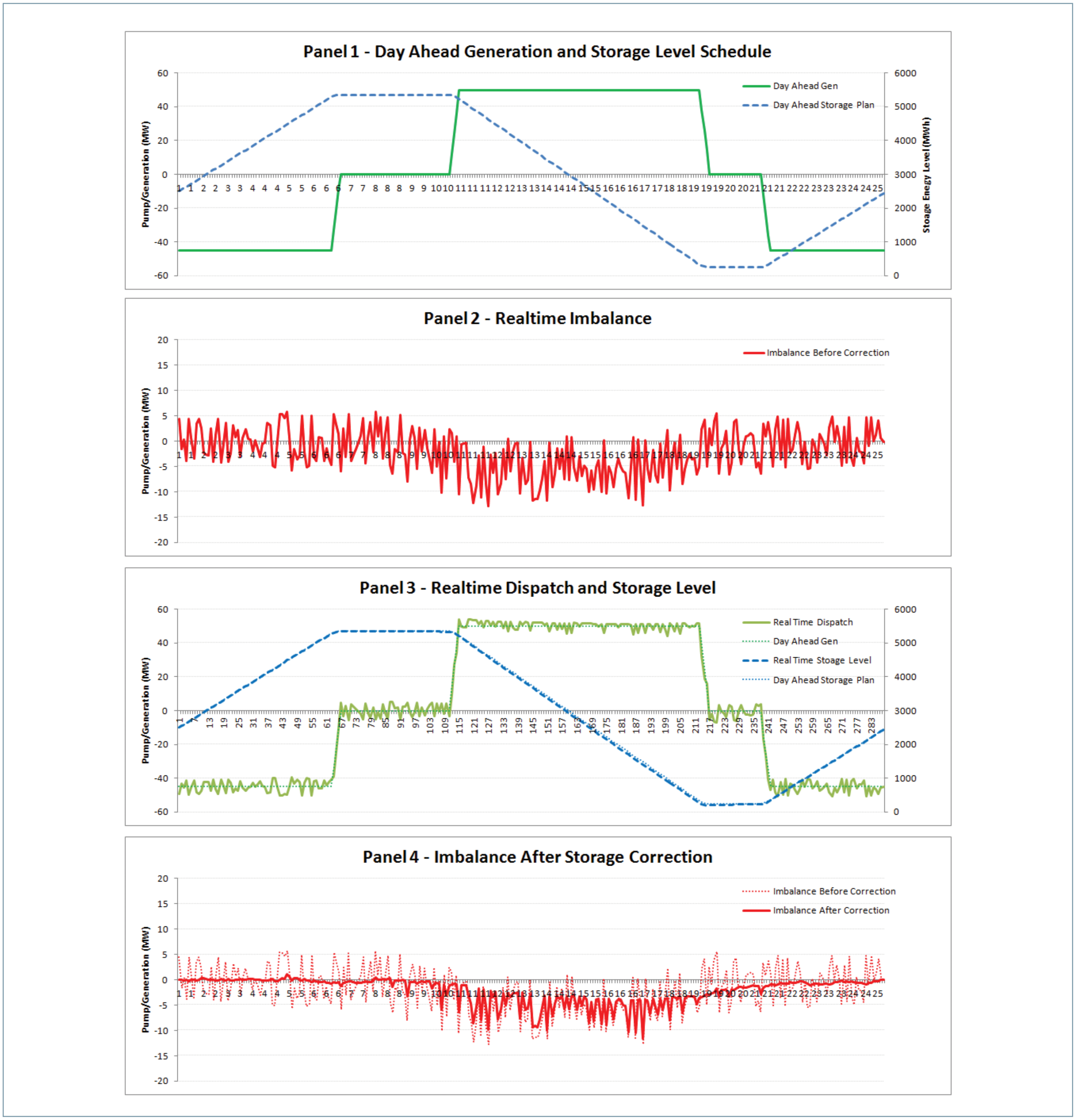
In assessing the cost-effectiveness of storage as a resource for reserves, it is important to keep in mind that thermal resources, once allocated to provide reserves, are available at any time to do so. Storage, on the other hand, is limited by a second objective which is to take advantage of temporal arbitrage (also referred to as "time shift"). Also, drawing down or raising storage too persistently is limited by finite storage capacity over an operating cycle. The illustrative example of Exhibit 6 lays this out:

- Storage resources are scheduled day-ahead keeping in mind the level of energy available at the start and end of the cycle. Panel 1 (of Exhibit 6) shows a day-ahead storage schedule.

- Panel 2 shows the gross imbalances at a sub-hourly level that need to be meet
- Panel 3 shows how the use of storage at a sub-hourly level varies from the day-ahead schedule, if it is deployed to meet imbalances. Importantly, as Panel 3, storage is deployed so as to maintain total energy stored at roughly the same level as the day-ahead schedule, which assumes no use of storage for reserves.
- Panel 4 shows that use of storage for reserves while following the day-ahead schedule for energy stored leaves some residual imbalance to be met with other resources.

The net cost of using storage in this fashion to provide multiple benefits – provide reserves while preserving the time shift value – is estimated in Step 4 of the process described above.

Exhibit 6: Dispatching Storage to Satisfy Dual Goals of Reserves and Time



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