Energy Research and Development Division

FINAL PROJECT REPORT

Applications and Demonstration of the UniGen Smart System for Renewable Integration

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PREFACE

The California Energy Commission's Energy Research and Development Division supports energy research and development programs to spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission and distribution and transportation.

In 2012, the Electric Program Investment Charge (EPIC) was established by the California Public Utilities Commission to fund public investments in research to create and advance new energy solutions, foster regional innovation and bring ideas from the lab to the marketplace. The California Energy Commission and the state's three largest investor-owned utilities—Pacific Gas and Electric Company, San Diego Gas & Electric Company and Southern California Edison Company—were selected to administer the EPIC funds and advance novel technologies, tools, and strategies that provide benefits to their electric ratepayers.

The Energy Commission is committed to ensuring public participation in its research and development programs that promote greater reliability, lower costs, and increase safety for the California electric ratepayer and include:

- Providing societal benefits.
- Reducing greenhouse gas emission in the electricity sector at the lowest possible cost.
- Supporting California's loading order to meet energy needs first with energy efficiency and demand response, next with renewable energy (distributed generation and utility scale), and finally with clean, conventional electricity supply.
- Supporting low-emission vehicles and transportation.
- Providing economic development.
- Using ratepayer funds efficiently.

Applications and Demonstration of the UniGen Smart System for Renewable Integration is the final report for the Scheduling and Market Participation by Variable Energy Resources project (Contract Number EPC 15-059) conducted by Onset, Inc. in collaboration with the California State University at Sacramento. The information from this project contributes to Energy Research and Development Division's EPIC Program.

For more information about the Energy Research and Development Division, please visit the Energy Commission's research website (www.energy.ca.gov/research/) or contact the Energy Commission at 916-327-1551.

ABSTRACT

California's Renewable Portfolio Standard, which requires 60 percent of electricity retail sales to be served by renewable resources by 2030, is ambitious and attainable. It is an undertaking, however, with its share of challenges, many of which can be summarized as maintaining the reliability of the transmission and distribution network in a cost-effective manner. The UniGen Smart System for Renewable Integration (UniGen) represents an approach, considerably different from those being currently pursued in the industry, for integrating large amounts of renewable energy into the daily operation of the California Independent System Operator grid without sacrificing reliability.

UniGen is primarily a tool that allows variable energy resources to use the day-ahead market. This is attractive to resource owners because negative prices are increasingly present in the real-time market but not in the day-ahead market. It is attractive to the California Independent System Operator because day-ahead schedules make the markets operate more efficiently and contribute to grid reliability.

However, variable energy resource owners are primarily scheduling in the real-time market, where they are not charged balancing costs in the event that the schedule is not met. Variable energy resource owners could use UniGen to schedule all forecasted generation into the day-ahead market and be assured that the schedule is met, thus creating financial incentives for variable energy resource owners to transition from the real-time market to the day-ahead market.

The use of UniGen by market participants to serve their own financial interests would support California ISO's efforts to maintain grid reliability.

Keywords: renewable integration, smart control system, market participation for renewable energy, duck curve, dog curve, enhanced frequency regulation, technology demonstration, day-ahead market

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

APPENDICES

EXECUTIVE SUMMARY

Introduction

California's Renewable Portfolio Standard, which requires 60 percent of electricity retail sales to be served by renewable resources by 2030, is ambitious and attainable. It is an undertaking, however, with its share of challenges, many of which can be summarized as maintaining the reliability of the transmission and distribution network in a cost-effective manner. This report describes a new approach, considerably different from those being currently pursued in the industry, for integrating large amounts of renewable energy into the daily operation of the California Independent System Operator (California ISO) grid without sacrificing reliability. Moreover, this approach provides financial incentives for owners of renewable energy resources to help solve the integration problem without intervention by the California ISO.

The 60 percent Renewable Portfolio Standard goal established for renewable energy generation, the bulk of which will come from variable energy resources such as wind and solar photovoltaic, requires changes to the operating and business practices that underpin California ISO's transmission network and market. The main objective of this study, *Scheduling and Market Participation of Variable Energy Resources*, is to demonstrate how a new integration tool called the UniGen Smart System can be an agent of that change.

Managing Variable Energy Resources Requires Transforming the Grid

Today's electricity networks were designed a century ago, on the presumption that electricity consumption (demand) and generation were reasonably predictable and slow moving. To help the grid operators manage system reliability, forecasts of supply and demand were submitted about one day in advance and became known over time as the day-ahead schedule and remains the primary tool used to ensure reliability. Any changes to these schedules were small and slow to develop. Under these conditions, grid operators in the control room had time to identify and then respond to schedule changes, either manually or with computers, thereby bringing the system back into balance in a timely manner.

With the advent of substantial amounts of variable energy resources, this underlying assumption — that demand and generation are predictable and slow moving — is no longer valid. Without changes, there will be an increasing number of events in which the California ISO grid does not meet National Electric Reliability Council standards that pertain to keeping demand and generation in balance. Violations of these standards involve expensive fines in the short term and Federal Energy Regulatory Commission intervention if the pattern of violations continues. To avoid this, California ISO potentially may limit the amount of renewable electricity generated (referred to as curtailment) and another result might be the widespread use of relatively expensive countermeasures. Of course, there is also the potential for costly service interruptions for California residences and businesses. These possible outcomes represent a barrier to meeting California's public policy goals for clean, affordable energy.

Project Purpose

To manage this variability, much of the industry favors enlarging the centralized control of resources that are able to compensate for it. The UniGen Smart System, on the other hand, is a distributed solution that disaggregates the seemingly intractable problem of renewable integration into smaller, more manageable problems. The California ISO market manages thousands of megawatts of firming resources available on the grid to collectively compensate for the variability of thousands of megawatts of wind and solar generation in the 5- to 15-minute time frame. A "firming" resource is one that can be predictably commanded (dispatched) to reach a specific power level; for example, energy storage systems and natural gas plants. In contrast, the UniGen approach is to manage specific resources—for example, 100 megawatts ()of solar with 50 MW of a gas plant (and/or storage)—in the 30-second time frame to maintain a constant level of generation.

In addition, UniGen provides the technology and financial incentives for variable energy resources and firming resources to work together. All generation resources are required by California ISO to schedule their expected generation in the day-ahead market. Constructing a schedule for a gas plant or storage system is easy because the output can be controlled. If the schedule calls for 50 MW to be generated, it is very likely that 50 MW will be generated and delivered. However, constructing a schedule for wind and solar generation is not easy, because as is well known, this generation cannot be controlled.

Typically, a schedule for a variable energy resource is constructed based on a forecast. These forecasts, however, are noticeably inaccurate in the day-ahead time frame. Therefore, if the schedule says that 50 MW will be generated, it is not usually likely that 50 MW will be generated and delivered. This has potentially severe financial consequences because the day-ahead schedule is a financially binding contract, which requires the resource owner to pay penalties for not meeting the schedule. In recognition of this, variable energy resources are exempted from the requirement to submit a day-ahead schedule. Instead, most variable energy resources participate in California ISO's Participating Intermittent Resource Program, which relieves them of these penalties (the cost is passed on to all ratepayers) but requires them to use California ISO's real-time schedule, often resulting in the variable energy resource being underused.

However, if owners of variable energy resources and firming resources work together, it is possible to schedule and use the full amount of variable energy resource generation. A day-ahead schedule can be created based upon the maximum amount of variable energy resource generation forecasted and when variable energy resource generation deviates from this schedule, the difference is made up by the firming resource. Penalties are avoided or at least minimized.

There are a number of benefits. Day-ahead market prices are higher than those for the real-time market, which makes variable energy resources more profitable. Moreover, there are no negative prices that lead to curtailment, as has been the case for variable energy resources using the real-time market. California ISO benefits because the use of a predictable day-ahead schedule reduces the uncertainty about how much generation will be available. Finally, UniGen contributes to frequency management because it self-corrects for schedule deviations, which are the ultimate source of frequency irregularities.

Research Approach

Work done by Onset prior to this research suggested that on a conceptual basis, the UniGen Smart System could integrate large amounts of renewable energy. One purpose of this research was to perform a more detailed and rigorous study of the behavior of the UniGen Smart System for a variety of important applications, including enabling VERs to avoid curtailment and be more profitable, mitigating the effects of the "Duck Curve," and actually improving reliability despite increasing use of VERs (Figure ES-1).

Figure ES-1: The Duck Curve

These studies were performed using the UniGen Smart System simulator developed by Onset. This simulator models the dynamic interaction of variable energy resources and dispatchable resources such as storage and natural gas plants. Using historical data as input, the simulator depicts and analyzes how well these resources maintain a constant, predetermined power level. The simulator has a module to compare the economic value of using the UniGen Smart System with not using it.

This project also tested a UniGen Smart System prototype. A successful demonstration test would provide confidence that a full-scale UniGen system would work as expected. The test plan was to first write the core UniGen code (and revise it as test results became known). Using variable energy resource fluctuations as captured by historical data, the UniGen software managed the operation of a natural gas plant to offset these fluctuations. The gas plant was represented by an existing software model. Over the course of several months, numerous tests were run in a lab located at California State University, Sacramento.

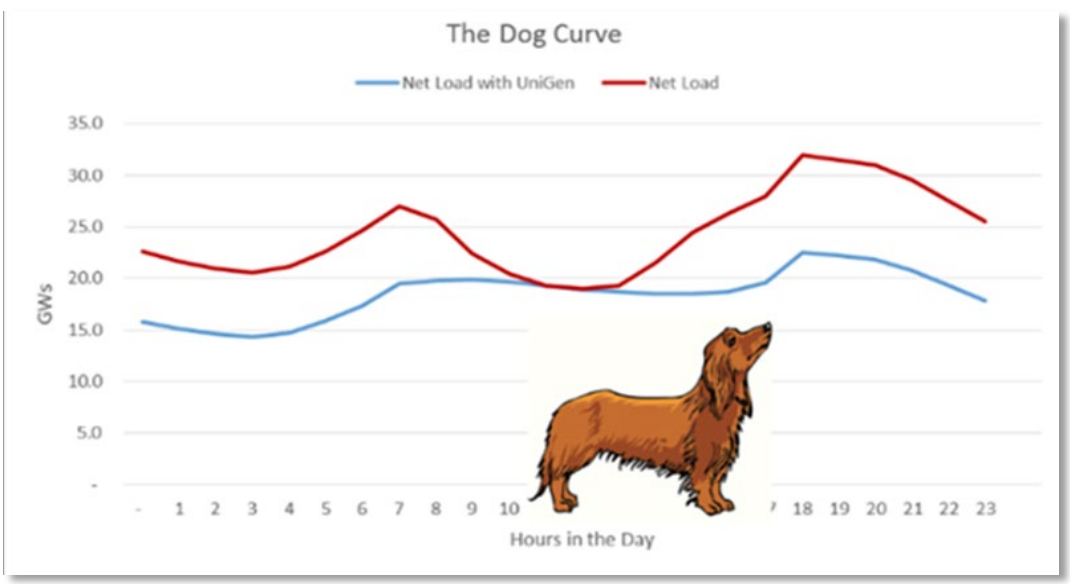
Project Results

Key Finding #1: UniGen is an Effective Tool for Renewable Integration. The most important finding of this study is that the UniGen Smart System is an effective tool by which variable energy resource generation can be scheduled in the day-ahead market, with much reduced financial exposure. The use of UniGen by market participants to serve their own financial interests will support California ISO's efforts to accommodate more renewable generation without sacrificing reliability.

Key Finding #2: UniGen Enables Higher Levels of Variable Energy Resources. Variable energy resource generation, in the amounts envisioned by California's Renewable Portfolio Standard, is generally viewed as a serious threat to maintaining grid reliability at affordable costs to ratepayers. A finding of this research is that the use of UniGen by market participants to serve their own financial interests will support California ISO's efforts to maintain grid reliability with fewer costs, even as the amount of variable energy resource generation continues to grow. UniGen-enabled resources assist California ISO with these efforts by (1) reshaping the Duck Curve to make it more manageable; (2) enhancing the frequency response characteristics of the grid; and possibly providing a solution to the impact of distributed energy resources on the grid.

Using UniGen considerably reshapes the Duck Curve by flattening the steep afternoon ramps that follow an oversupply condition. The difficult-to-manage Duck Curve (Figure ES-1) becomes the manageable Dog Curve (Figure ES-2).

Figure ES-1: The Dog Curve



Source: Onset, Inc.

Without UniGen, system frequency disturbances caused by unexpected swings in power generated by variable energy resources are often not in compliance with National Electric Reliability Council standards. However, with a moderate number of UniGen hybrid plants, it is possible to constantly regulate system frequency within +/- 0.05 Hertz as required by the National Electric Reliability Council. This is because UniGen reduces schedule deviations and complements automatic generation control and other routine frequency response measures. Moreover, UniGen provides a measure of primary frequency response, which is needed for nonroutine changes in system frequency. (The decrease in primary frequency response has become a new Federal Energy Regulatory Commission concern). The primary frequency response provided by UniGen is the result of performing its core function, which is the canceling out of deviations in variable energy resource generation from those scheduled. This primary frequency response is always present, does not need to be procured or dispatched, and does not require revenue enhancements from the California ISO market.

Included in the research was a quick evaluation to see if UniGen could help manage the impact of distributed energy resources on the transmission network. In Chapter 4, the authors discuss a UniGen-enabled strategy to schedule the distribution net load in the day-ahead market, firm that schedule between the hours with an adequately sized battery storage system, and then procure generation in the day-ahead market or from a dedicated power plant at the start of a new hour. A predictable, hourly load schedule provides transparency and predictability to California ISO, which ensures a feasible strategy for maintaining regular power flows between the transmission system and the various distribution networks.

Knowledge and Technology Transfer

Benefits to California

As can be seen from the discussion above, there are several potential benefits to California if the UniGen Smart System is used with existing generation and storage resources.

- UniGen enables variable energy resources to generate more energy (by avoiding curtailment), which improves the financial viability of these resources and decreases carbon emissions. This is a policy and cost benefit not only for variable energy resource owners, but also for ratepayers because the cost of renewable energy is declining.
- UniGen reduces the cost of maintaining the day-ahead schedule typically by $25 million per year per 100 MW of variable energy resource capacity.
- Scheduling variable energy resources in the day-ahead market reduces uncertainty and therefore the number of power plants that California ISO procures to cover that uncertainty. This is a cost benefit for ratepayers estimated to be worth up to $36 million per year (based on information presented by California ISO at the Market Performance and Planning Forum on July 21, 2016).

- By flattening the Duck Curve, potentially less on-line gas-fired plants are required to respond to the ramps in demand. This will reduce gas consumption and greenhouse gas emissions by an estimated 10 percent.
- By enhancing the frequency management ability of the California ISO grid, the potential cost of enforcements by the National Electric Reliability Council for violations is avoided.

The UniGen *Smart System* is a new and different tool for integrating large amounts of new variable energy resources envisioned by the 50 percent Renewable Portfolio Standard. It is perhaps compelling that participants in the California ISO market, including owners of variable energy resources, storage systems, power plants, and demand aggregators would have a financial incentive to voluntarily adopt the UniGen approach without requiring any changes in the market.

CHAPTER 1: Renewable Energy Has Transformed the Grid

Today's electricity networks were designed with the presumption that load and generation were predictable and slow moving. Because of this presumption, control room operators had time to wait for the energy management system to identify the size of any change and the available resources required to respond to the change; and to manually dispatch the generation resources necessary to bring the system back into balance.

With the advent of variable energy resources (VERs), that is no longer the case. As larger amounts of VERs such as wind and solar photovoltaic energy are put into use, the underlying design basis of the transmission grid is increasingly invalidated. The result will be either increasing threats to maintaining acceptable electricity reliability and affordable rates, or limits on the amounts of renewable electricity generation that can be used. Either outcome is a barrier to meeting California's greenhouse gas (GHG) reduction goals.

Variable Energy Resources Have Transformed the Basic Nature of the Grid

Scheduling of load and generation is critical to the reliable operation of electric grids because it ensures that there is adequate transmission and energy available to balance the two. Scheduling has worked well in the past because the output of conventional generation resources had the same characteristics as load. Except on very rare occasions, generation and load were highly predictable and changed relatively slowly with time. Most of the potential causes of those rare events (for example, the sudden loss of generation from a nuclear plant) were well known, allowing compensatory actions to be developed and held ready to be implemented if necessary.

Energy production from wind and solar photovoltaic is notoriously prone to unpredictable swings. Using publicly available data, Onset has calculated the wind forecast errors for the California Independent System Operator (California ISO) system for most of 2014. The results are shown in Figure 1 and clearly indicate the difficulty of maintaining a schedule for wind resources. It is worth noting that the largest error, which is over 1,800 megawatts (MW) less than forecast, is equivalent in size to a major contingency event (for example, the loss of Diablo Canyon or a major combined cycle plant) that represents a grave threat to grid reliability. Unlike those events, however, the loss of generation occurs in multiple locations, making preplanning contingency actions impractical.

The prevailing response to this variability is to enhance the ability of balancing authorities to reactively mitigate these forecast deviations by increasing the pool of “flexible” gas-fired generation, either by building out capacity or by enlarging energy imbalance markets. While there is merit in this approach, it raises a few questions:

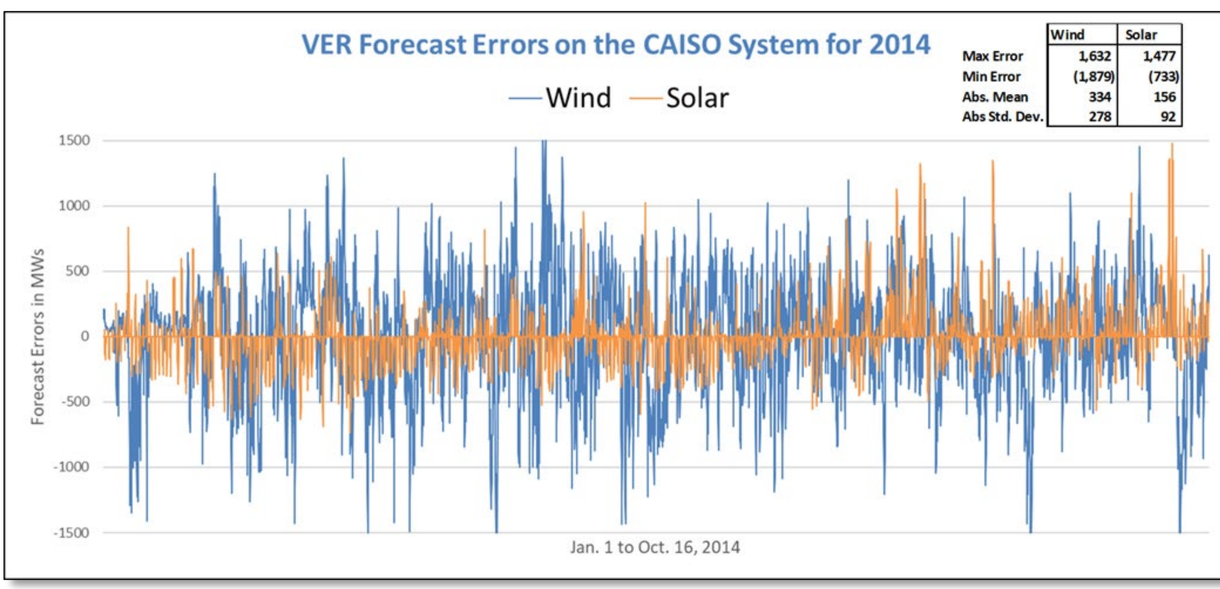
- Does it mean that the industry needs to abandon the schedule as the primary tool for balancing load and demand and ensuring grid reliability?
- Even with more generation at its disposal, will balancing authorities be able to meet National Electric Reliability Council (NERC) compliance requirements by reactively managing schedule (forecast) errors with centralized dispatch, especially as the level of renewable generation increases?
- Must we accept the cost of this approach with its heavy reliance on the energy imbalance markets and capacity contracts?

Managing Variability and Unpredictability is the Challenge

Propelled by public policies such as the Renewable Portfolio Standard (RPS), technology improvements, and reduced costs, generation by VERs is expected to grow at a pace exceeding 6,000 gigawatt-hours (GW) per year. By 2030, generation from these sources will be triple what it is today. Most of this growth will come from solar photovoltaic resources, which are prone to rapid changes in power generation.

The variability of these generation resources is best demonstrated by examining forecast errors. Using data sets[1] for actual wind and solar resources, our research found that there is rarely a time when the forecast was not in error, as shown in Figure 1.

Figure 1: Actual Generation Compared to the Day-ahead Forecasted Generation

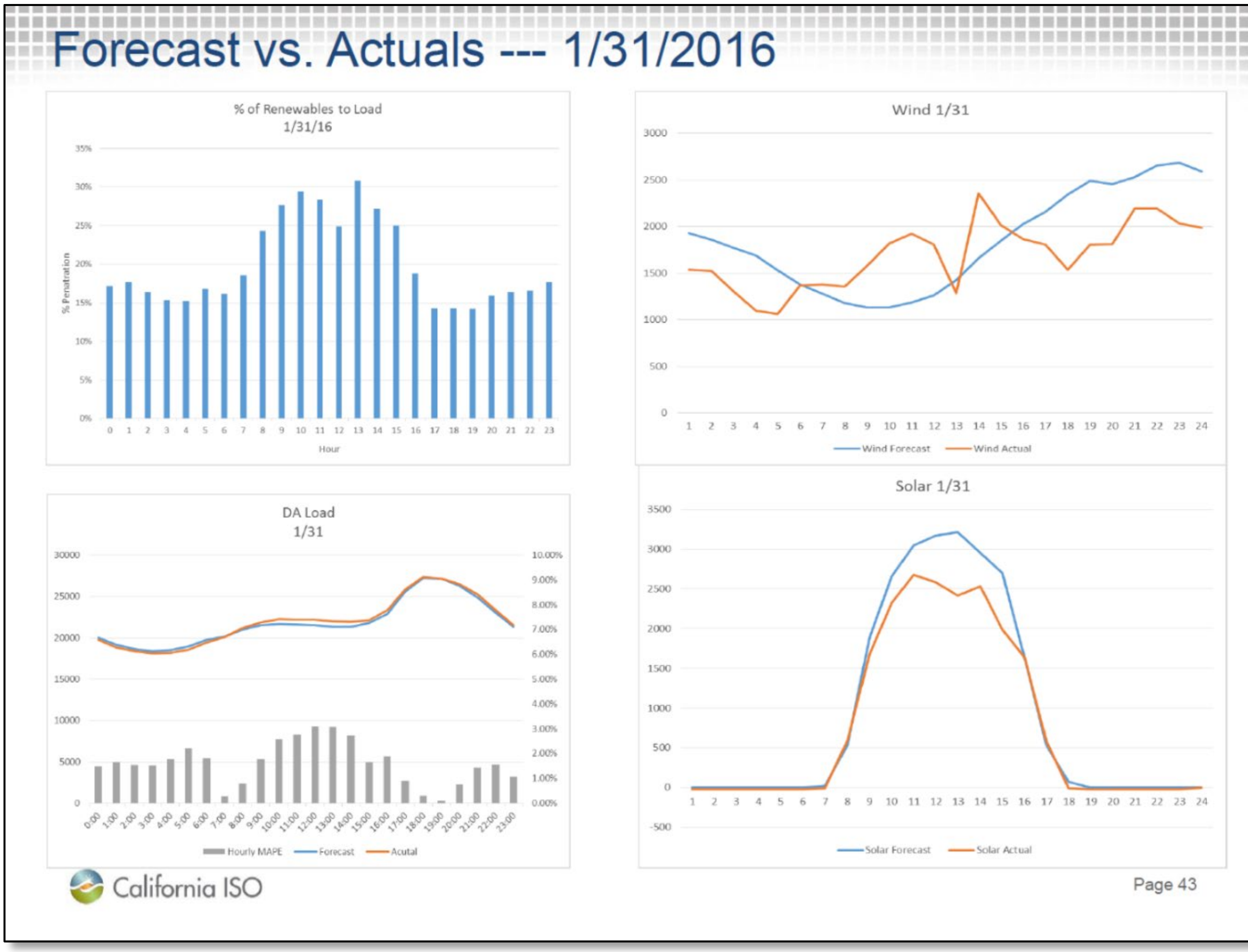


Source: Onset, Inc.

[1] The data sets are for actual projects in California. The day-ahead forecasts are hourly and the actual generation is for every five minutes. The data cover the time span from July 1, 2015 to June 30, 2016.

Sizable deviations from forecasts occur frequently. This condition was just as pronounced in 2016, as illustrated by Figure 2.

Figure 2: Forecast Errors for Demand and Variable Energy Resource Generation



Source: California ISO Market Performance and Planning Forum, July 2016.

Early in its growth period, variable generation was small in comparison to all the generation on the California ISO system and its struggle to predictably deliver the expected generation was readily managed with existing resources and operating practices. But eventually, and certainly by 2030, when VER levels will be about 50 percent of all generation in California ISO, the unpredictability of VER generation will put severe strains on the current system. California ISO has indicated that it was not uncommon in 2016 for 800 MW to 1,000 MW of VERs to abruptly disappear, only to reappear 10 to 15 minutes later. This places a stressful burden on control room operators as they struggle to manage these perturbations to the grid.

What Are the Solutions?

The Day-ahead Scheduling Process

The most effective tool for ensuring grid reliability is the use of the day-ahead schedule. The day-ahead schedule is information used as input to California ISO's day-ahead market[2], the results of which become the grid's operational plan for the next day. The day-ahead schedule is an hour-by-hour schedule (encompassing one day) of the generation that a resource owner intends to sell into the California ISO market and then deliver using the transmission network. As the name implies, the day-ahead schedule is submitted to California ISO the day before the generation will actually be produced and delivered. This information is then used by California ISO to ensure that when all of these supply schedules, as well as the schedules for demand are considered, demand and generation will balance without congestion, instability, or other problems occurring.

Reliability would never be an issue if all demand and generation schedules were met. Problems arise when they are not—meaning actual demand or generation deviates from schedule. (Minimizing schedule deviations with the UniGen Smart System is the central theme of this study.) As seen in Figure 2, demand schedule deviations are usually small (within 2 to 3 percent according to California ISO) although there are well-known exceptions such as when summer temperatures peak. Operators using peaking plants have routinely handled these situations. By contrast, the VER forecasts are much less predictable.

Before large amounts of VER generation were used, about the only time actual generation deviated from scheduled generation was when a power plant experienced an unexpected outage, or if a transmission line failure effectively isolated a plant from the grid. Now, however, schedule deviations associated with the normal variability of VERs are as important as an unexpected outage at one or more major power plants and happen with greater frequency.

Problems That Prevent VERs From Using the Day-Ahead Scheduling Process

The day-ahead schedule for generation is a financially binding contract. When the schedule is not met, the missing generation (a schedule deviation) is replaced by the California ISO market. The generator, as the party responsible for meeting the schedule, is then charged for that missing electricity at whatever price was in effect at

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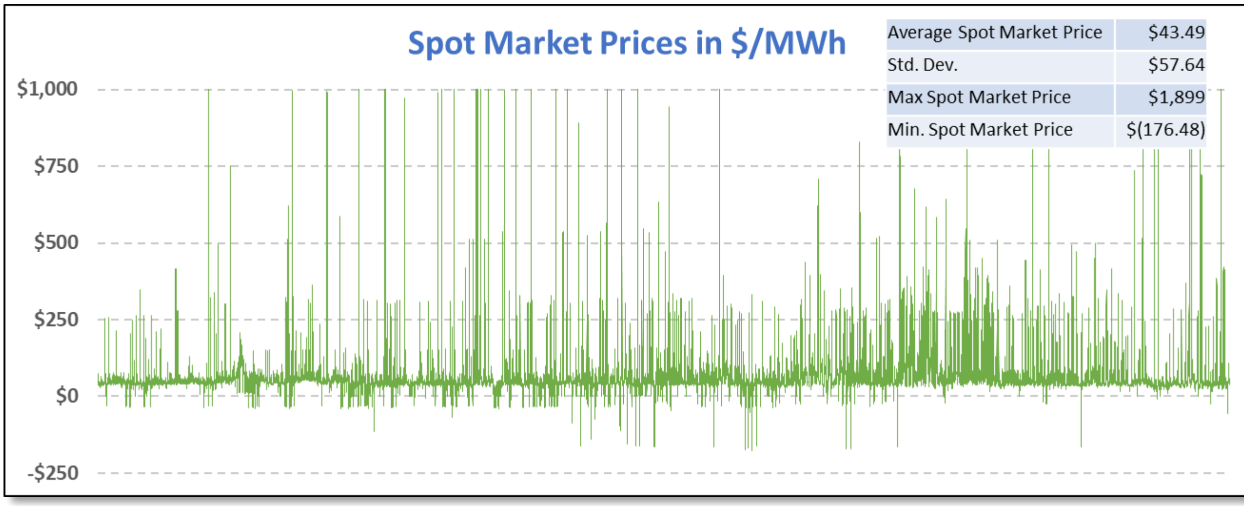
[2] "The day-ahead market is made up of three market processes that run sequentially. First, the ISO runs a market power mitigation test. Bids that fail the test are revised to predetermined limits. Then the integrated forward market establishes the generation needed to meet forecast demand. And last, the residual unit commitment process designates additional power plants that will be needed for the next day and must be ready to generate electricity. Market prices set are based on bids. A major component of the market is the full network model, which analyzes the active transmission and generation resources to find the least cost energy to serve demand. The model produces prices that show the cost of producing and delivering energy from individual nodes, or locations on the grid where transmission lines and generation interconnect." Source: California ISO website.

the time in the real-time (spot) market.[3] Because spot market prices are volatile and often reach or exceed $1,000/megawatt-hour (MWh) as shown in Figure 3, the financial consequence of not meeting the schedule could exceed the entire daily revenue from the electricity being sold. For this reason, there has been a move away from using the day-ahead schedule as a reliability tool for the integration of large amounts of renewable generation. Chapter 2 of this report discusses in more detail these challenges and recent developments regarding the use of the day-ahead schedule by VERs.

Figure 3: Spot Market Prices—California ISO, January–October 2014



Source: California ISO Market Performance and Planning Forum, July 2016.

Solutions That Rely on Increasing the Extent of Centralized Control

There are other worthwhile approaches to replacing the missing generation; that is, compensating for forecast errors and schedule deviations. Many of these involve enlarging the geographical area and the number of generation resources under centralized control. For example, the prevailing response in the industry to the increase in variability is to enhance the ability of balancing authorities like California ISO to *reactively* mitigate these schedule deviations by increasing the pool of "flexible" gas-fired generation, either by building new power plants or by enlarging energy imbalance markets. The measure of success for these solutions, of course, is how they improve compliance with NERC standards and their long-term cost. In terms of these measures, the solutions certainly do differ.

Nevertheless, while there is merit to all the various approaches, questions raised include:

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[3] The energy purchased in the California ISO market is referred to as imbalance energy and the costs are referred to as imbalance energy costs.

- Do the variability and unpredictability of VERs mean the industry should abandon the practice of using the day-ahead schedule,[4] which has been the primary tool for balancing demand and generation, thereby ensuring grid reliability?
- Even with more generation at its disposal, will balancing authorities be able to meet NERC compliance requirements by reactively managing schedule (forecast) errors with a centralized control system, especially as the size and frequency of those errors increase?
- Are ratepayers willing to accept the cost of a solution that entails giving costly capacity contracts to power plants in California that would otherwise shut down or install expensive energy storage instead?
- How dependable a source of power is the regional energy imbalance market over time since it includes a large number of resources owned and regulated in other states with different needs and objectives?

Current Markets: Do They Help or Hurt Public Policy?

VER owners can sell their output in either the day-ahead market or the real-time market. Each market has its good and bad points, as shown in Table 1—use of one or the other results in less renewable energy being generated or higher costs for ratepayers. It seems to be a case of pick your poison. Either outcome frustrates California's clean energy policies.

What the comparison in the table shows is that VER owners would benefit greatly by participating in the day-ahead market, except for the financial risk of deviating from the day-ahead schedule. A primary purpose of this project is to demonstrate that the use of the UniGen Smart System reduces that risk to the point where VERs can participate in the day-ahead market.

Table 1: Comparing Day- Ahead and Real-Time Markets

	Negative Prices	Prices in General	Potential for Schedule Deviations	Risk Avoidance
Day-ahead Market	No	Higher than real-time market	High because forecasts are less dependable.	Minimize schedule deviations by underscheduling.*

[4] The day-ahead schedule is the amount of generation that a resource owner expects to sell into the California ISO market. As the name implies, it is submitted to California ISO about one day before the generation will actually be produced and delivered. This information is then used by California ISO to ensure that when all of these schedules are taken into account, there will not be undue congestion, instability, or other problems on the grid. For VERs, a day-ahead schedule would be prepared based upon the forecasted generation. Therein lies a problem, since the actual generation by VERs deviates, sometimes considerably, from the forecast.

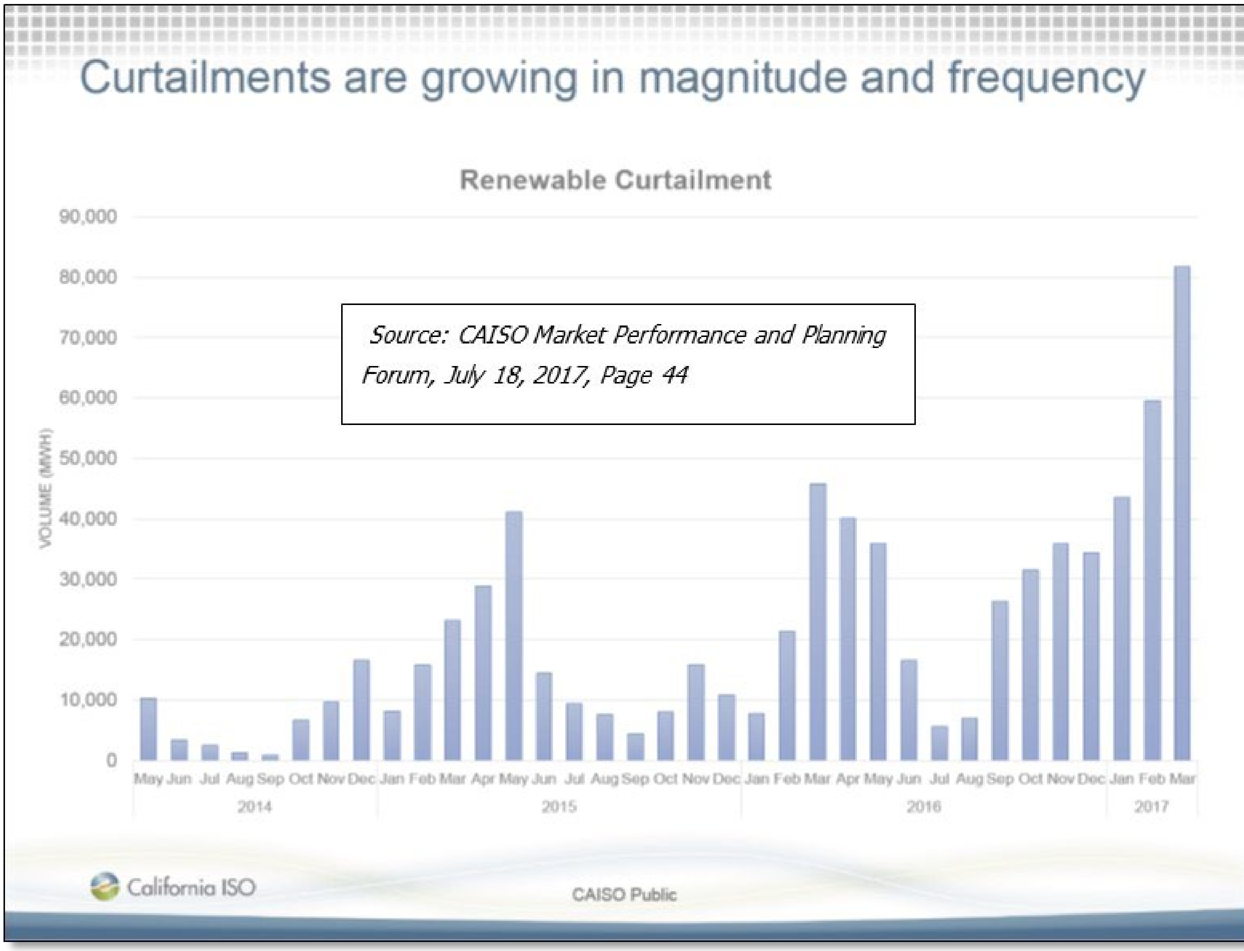
Real-Time Market	Yes, increasingly so.+	Lower than day-ahead market	Lower because forecasts and schedules are made just before actual generation.	Voluntarily curtail to avoid paying negative prices.#
Consequences for owners of VERs	Negative prices lead to voluntary curtailment for economic reasons	More revenue is available in the day-ahead market.	Schedule deviations result in the VER owner being charged for the missing generation, the cost of which is frequently very high.	Pick your poison.

*** California ISO Market Performance and Planning Forum, March 14, 2017, Pages 16 and 17.**
+ California ISO Market Performance and Planning Forum, March 14, 2017, Page 23.
 # Refer to Figure 4.

Source: Onset, Inc.

The results of the analysis show that there are in fact financial incentives to use the UniGen Smart System. Onset believes that the industry should not give up on using the day-ahead scheduling process as a cost-effective and market-based reliability tool and that it can be used even when the amount of VER generation becomes quite high. This belief is what led to development of the UniGen system. The purpose of this project is to confirm the technical and economic feasibility of the UniGen approach.

Figure 4: Curtailment of Renewable Energy Is Increasing



Source: Onset, Inc.

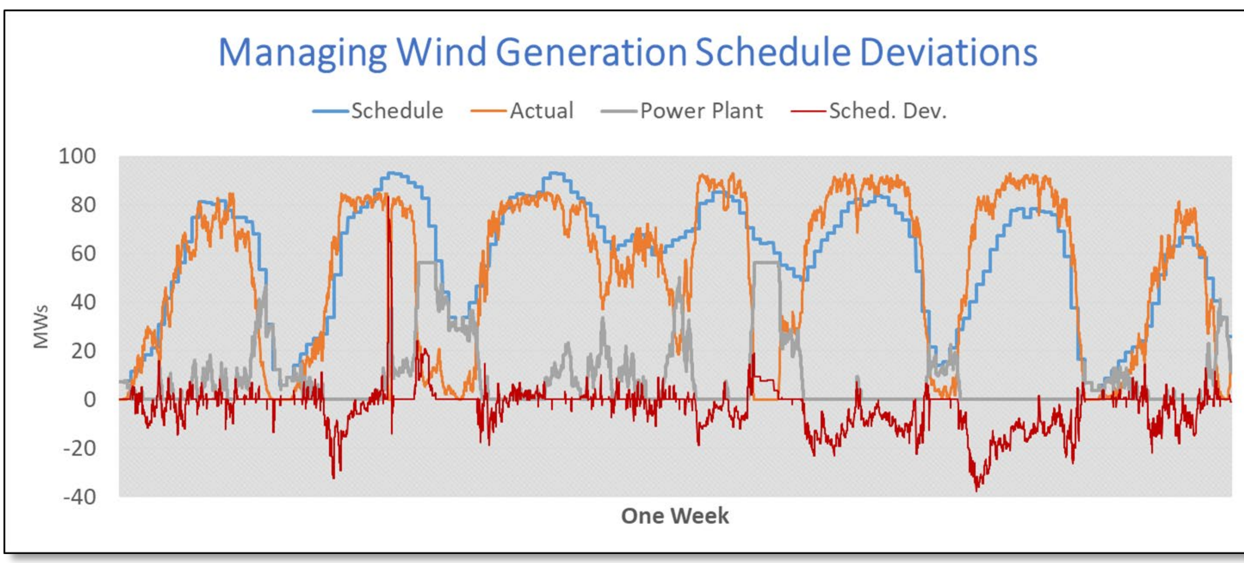
CHAPTER 2: Purpose and Description of the UniGen Smart System for Renewable Integration

Summary

Since much of the industry favors enlarging centralized control of resources, the approach that underlies UniGen moves in the other direction — toward distributed solutions that disaggregate the seemingly intractable problem of renewable integration into smaller, more manageable challenges.

UniGen is a new way of managing the variability and uncertainty of VERs. It does so by supervising the combined operations of a specific number of VERs and other dedicated resources to maintain a day-ahead schedule. The dedicated resources can include a natural gas plant, an energy storage system, or aggregated demand response. These resources are characterized by the fact that they can be "dispatched"; that is, they can change output (or decrease consumption) in real time to compensate for changes in the scheduled VER generation (Figure 5).

Figure 5: UniGen Manages Combined Outputs to Minimize Schedule Deviations



Source: Onset, Inc.

It can be seen why it is financially risky to schedule wind (or solar) generation in the day-ahead market. Actual wind generation is rarely the same as the scheduled amount (which is based upon forecasts.) However, UniGen detects when the actual generation does not conform to the schedule and uses dispatchable resources, in this case a dedicated power plant, to compensate for the deviations. The figure shows that almost all positive deviations are eliminated, and the compensation takes place automatically, in real time, fulfilling schedule commitments without California ISO operator intervention. The problem of variability is addressed at the project level and never makes its way into California ISO's system of centralized control. UniGen is a distributed solution that helps to reduce the swings in power that California ISO must manage.

This allows VER generation to be scheduled in the day-ahead market with a minimal risk of schedule deviations. It effectively levels the market playing field for VER generation so it can take advantage of the benefits of the day-ahead market in the same way a conventional plant does today.

UniGen is a Renewable Integration Tool

UniGen is a renewable integration tool and as such its primary purpose is to help maintain grid reliability. It does this by using an intelligent control system to reduce schedule deviations that would otherwise result when VER generation is higher or lower than forecast. As it stands today, just before each trading (operating) hour, California ISO uses its own forecast to predict how much VER generation it expects to be on the system. These forecasts have an appreciable degree of error and deviations require constant management by control operators. Moreover, it is becoming increasingly common that 1,000 MW or more of VER generation will disappear in an instant. Consequently, control room operators find themselves in a reactive mode trying to manage the problem manually and without adequate information—such as which VER was lost, why, and how long the problem will persist. A period of 10 to 30 minutes can elapse before other generating resources can be assembled to solve the problem, if it still exists. As a result, control room operators spend more time in reactive mode.

The idea behind UniGen is to partner a VER resource with a mix of firming resources such as a power plant and energy storage, each with a unique role to play.[5] A schedule is prepared and submitted in the day-ahead market and then maintained by this mix of resources. This is done automatically and, because computers and intelligent software are in control, it is done in real time. UniGen compensates for deviations from the schedule automatically and quickly and prevents such problems from making their way into the control room.

Furthermore, the day-ahead schedule, because it is automatically maintained, provides predictable information to California ISO that helps it manage resources better. This is more important than perhaps it sounds. Prior to the advent of an important renewables generator on the system, the day-ahead schedule was the primary tool for ensuring reliability and optimizing the use of existing generating resources. The day-ahead schedule provides credible information about what the grid will be like the following day. This information could be used, for example, to determine the proper amount of

[5] As seen in Chapter 2, energy storage provides enough short-term balancing energy that it can meet short-term schedule deviations without starting and stopping combustion turbines. Replacing one combustion turbine with an equivalent amount of storage reduces the number of starts by nearly 25 percent.

generation to have available for unanticipated perturbations, as the following excerpt from the footnoted California ISO document explains:

> *Currently, there is no requirement, and only weak financial incentives, for wind and solar resources to schedule or offer their power into the IFM (as discussed below, most wind and solar resources today bid or schedule only in the real-time market through the schedule submission process that occurs hourly in advance of the operating hour). There is currently some limited day-ahead scheduling of wind resources, but little compared to expected next-day output. As the ISO sees additional wind and solar resources generation at higher RPS levels, this lack of Day Ahead scheduling may lead to an unnecessary over-commitment of thermal generation (to minimize the risk of a supply shortfall) and a divergence of prices between the day-ahead and real-time market. Hence, a need exists to change in the incentives for renewable resources to schedule day-ahead or alternatively to encourage the participation in the forward market by financial entities that can anticipate next-day renewable output (i.e., convergence bidders).*[6] [Emphasis added]

The current practice of scheduling VERs in the hour-ahead time frame using inaccurate forecasts has increased the uncertainty with which California ISO must deal. It costs money to manage the risks of uncertainty. The day-ahead schedule for VERs created and maintained by UniGen provides more information, which allows California ISO to plan, instead of react, and thereby optimize the use of resources, reducing costs.

UniGen is a Tool That Can Change the Institutional Framework to Accommodate More Renewable Generation

It is a widely held belief that the nature of the operating grid and its supporting structures such as the market must be transformed to adapt to the growth of renewable energy. UniGen is a computer-assisted method that can enhance that transformation by:

- Disaggregating the integration problem into smaller segments that are solved by a mix of local resources.
- Changing the way VER generation is scheduled.
- Changing the financial incentives so the market participants help solve the integration problems.
- Shifting California ISO out of a reactive mode and into a planning one.
- Changing the way resources are dispatched.

[6] http://www.caiso.com/Documents/TechnicalAppendices_RenewableIntegrationStudies-OperationalRequirementsandGenerationFleetCapability.pdf

Description of the UniGen Smart System for Renewable Integration

UniGen is a new computer-assisted methodology for managing the variability and uncertainty of VERs. It does so by supervising the combined operations of VERs, a natural gas plant and an energy storage system. The set point for the UniGen control system is the scheduled delivery of power in megawatts from the wind or solar generator. The natural gas plant and/or storage system is used to keep the combined outputs at the set point.

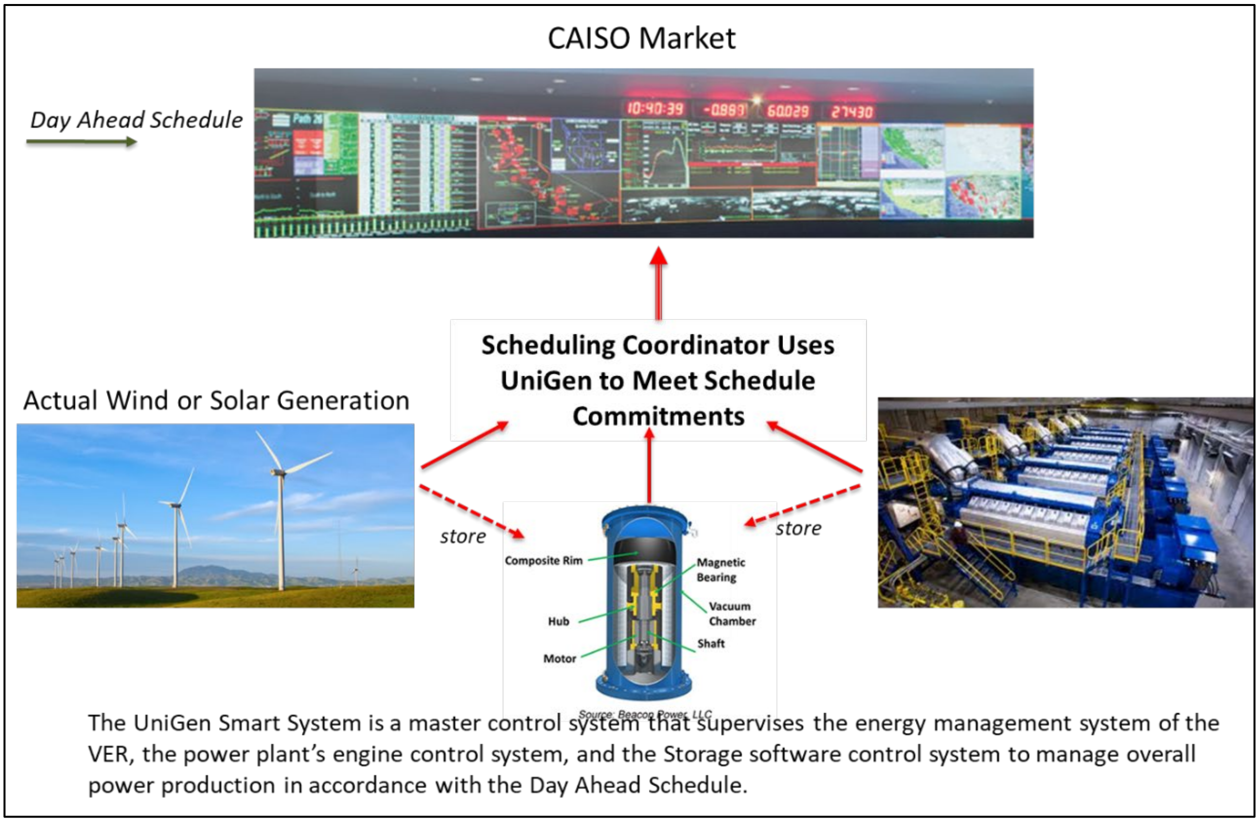
UniGen disaggregates the large, seeming intractable problem of integrating renewables into smaller, more manageable problems that can be resolved at the generator project level rather than the grid level.

Currently, grid managers rely on an energy management system to identify imbalances between supply and demand at the balancing authority area level, after which operators and the energy management system make adjustments and wait for the adjustment to take effect. All this can take 10 to 30 minutes, by which time it may be too late to act in response to the disruption caused by the volatility of wind and solar. Control engineers refer to this lengthy control process as a long-loop process. Without an ability to correct the swing in power within the 10-minute timeframe, which is becoming an increasingly difficult task, balancing authorities run the risk of violating basic NERC reliability standards.

UniGen is a short-loop control system that directly couples renewable resources and any firming resource, such as gas-fired power plants and/or energy storage resources, in near real time. This is accomplished by slaving the output of the firming resource to the output of the VERs using algorithms and software developed by Onset. UniGen operates in real time to greatly reduce deviations between the combined output and the committed schedule. In addition, unlike the centralized approach to offsetting schedule deviations, UniGen is a distributed solution. The problem is automatically and quickly analyzed and addressed at the generation project or unit level, instead of allowing the problem to make its way into the grid manager's energy management system.

Figure 6 illustrates how UniGen would schedule and then manage a mix of dedicated resources, allowing VERs to fully participate in the California ISO markets.

Figure 6: UniGen Supervises Power Generation to Maintain Schedules



Source: Onset, Inc.

Description of the UniGen Simulation Model

Onset has developed a simulation model[7] of UniGen for analyzing the dynamic interaction of the VER resources, gas plants, and energy storage systems, all working together, to maintain a predetermined schedule. The model calculates the cost of using UniGen's managed resources to maintain the schedule and compares it to the cost of purchasing balancing energy from the California ISO real-time market to compensate for VER forecast errors (the non-UniGen case.) Finally, the model calculates air emissions and CO2 releases from the power plant. The simulation uses one-minute time intervals.

Realistic operating characteristics of the various resources are used. For example, the power plant's operating characteristics that are important for analyzing renewable integration strategies include the startup time, ramp rate, allowable minimum load, and plant efficiency (heat rate). Battery storage characteristics of importance are storage capacity (MWh), discharge rate (MW/minute), round-trip efficiency, and the depth of discharge limit.

[7] The UniGen Smart System model was developed with the widely used Simulink simulation software licensed by MathWorks.

The resources used in the various analyses are:

- Simple cycle combustion turbine (GE's LMS1000).
- Internal combustion engine (Wartsila's 50V34SG).
- Combined cycle power plant (Siemens' SGT6-5000F).
- Battery energy storage (4 MW lithium-ion by NEA Electronics).

UniGen has the ability to calculate wind and solar generation using the basic equations that characterize these resources. It is important to note that the datasets the authors received from various entities that own wind and solar resources used in the simulation model contain forecast and actual generation, as opposed to wind speeds and solar irradiance.

Metrics Used to Determine the Effectiveness of UniGen

The function of UniGen is to make optimal use of VER and its dedicated firming resources to create and maintain a day-ahead schedule with as few deviations as possible.

For this reason, the authors have chosen reductions in schedule deviations as a metric for mitigating the impacts of large amounts of variable energy resource generation on the California ISO system. The first part of this report analyzes and discusses various strategies for reducing schedule deviations using UniGen.

It is not enough, however, to show that UniGen is an acceptable tool for reducing schedule deviations. It must result in cost savings—specifically for VER and other resource owners—so that these market participants have a financial incentive to modify current business practices and assist California ISO with the task of integrating larger and larger amounts of VER generation. The second part of this report describes and calculates such cost savings.

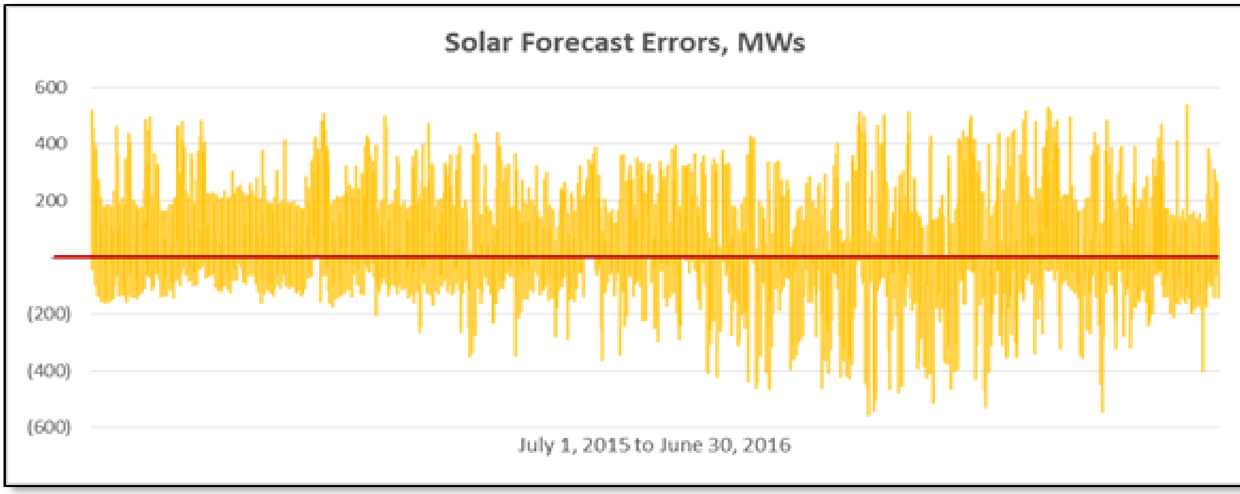
A final note is that while this study looks at a mix of resources that includes VER, power plants, and storage, the authors believe that other resources can be included in the mix—specifically, demand response.

Scheduling of Variable Energy Resources in the Day-ahead Market

Current practice in California ISO is for VER owners to submit a day-ahead forecast to California ISO. Unlike for other generators submitting day-ahead forecasts, the VER's forecast is not treated as a financially binding commitment. Instead, about an hour before each actual trading hour, California ISO's control room operators substitute their own VER generation forecasts for the day-ahead forecast and purchase balancing energy in the real-time market to account for the forecast errors. The cost of balancing energy is then spread among all users.

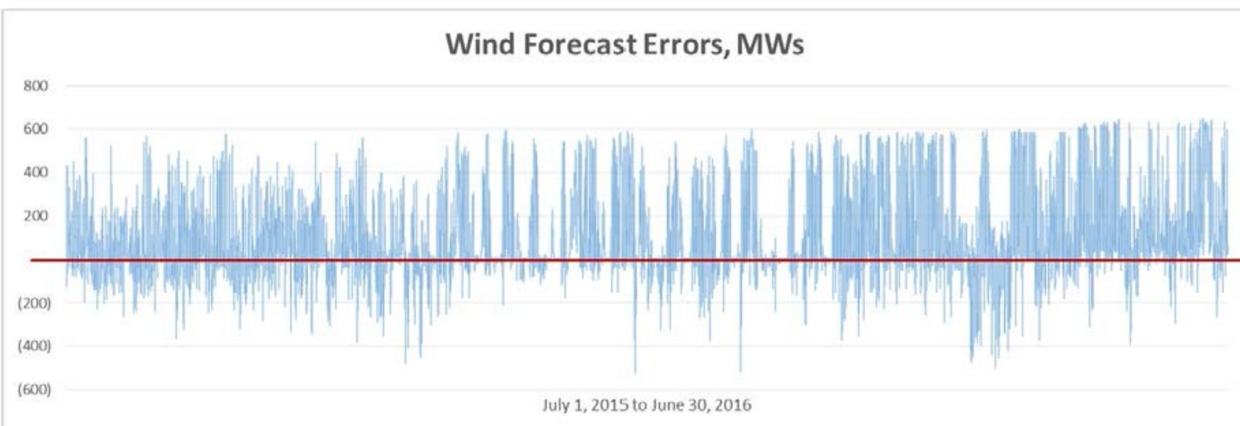
In the last two years, the authors have examined numerous sets of data and found them all to have large forecast inaccuracies. The data sets used in this study (which were provided by a cooperating load-serving entity) also exhibit the same inaccuracies and sometimes considerably so demonstrated in Figure 7 and Figure 8.

Figure 7: Solar Forecast Errors



Source: Onset, Inc.

Figure 8: Wind Forecast Errors

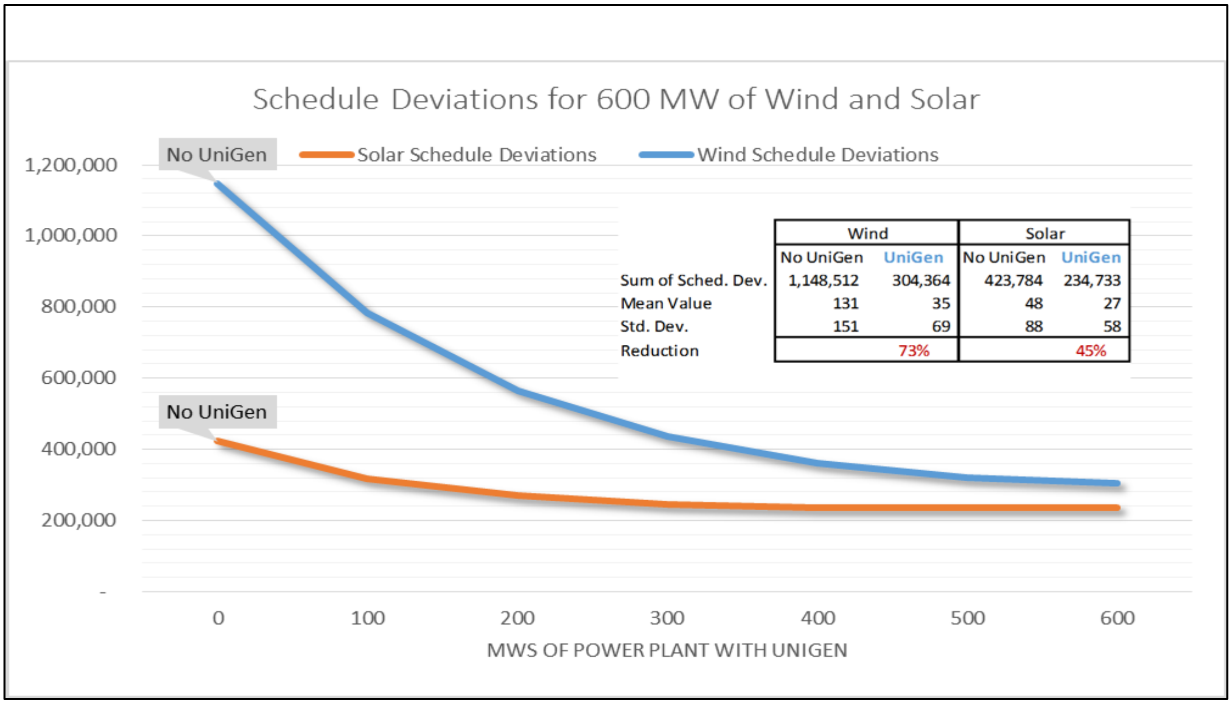


Source: Onset, Inc.

Schedule deviations form an important metric for determining the effectiveness and value of UniGen. Fewer schedule deviations represent fewer perturbations that make the grid difficult to operate reliably.

When VERs are scheduled *without* using UniGen, the schedule deviations are identical to the forecast errors shown in the previous figures. When UniGen is employed to firm the schedule — that is, to manage the combined outputs of VERs and gas plants and/or storage systems to maintain the schedule — schedule deviations are reduced by as much as 50 percent to 75 percent, as shown in Figure 9. Since UniGen operates in real time to reduce schedule deviations, it clearly helps the grid operate in a more stable manner.

Figure 9: UniGen Reduces Schedule Deviations



Source: Onset, Inc.

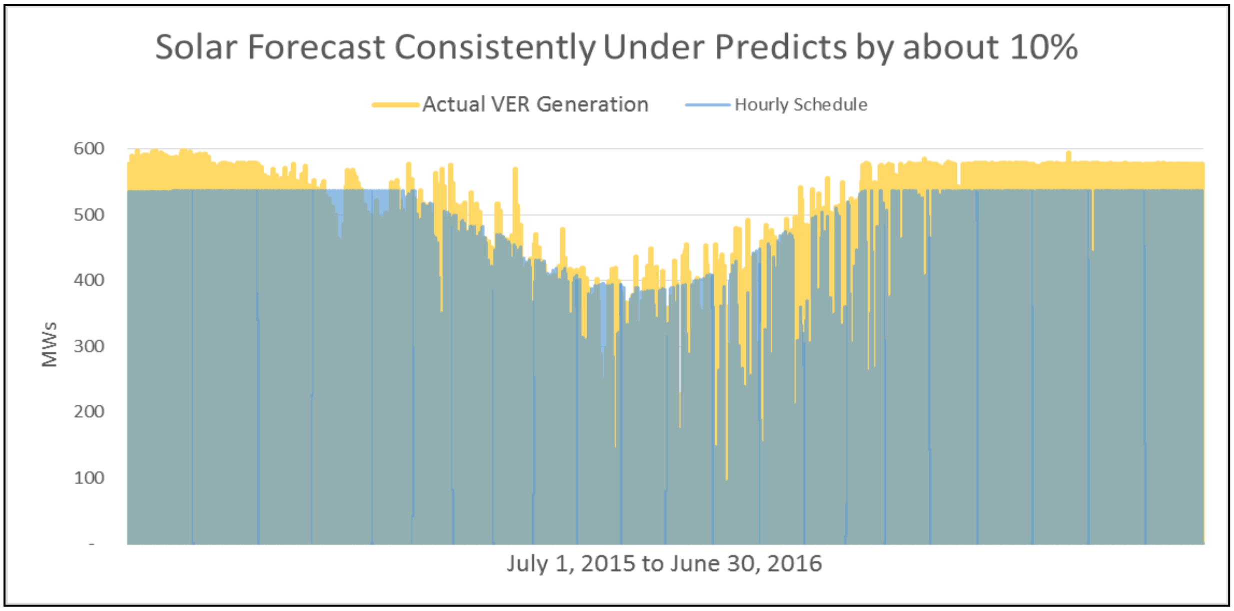
It is also important to point out that the total capacity of the power plants relative to the capacity of the VER is a variable, which can be changed on a case-by-case basis to obtain optimal results. For instance, it is clear that the marginal reduction in schedule deviations as a function of more power plants approaches zero in both cases; 300 MW for solar and 400 MW in the case of wind. There are not enough data to make a generalization about whether solar generation is easier to firm than wind. On the contrary, the authors would expect each VER to behave differently and that additional engineering studies would be needed to confirm this result.

It turns out that the curves below can be almost perfectly fit with a simple exponential function. This is also true for all the other curves that appear in this report—a surprising discovery—which means that these equations can be used in engineering tradeoffs to find the optimal amount of firming required to adequately reduce schedule deviations.

Customizing Schedules to Further Reduce Schedule Deviations

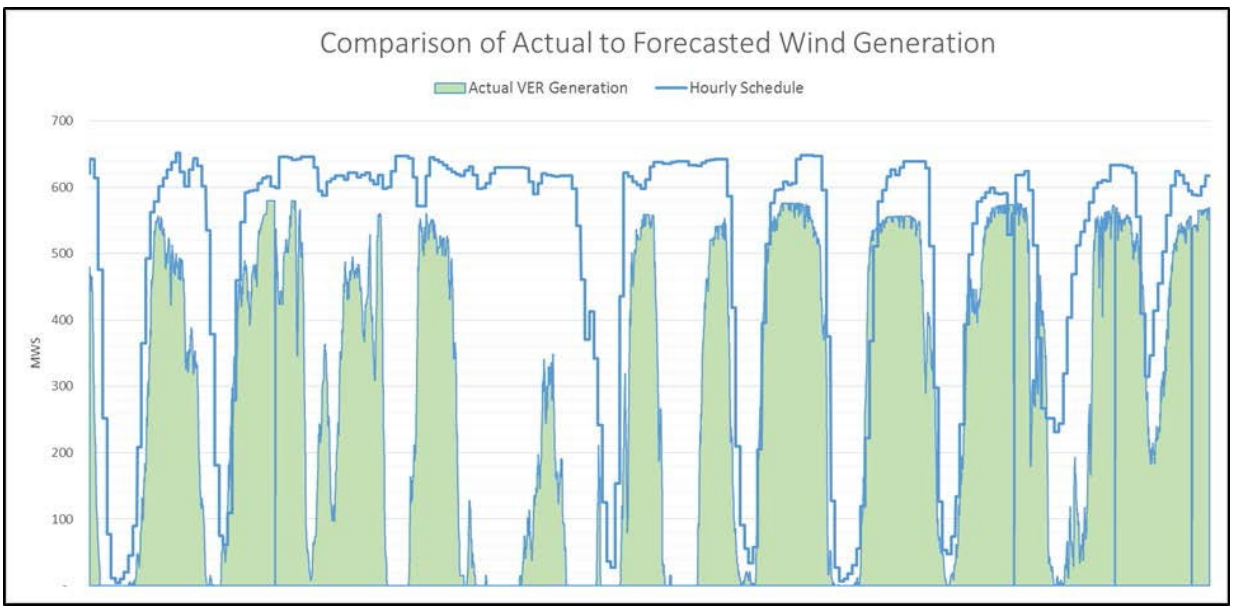
UniGen is not limited to firming a day-ahead schedule that is based solely on the VER forecast. That is only one possible scheduling strategy. Having command of a mix of generating resources that includes VERs, power plants, and energy storage, UniGen makes it possible to customize the day-ahead schedule to obtain optimal operating results. For example, it is evident from the data that day-ahead forecasts consistently underpredict VER generation, observed in Figure 10 and Figure 11.

Figure 10: Forecasts Appear to Deliberately Underpredict Generation



Source: Onset, Inc.

Figure 11: A Closer Look at Forecast Errors

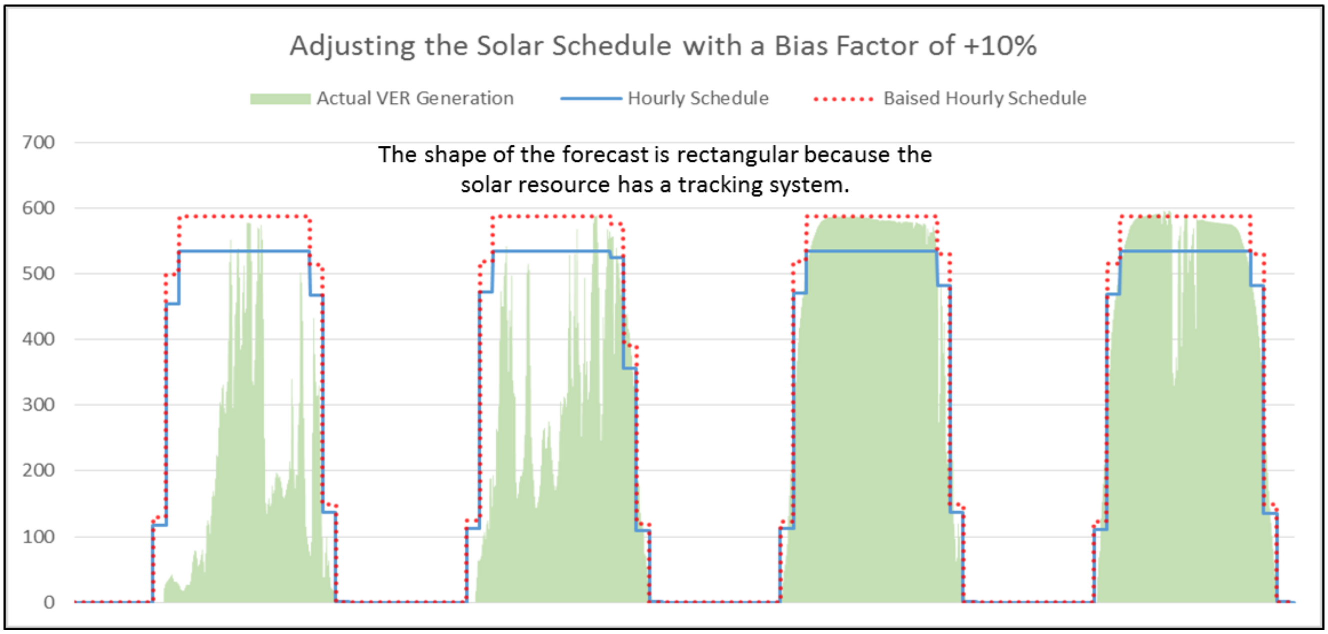


Source: Onset, Inc.

If VERs were required to schedule in the day-ahead market, it would, in fact, be wise to intentionally schedule less generation than predicted by the forecasts. The schedule, after all, is a contractual commitment each VER would make that results in a cost if not met. Currently, California ISO makes up for schedule deviations by purchasing balancing energy in the real-time market and passes that cost back to the scheduling entity representing the resource owner.

With UniGen, it is possible to choose from among a number of scheduling strategies and not be limited to using the VER forecast as the schedule. For example, one strategy is to adjust the forecasts used in this analysis by a biasing factor to offset the underpredictions. Although more VER generation has been contractually committed, any shortfalls would be made up by the firming resources (gas plant and/or storage). The results are found in Figure 12.

Figure 12: Creating a Schedule by Adjusting the Solar Forecast Upward



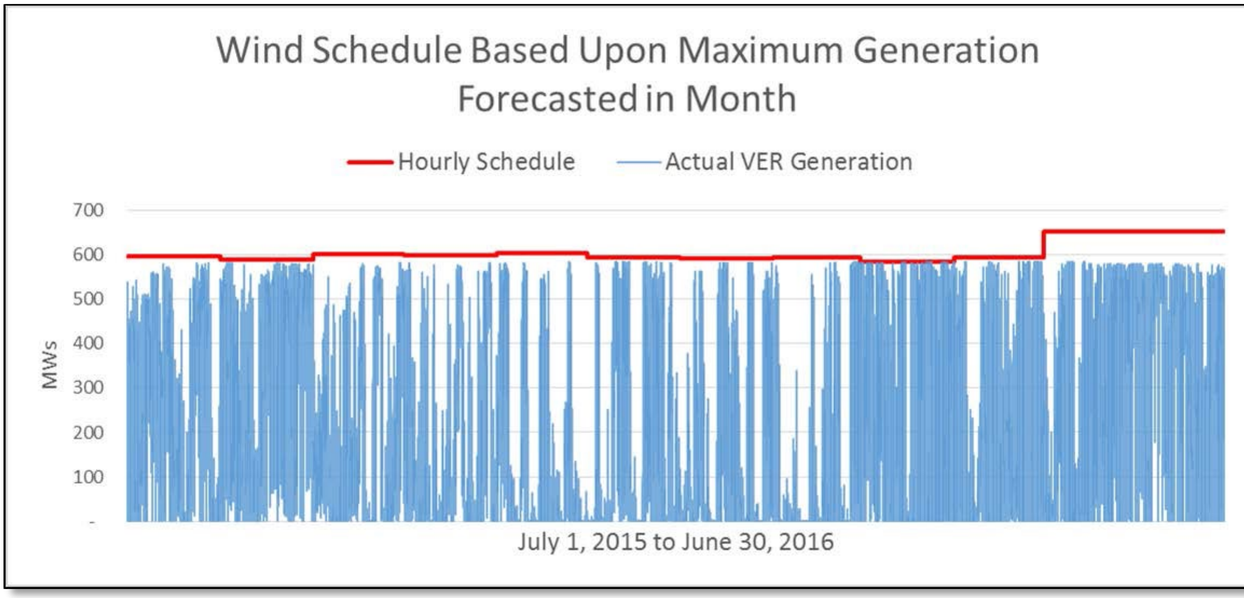
Source: Onset, Inc.

Another scheduling strategy that works well for wind in particular is to base the schedule upon the maximum amount of wind generation predicted in the upcoming month (or week or day.) This eliminates the possibility of having to curtail wind generation or selling in the real-time market for less than the power purchase agreement price.[8] This schedule of block deliveries based on the maximum forecast for the next month is depicted in Figure 13 and resembles closely the behavior of a baseload plant. The only difference would be, in the case of the hybrid baseload plant, to set the schedule to the rated capacity of the VER resource. If the VER resource had a capacity factor of 33 percent, for example, then the hybrid plant would be one-third

[8] Until recently, the prices given to wind and solar under long-term power purchase agreements were much higher than today. Legacy prices range from $80 to $100 per MWh. Real-time market prices are typically $30 to $40 per MWh, so there is an opportunity cost associated with generating VERs in excess of the schedule.

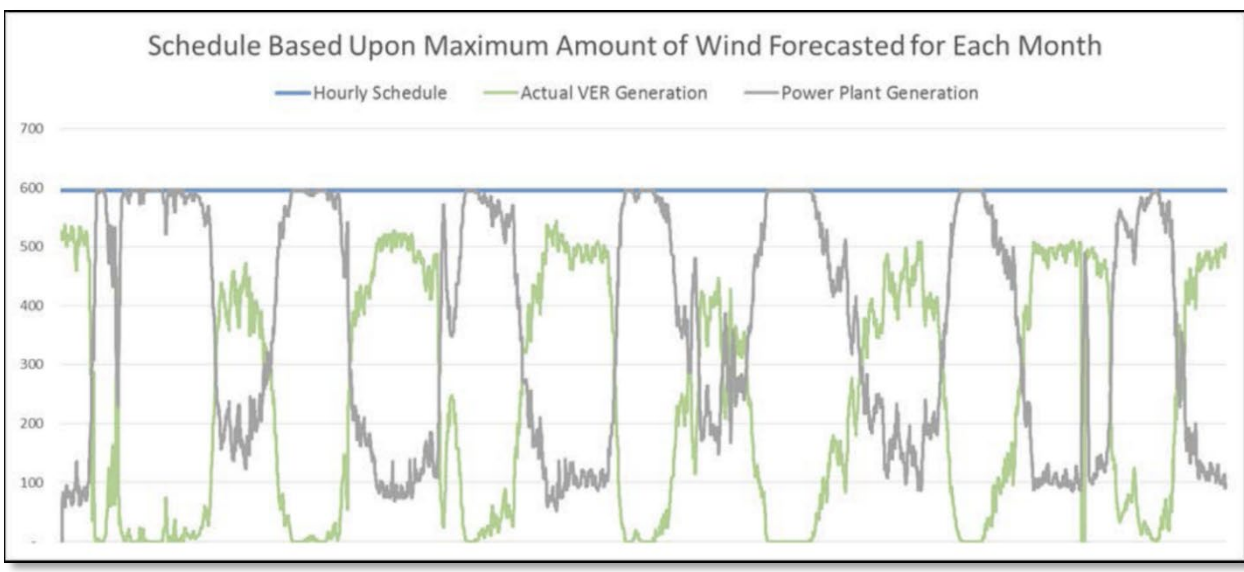
wind generation. The VER capacity becomes the setpoint for UniGen and Figure 14 illustrates how the output of a gas plant is changed up and down in a way that mirrors the output of the wind project.

Figure 13: Schedule that Ensures VERs Are Not Curtailed



Source: Onset, Inc.

Figure 14: Baseload Hybrid Plant



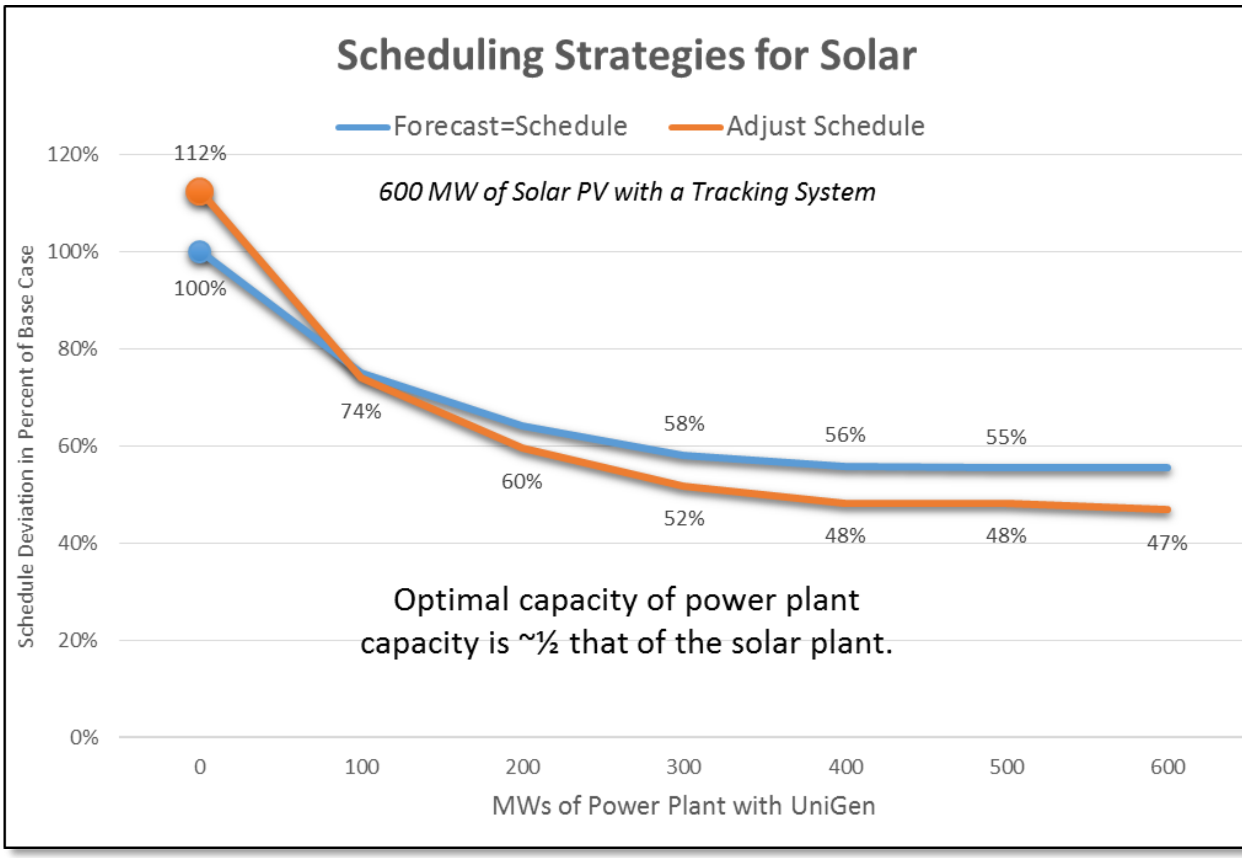
Source: Onset, Inc.

Results of Customizing Schedules to Reduce Schedule Deviations

Solar

In the case of the solar plant, schedule deviations can be further reduced by simply adjusting the forecast by a biasing factor (in this case, a constant multiplier of +1.1). Although a crude approach, it results in another 6 to 8 percent reduction compared to using the original forecast, as depicted below in Figure 15. This suggests that applying good analytics to design schedules can have a considerable effect on reducing schedule deviations, which reflect the variability and unpredictability of VERs. Thus, reductions in schedule deviations make a good metric for measuring how effective a renewable integration technology or strategy is.

Figure 15: Adjusting the Schedule with a Bias Factor Reduces Schedule Deviations



Source: Onset, Inc.

The analysis resulted in another finding, which is that the capacity of the firming resource (gas plant) is a variable that can be optimized. As seen below, there are minimal reductions in schedule deviations once 300 MW of firming capacity is used. The authors have seen these results in other work and conclude that the optimal ratio of power plant capacity to VER capacity is within the vicinity of 1:2. This seems to hold true for solar and wind alike.

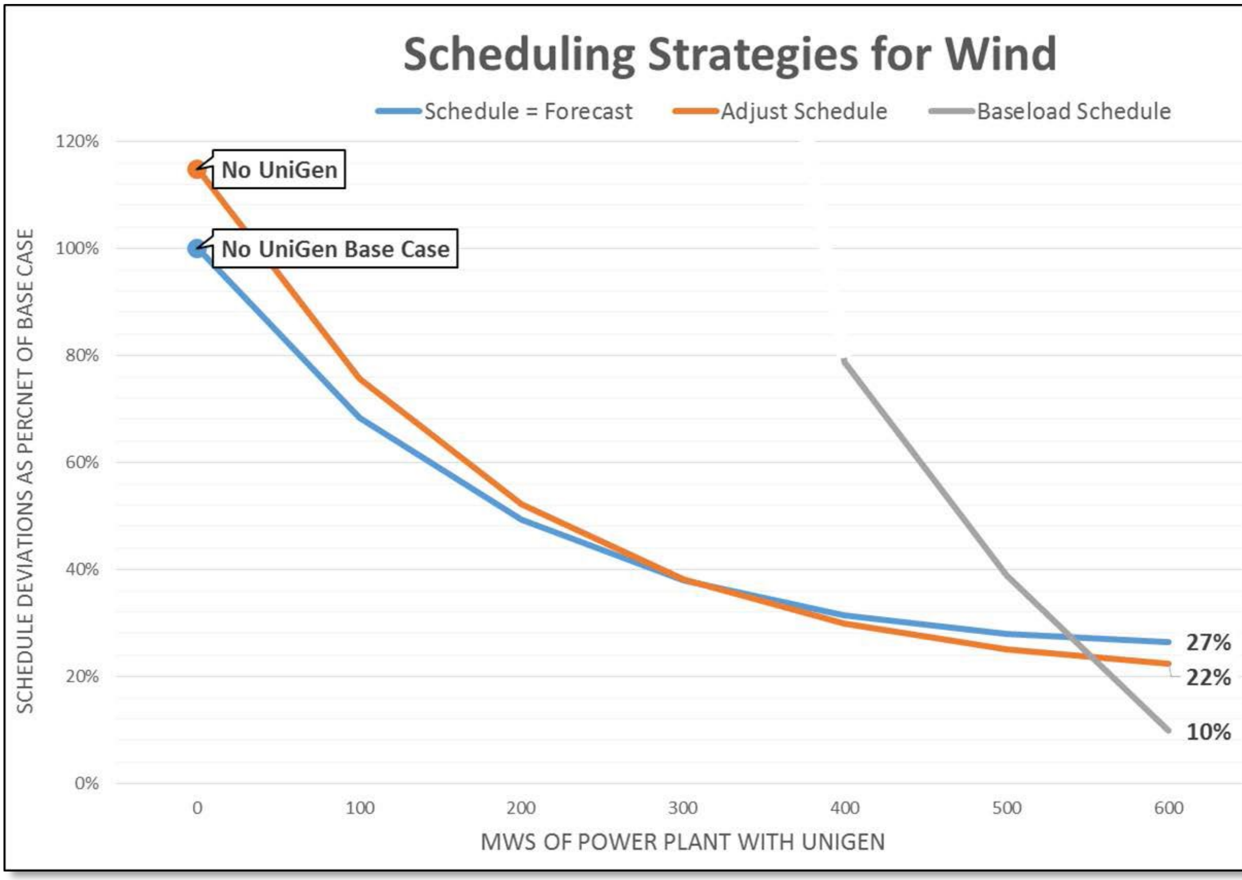
Wind

The results for wind are similar to that of solar. A general conclusion is that there are a number of scheduling strategies from which to choose to reduce schedule deviations as much as possible.

For the wind project, the authors examined an additional scheduling strategy based upon turning the maximum amount of wind generation forecasted into the hourly schedule for the entire month. This is equivalent to the schedule of a baseload plant. This was not done for the solar plant because the tracking system already produces a very flat schedule and output. (Note: the authors plan to update this report after receiving another set of solar data from California ISO.)

The intent of this strategy is to ensure that close to all VER generation is scheduled and delivered. This eliminates the possibility of negative schedule deviations, which result when there is more VER generation than forecasted/scheduled. Eliminating the possibility of negative schedule deviations increases the possibility of larger positive schedule deviations (overscheduling) but this is addressed by properly adjusting the capacity of the power plants. All this can be seen in Figure 16, where the schedule deviations for the baseload schedule are much higher than the two firming schedules used until the capacity of the power plant matches that of the wind project. When that happens, schedule deviations are reduced by 90 percent from the base case and the amount of wind generation delivered increases by about 10 percent.

Figure 16: Scheduling Strategies for Wind

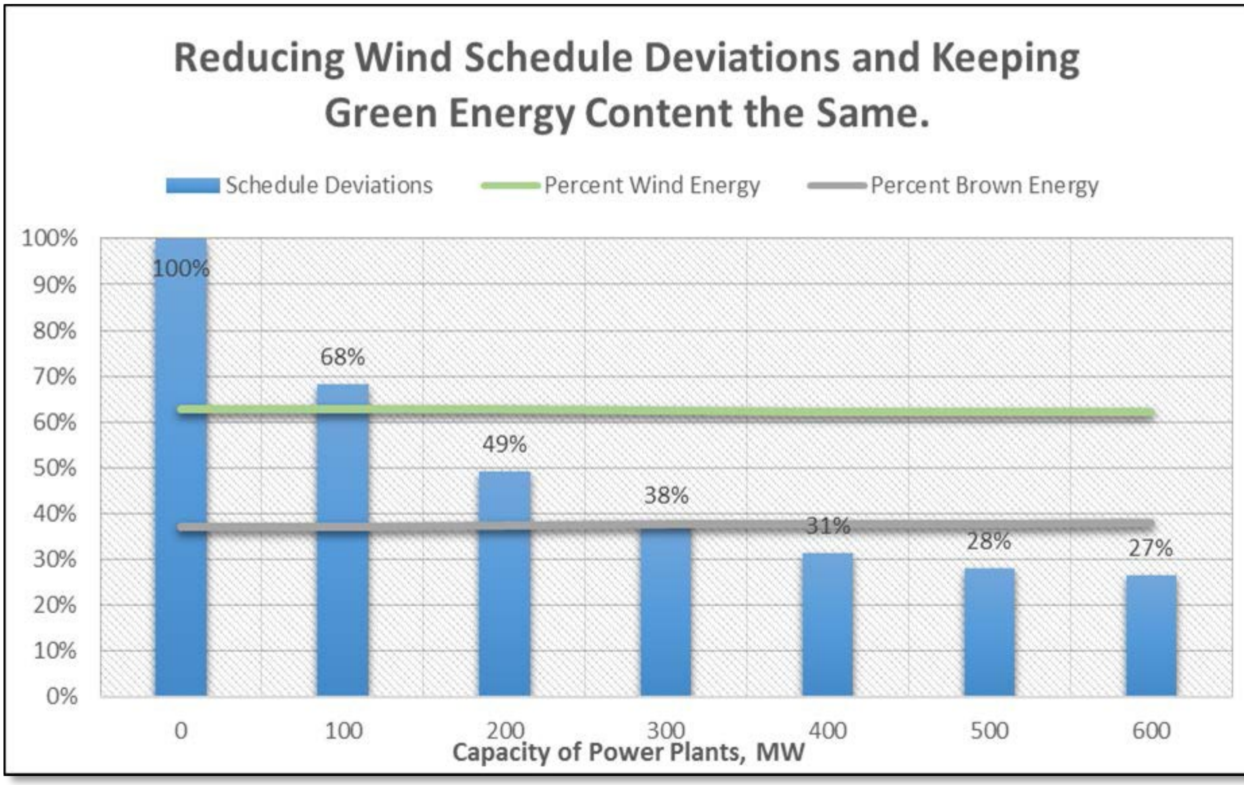


Source: Onset, Inc.

Repurposing Brown Energy to Reduce Schedule Deviations

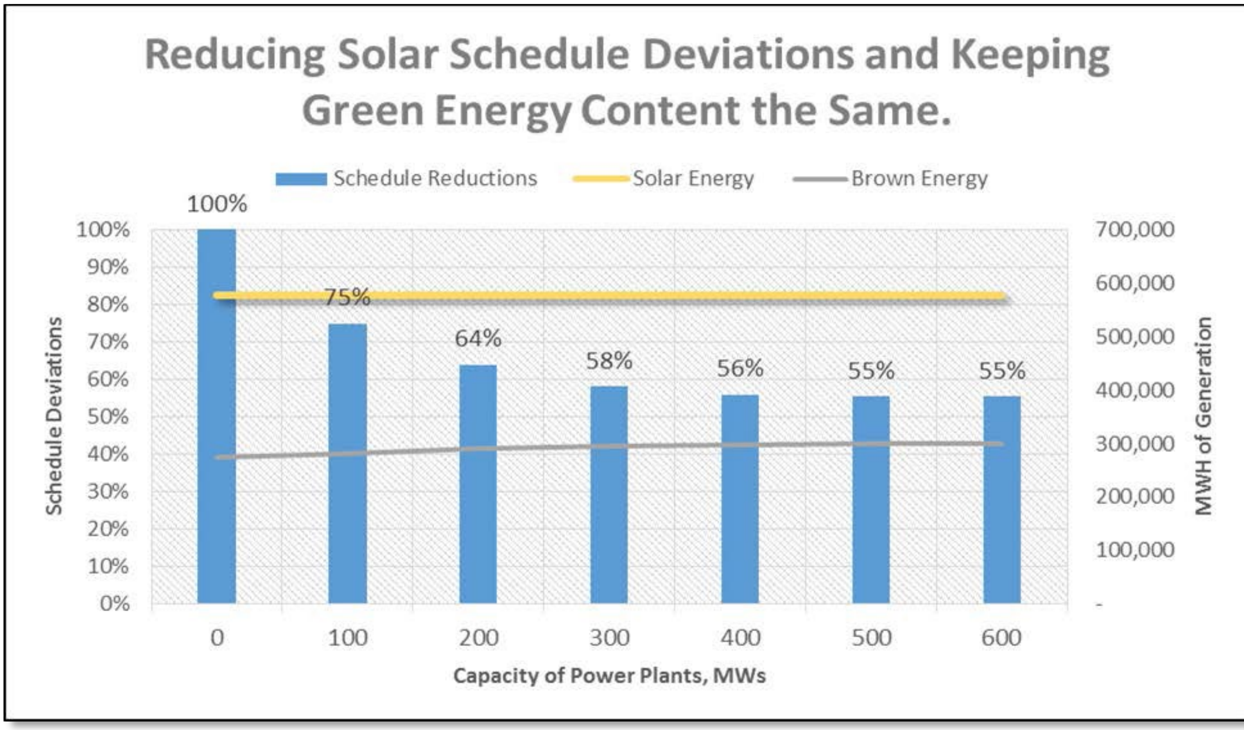
Conceptually, what has happened is that UniGen has used brown energy, which would have been generated anyway as balancing energy, to not only meet the served load but to reduce schedule deviations. Higher levels of renewable energy can be successfully integrated by using brown energy in a new way but without increasing the amount generated as shown in Figure 17 and Figure 18.

Figure 17: Repurposing Brown Energy to Support VERs (Wind)



Source: Onset, Inc.

Figure 18: Repurposing Brown Energy to Support VERs (Solar w/Tracking)



Source: Onset, Inc.

Financial Incentives for VER Owners to Use Day-ahead Schedules with UniGen

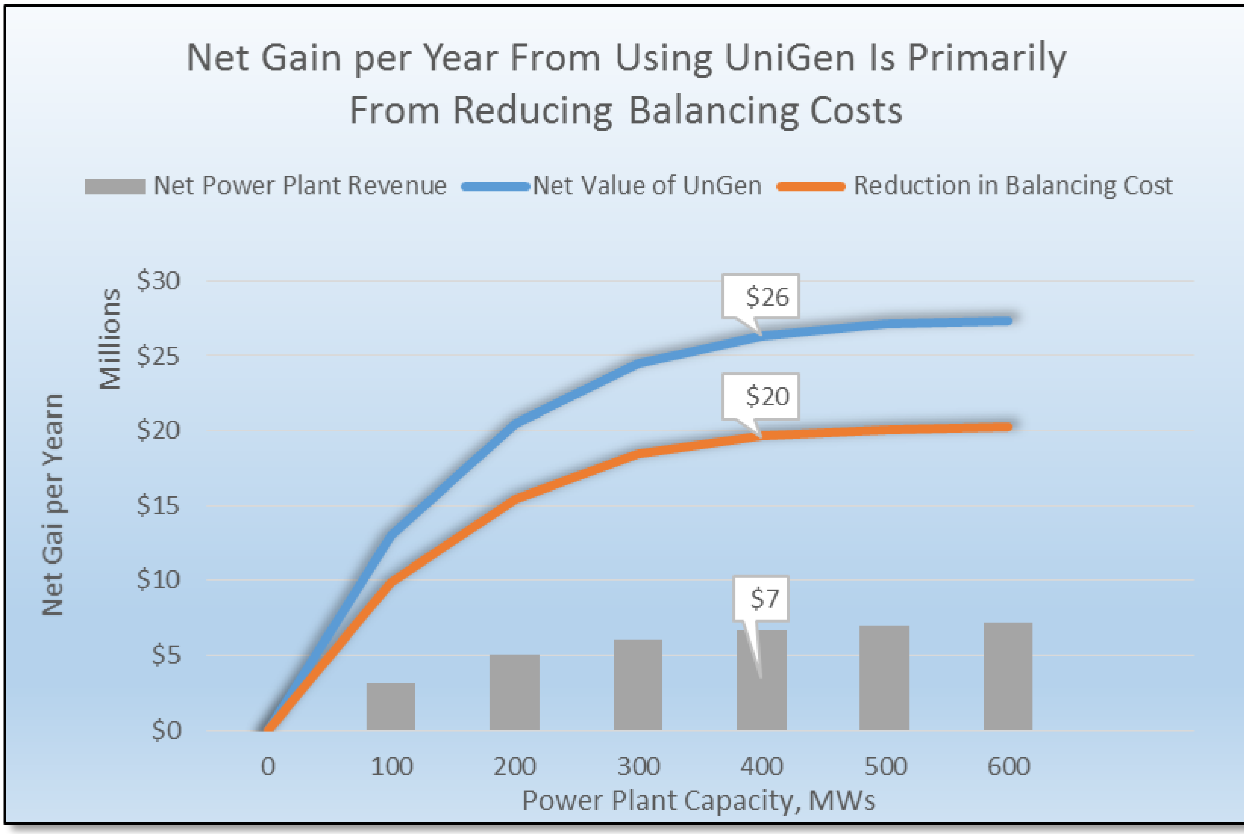
Framework for Calculating Costs

The economic benefits were calculated using locational marginal prices for the period of interest. These were download from the California ISO's OASIS website. Locational marginal prices are recorded on a five-minute basis and represent the cost of purchasing balancing energy in the real-time market. The cost of scheduling VERs without the benefit of UniGen is the product of the schedule deviation and the locational marginal price.

This cost is compared to the cost of operating the dedicated resources that are paired with a VER. In the case of a natural gas plant, the principal operating cost is for fuel. Natural gas prices are also available at the OASIS website and are recorded on an hourly basis. This economic framework is embedded into the UniGen simulation model, which calculates each revenue and cost component on a minute-by-minute basis.

The difference between the net revenue for scheduling in the day-ahead market without UniGen, compared to that when UniGen is used (Figure 19), is the net gain attributable to UniGen.

Figure 19: Net Gain for Wind Using the Generation Forecast as the Schedule

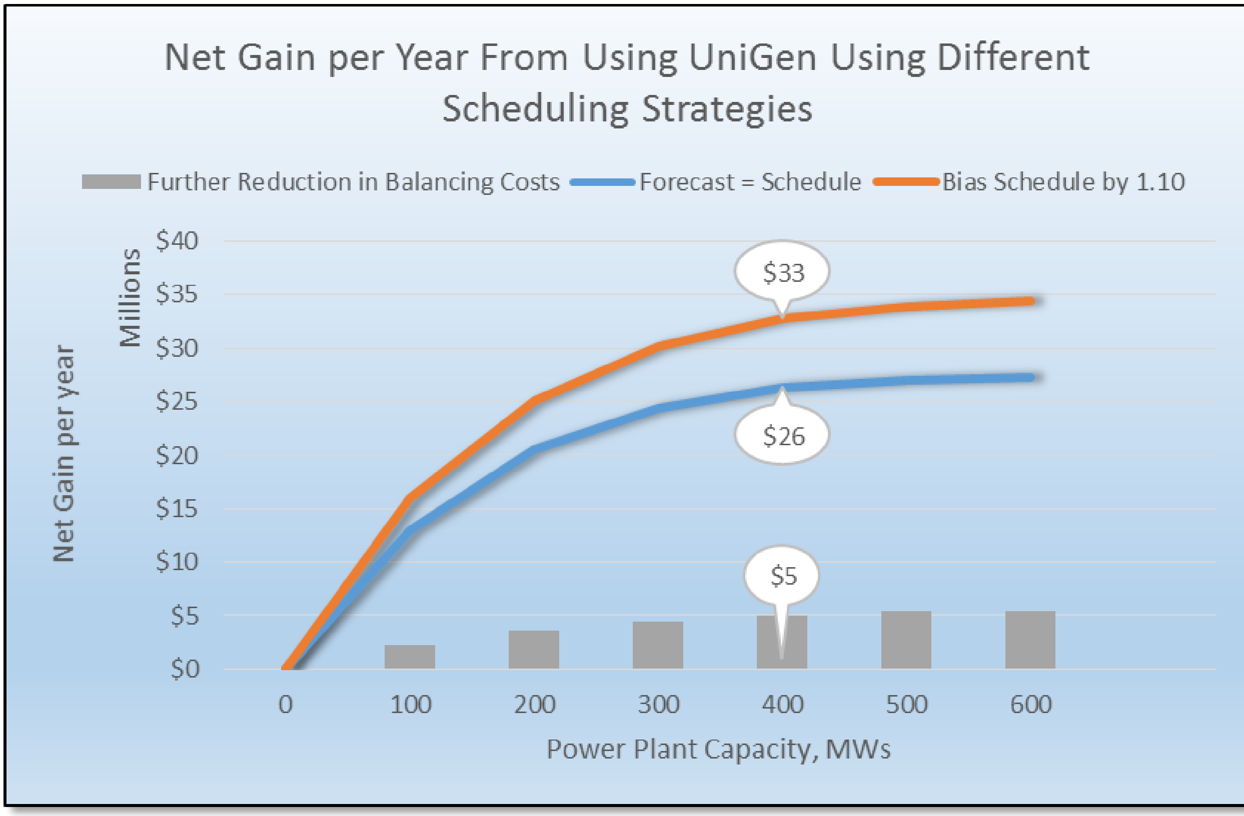


Source: Onset, Inc.

Economic Results

For the 600 MW wind resource used in this study, the net gain from UniGen depends on the capacity of the power plant and the scheduling strategy, as shown in the next three figures. These figures show the annual gain is primarily due to reductions in balancing energy costs purchased in the spot market. There is also a gain derived from selling the output of the power plant. Figure 20 shows how the net gain can be improved using a biased schedule.

Figure 20: Further Gains from Biasing the Schedule



Source: Onset, Inc.

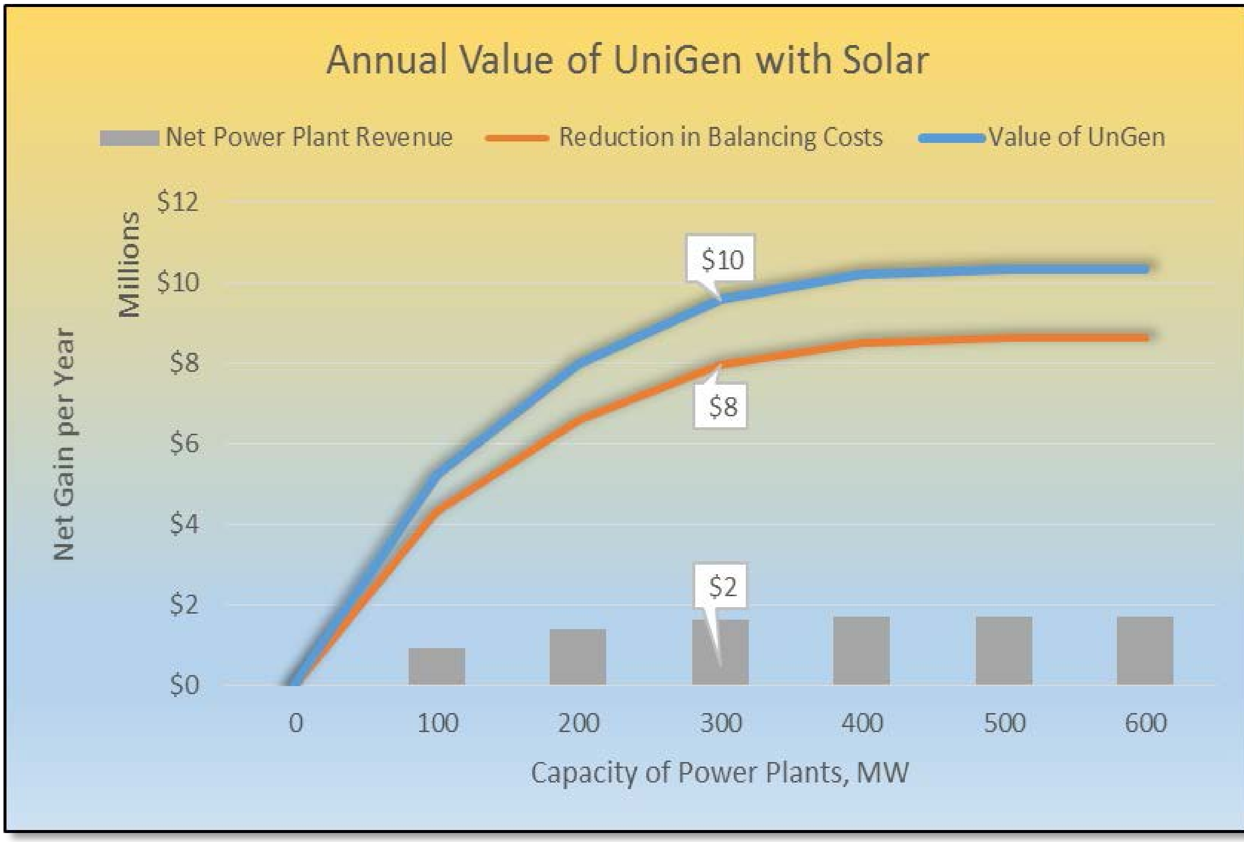
As was the case with schedule deviations, the net economic gain shows a predictable pattern. As the amount of firming capacity equals about 50 percent of that for the VER, marginal increases in economic value are minimal.

The results for the solar resource are very similar but the overall net gain is smaller. The resource used in this study has a tracking system, which makes the generation less variable. In fact, on a day with clear skies, the output of the solar plant is flat for most the day and deviates little from the forecast.

Days without clear skies are another matter and the deviations are sudden and fast moving. The challenge for any control system, UniGen included, is how to keep the system stable when solar generation suddenly reappears (for example, when moisture or dust in the air moves away.)

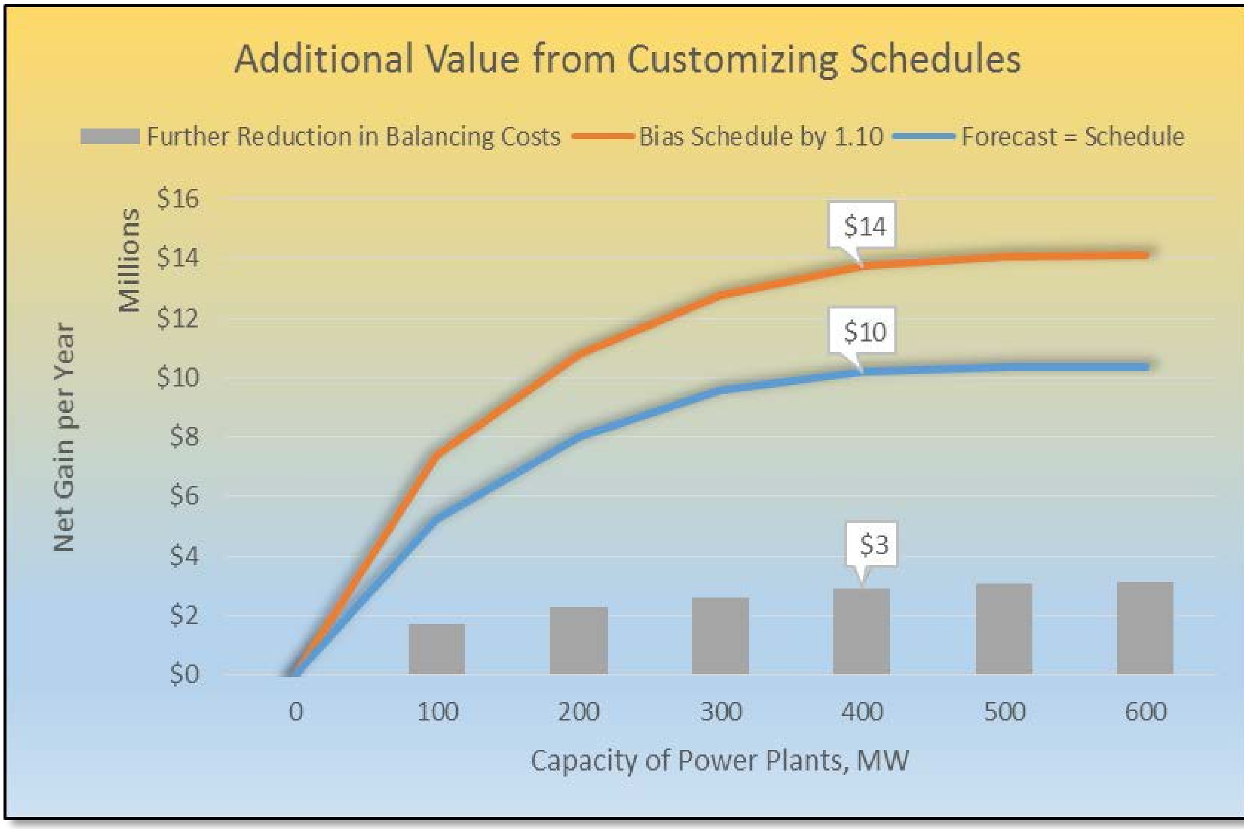
The authors analyzed a solar resource without a tracking system and compared the results to one that does use a tracking system. As expected, the amount of generation is higher (22 percent). It was surprising that the schedule deviations were comparable. This may be the case because, although the generation with a tracking system is constant for most hours, the ramps in the morning and evening are much bigger and more difficult to manage as shown in Figure 21, Figure 22, and Figure 23.

Figure 21: Value of UniGen with Tracking Solar



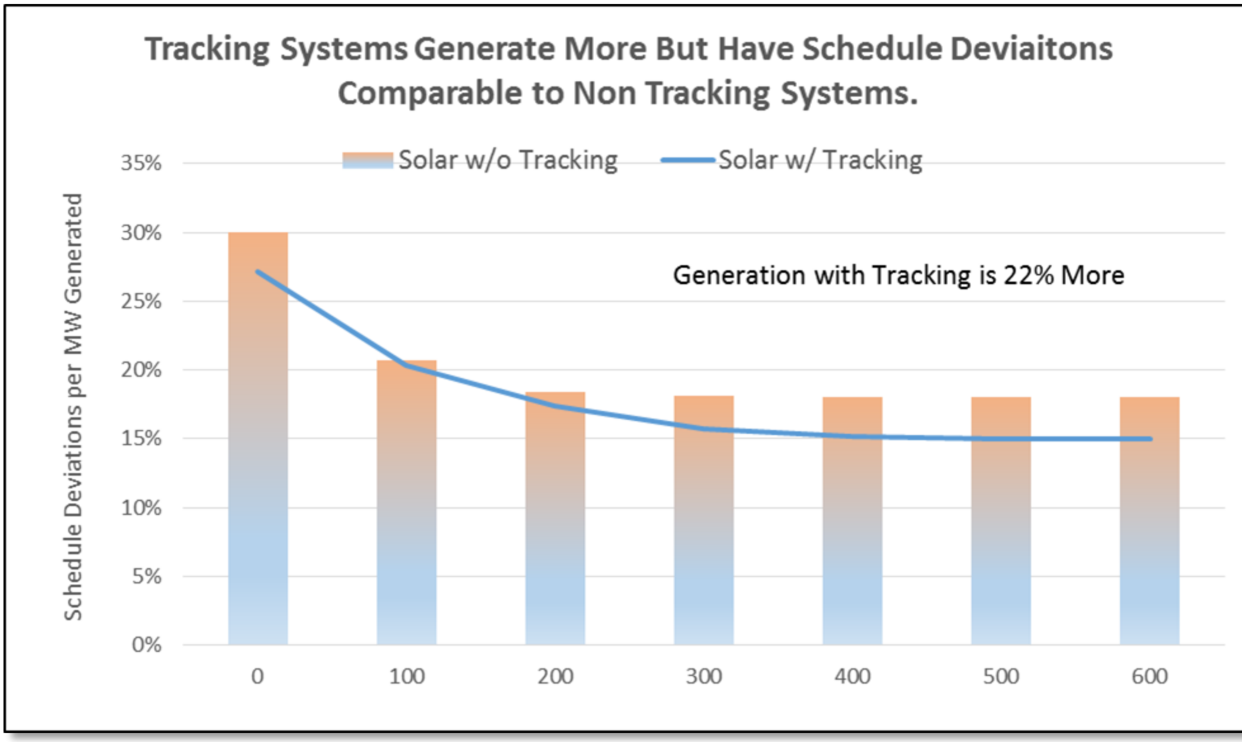
Source: Onset, Inc.

Figure 22: Value of UniGen with Tracking Solar for Different Schedules



Source: Onset, Inc.

Figure 23: Comparison of Solar Plants With and Without Tracking Systems



Source: Onset, Inc.

A Renewable Baseload Plant

So far, the authors have used UniGen to firm the schedule of variable resources. Having command of two or more resources gives UniGen the ability to create hybrid plants with unique schedules.

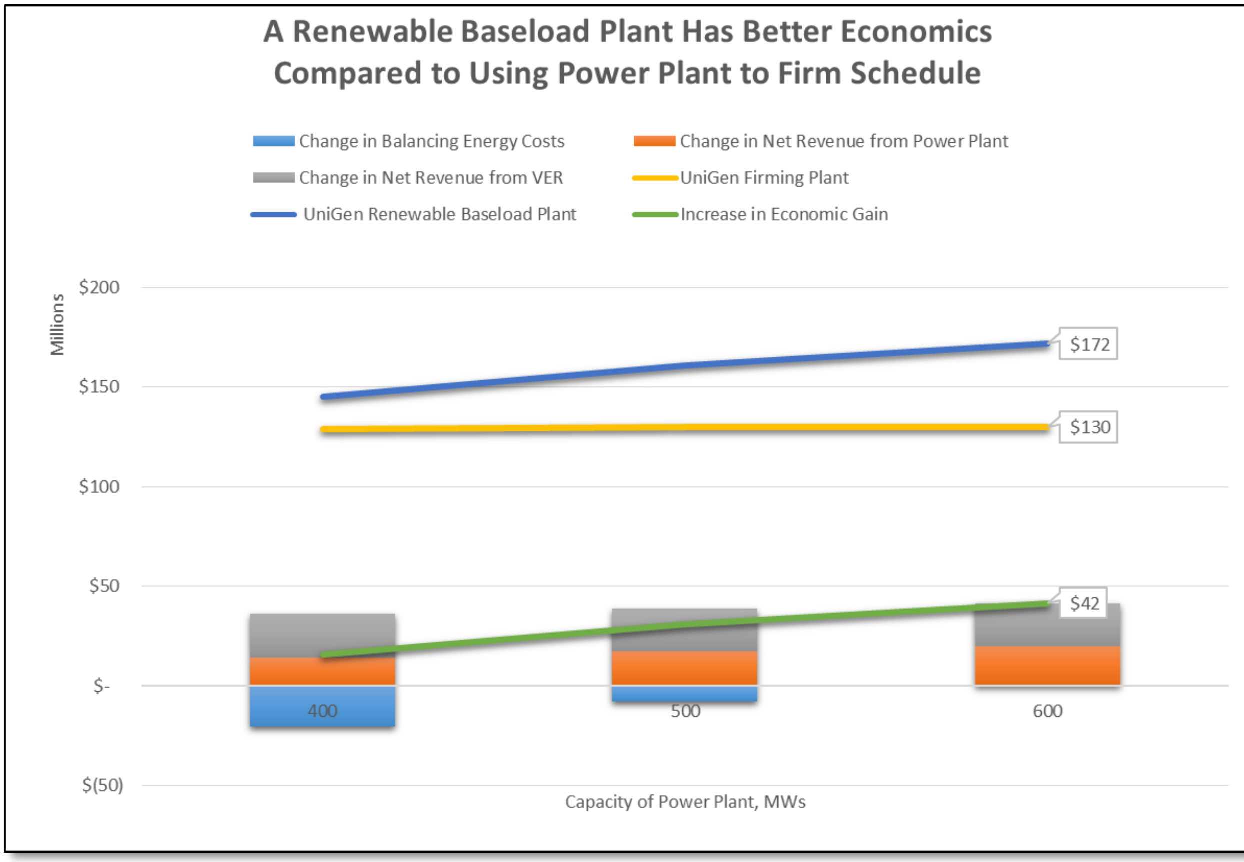
For example, UniGen is able to create a renewable baseload plant from a mix of VERs, power plants, and storage and plant. This hybrid plant could serve the load on a 24/7 basis and be a replacement for resources like Diablo Canyon. This approach offers important value for resource owners, as shown in Figure 24.

When UniGen is used to firm VER generation, the economic gain is primarily the result of reducing balancing energy costs. However, the power plant generates net revenue as well, contributing to the overall economic gain. For a renewable baseload plant, the net revenue of the power plant makes a greater contribution.

Analysis of Battery Energy Storage

In this section, the authors evaluate the benefits of using battery storage alone or with other resources to maintain a day-ahead schedule. There are other potential uses for storage, including frequency response and price arbitrage, but these are not explored in this study.

Figure 24: Using Power Plants in a Renewable Baseload Configuration Increases Economic Gain

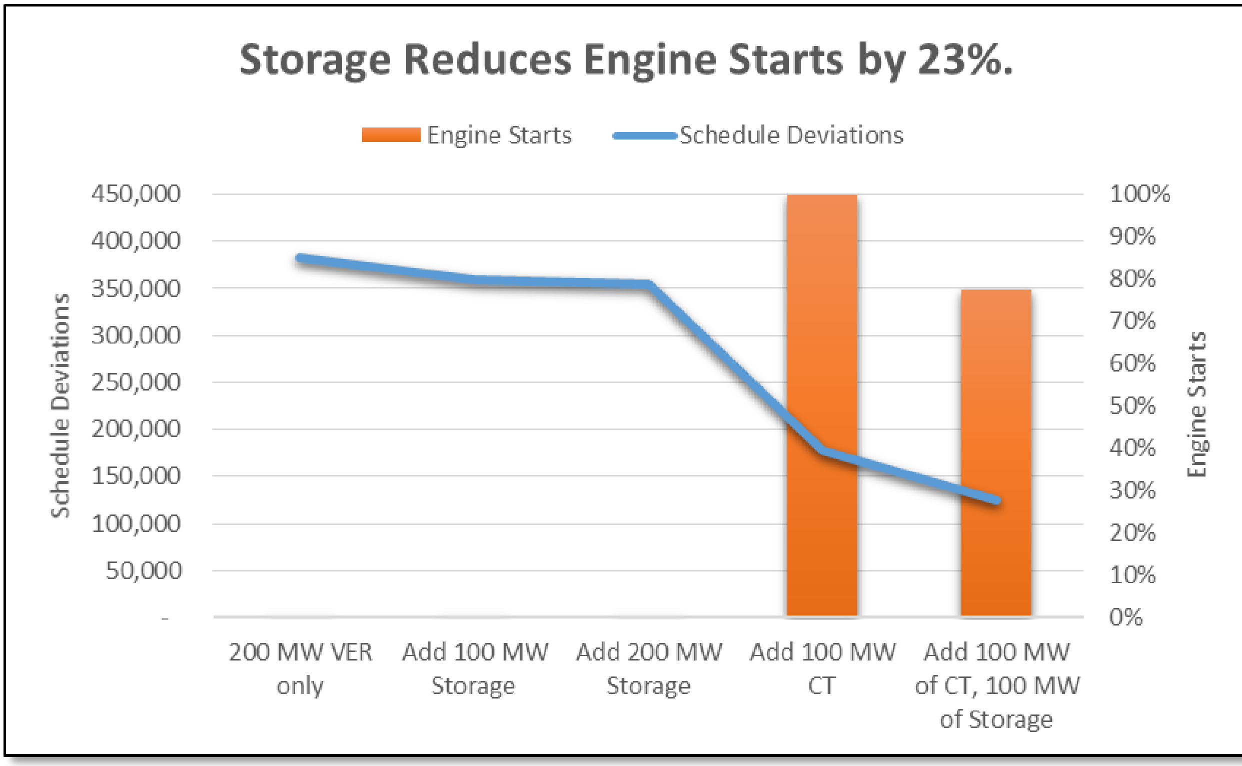


Source: Onset, Inc.

This study looked at two cases. In the first one, any VER generation in excess of the schedule is stored and later discharged whenever the VER generation is less than forecast. This is in fact a role commonly envisioned for storage. In the second case, the authors used storage and a power plant to maintain the schedule. Storage is used preferentially to minimize engine starts and stops, which are expected to be high when used to integrate renewables. The results are given in Figure 25.

Storage by itself does not reduce schedule deviations in any meaningful way. This is somewhat counterintuitive but detailed analysis provides an explanation. The timing and amount of schedule deviations is unpredictable enough that it can be thought of as a random variable, although future work with predictive analytics may change that understanding. As a result, there is not at present a way to ensure that the battery has enough storage space when there is excess VER to be stored; or enough stored energy for those times when actual VER generation is about 40 percent.

Figure 25: Storage Could Play an Important Role by Reducing the Number of Engine Starts



Source: Onset, Inc.

However, the authors discovered that a storage system can play an important role in reducing the number of starts and stops by the power plant, as seen in Figure 28. The reason for this is that if maintaining the schedule requires starting up a combustion turbine, UniGen first checks to see if the battery can be discharged to meet this demand. There are times when the schedule deviations are transitory and can be met with the battery for this short period. Afterwards, the power plants replenish the battery with any unused generating capacity.

The result, as shown in the table below, is that the battery use factor increases as it helps maintain the schedule in lieu of starting power plants.

Findings and Conclusions

Transmission operators use a single, centralized control system to ensure that demand and supply are balanced, the metric for which is system frequency. This control system, which includes an energy management system, an integrated market, and human beings (control room operators) is inherently a long-loop control system, which is characterized by built-in time delays and incomplete information. Prior to the use of large amounts of VERs, these shortcomings were acceptable. Today, they are not.

UniGen is a short-loop control system. Distributed computers in real time, using accurate information about the nature of the problem and the resources available to correct it, automatically make necessary decisions in response to perturbations in VER output.

This is the true meaning of the smart grid. *Smart system*s such as UniGen promise to get smarter with data collection and the use of predictive analytics.

The UniGen simulation model was developed to ascertain if the operating characteristics of firming resources (start times, ramp times, and energy storage discharge rates, to name a few) would frustrate the attempts of a short-loop control system to manage the sudden and unpredictable changes in VER output. Important for this analysis was the use of historical data that recorded forecasted and actual VER generation.

Finding #1 Schedule Deviations Are Considerably Reduced

The first finding is that considerable reductions in schedule deviations are possible with existing power plants and storage systems within the periods (one minute or less) of a short-loop control system. Figure 9: UniGen Reduces Schedule Deviations, for example, shows that schedule deviation can be reduced by two thirds and that the mean and standard deviations are smaller as well, indicating less volatility in the supply of electricity.

Reducing schedule deviations in real time, as opposed to the current way of managing them, is clearly a benefit in terms of system reliability.

Finding #2: The Amount of Firming Capacity Can Be Predetermined

An unexpected but important finding is that the amount of firming capacity needed for UniGen to achieve these reductions is about one half that of the VER capacity. To create the first UniGen hybrid plant, it is possible that the amount of firming capacity can be predetermined using historical site data to predict the number of forecast errors (schedule deviations) expected from a particular resource. At the system level, this would give California ISO reason to reduce the amount of reserve capacity it keeps on hand to manage unexpected frequency changes.

Finding #3: UniGen Repurposes Brown Energy to Support Renewable Integration and Serve Load

Brown energy (that is, gas-fired generation) is usually thought of as either serving load or serving another purpose such as providing balancing energy via the market. The authors discovered that UniGen provides the means by which it can serve both purposes. As shown in Figure 17: Repurposing Brown Energy to Support VERs (Wind) and Figure 18: Repurposing Brown Energy to Support VERs (Solar w/Tracking) the ratio of green to brown energy remains the same even as the amount of brown, firming capacity is added to UniGen. The reason is that the brown energy purchased by California ISO to offset changes in VER generation is replaced with brown energy produced in equal amounts by the dedicated power plant in UniGen. But in the case of UniGen, the brown energy is also being used to meet scheduled deliveries that are serving load. In this way, a load-serving entity that purchases the combined output of a UniGen hybrid plant is helping California ISO integrate renewables.

Finding #4: There Are Financial Incentives to Schedule VERs in the Day-ahead Market

In the absence of contingency events, system reliability would never be an issue if all generation schedules were met. Problems might arise when demand is more than the scheduled generation, but these situations are easily managed by dispatching peaking plants or employing demand response services in more extreme cases.

However, all that has changed. The focus of concern now is the disparity between forecasted VER generation and actual generation (which at times makes up over 50 percent of the total) because of its effect on system frequency.

The industry should not give up on using scheduling as a cost-effective reliability tool for using VERs such as wind and solar photovoltaic power generation. The authors recognize the financial risk entailed by scheduling in the day-ahead market—namely incurring balancing costs when the schedule is not met. This perhaps explains California ISO’s current practice of not requiring VER generation to schedule in the day-ahead market as other generators must.

The most important finding of this study is that UniGen is indeed a tool by which VER generation can be scheduled in the day-ahead market without undue financial exposure and in fact can increase the value of the combined resources.

UniGen not only levels the market playing field for VER generation but also allows VER owners to take advantage of one feature of the day-ahead market that is increasingly important to them—the lack of negative prices.

Finding #5: UniGen Repurposes Idled or Underused Power Plants

Falling market prices have made it difficult for gas-fired power plants without contracts to be financially sustainable. A notable example is Calpine’s decision in January 2016 to shut down the Sutter plant. Recently, Rockland Capital issued a press release saying that declining market revenues are not enough to justify its ongoing operation, absent some other form of compensation.[9]

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[9] "Despite being regularly dispatched by the CAISO for energy, La Paloma has seen a substantial decline in its merchant market revenues and minimal sales of resource adequacy ('RA'). Absent some change in compensation, La Paloma has determined that continued economic operation of its units is not justified, at least in the short to medium term, given the non-compensatory market revenues the plant has received and expects to receive during this time frame. Representatives of La Paloma have been discussing these market signals and their likely effect on continued operations of the facility absent contractual or other relief with representatives of the CAISO and other California state agencies on various occasions since 2014." Source: *Power Engineering* magazine, dated June 27, 2016; https://www.power-eng.com/2016/06/27/la-paloma-says-965-mw-california-plant-may-shut-without-help/.

The authors recommend that California ISO consider creating a new product that would compensate those gas-fired plants that dedicate their output to firming VER schedules. That compensation, plus the revenue from selling energy, would give these plants a new lease on life. Another route to the same end is for a Load Serving Entity to award a contract for the combined output of a VER and power plant to serve their load predictably. This would probably require a renegotiation of existing contracts but given the stakes, it may prove to be desirable if not necessary.

Finding #6: UniGen Gives Energy Storage an Important Role in Maintaining Schedules

Energy storage has the potential to play an important role in meeting California's clean energy goals. There are many possible applications for energy storage, and the authors want to propose one more: acting as a resource to maintain a generation forecast. A finding of this study is that storage has an important role to play but not the expected one.

The most obvious application of energy storage is to store VER generation when there is more generation on the system than demand and then to discharge it later in time when the opposite situation exists. This might be done to offset the demand for gas-fired generation or to engage in price arbitrage.

What this study found is that the energy storage system has a low use factor when used in these ways. The storage system is either discharging or storing less than 10 percent of the time. The reason for this is the pattern by which overgeneration and undergeneration occur. These do not align with the state of the storage system. For example, when excess VER generation appears, it is stored until the battery is full. Ideally, the next period of time would involve undergeneration; the battery would be fully discharged; and the pattern would repeat. What the authors discovered from the historical data is that the periods of overgeneration extend well past the time when the battery is full and periods of undergeneration occur past the time when the battery is fully discharged. This happens enough that the battery is mostly idle.

Conclusions

The findings of this study point to the general conclusion that UniGen is a very effective tool for integrating renewables. In particular, UniGen makes it financially attractive for market participants to schedule VERs in the day-ahead market, which will help California ISO maintain reliability with fewer resources, thereby wringing costs out of the market for the benefit of California ratepayers.

The expected growth of solar generation in California, as detailed in Appendix A, is unprecedented. Without advanced planning, the inherent variability of solar generation magnified by this explosive growth will strain the system, which currently lacks sufficient tools to manage it.

To stay ahead of this impending problem, the authors propose that new tools like UniGen be examined and considered in all planning processes.

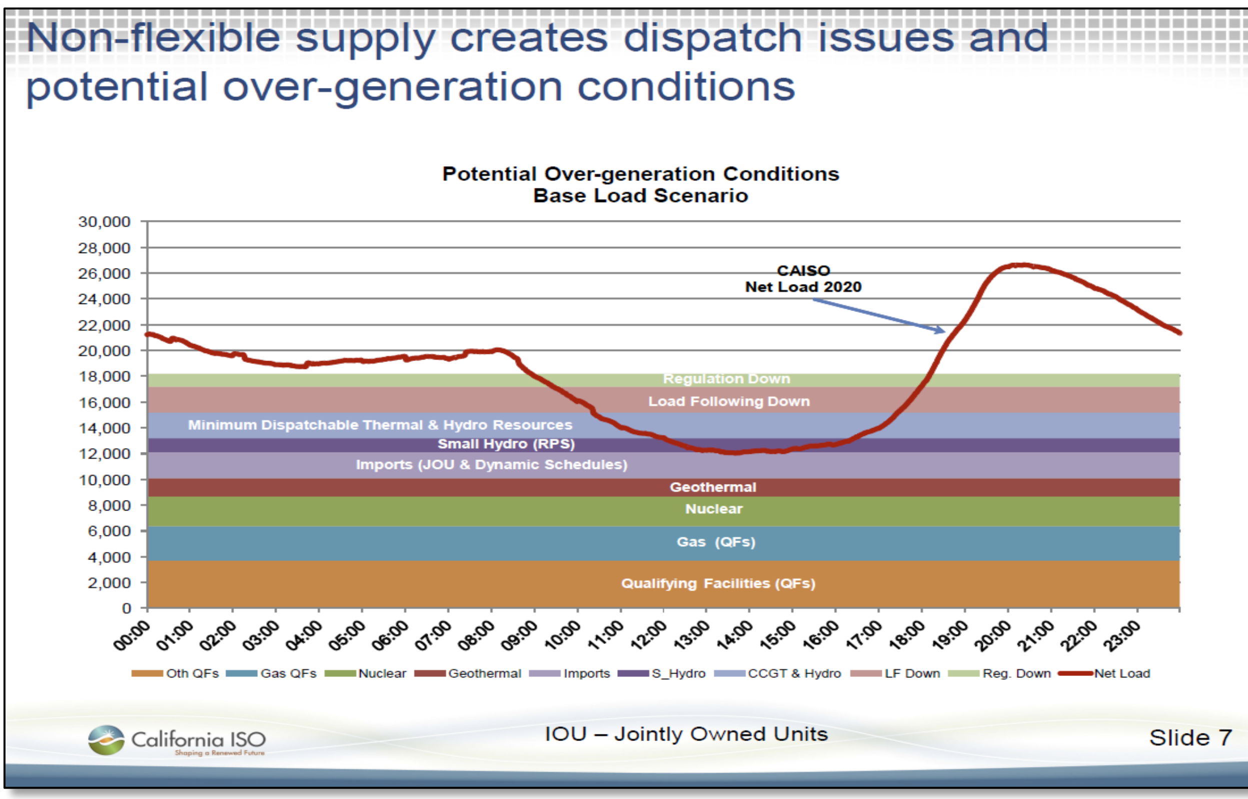
CHAPTER 3: Reshaping the Duck Curve

Is Overgeneration of Renewable Energy Too Much of a Good Thing?

With a 50 percent RPS by 2030, California has the most ambitious goal in the country for using VERs. Efforts to meet that goal have thus far been successful. VER generation is growing faster than expected and the 50 percent goal will likely be reached in 2024, six years ahead of schedule.[10] Much of this growth is from solar resources.

The California ISO has indicated that in certain circumstances, the increased level of VER generation will lead to operational and reliability issues. This situation, which is referred to as overgeneration, is best understood by referring to Figure 26.

Figure 26: Breaking Down the Oversupply Problem



Source: Onset, Inc.

When the percentage of must take and publicly preferred VER generation grows large in comparison to system load, the net load (system load minus VER generation) begins to decline over time as famously portrayed by the Duck Curve (Figure 27). California

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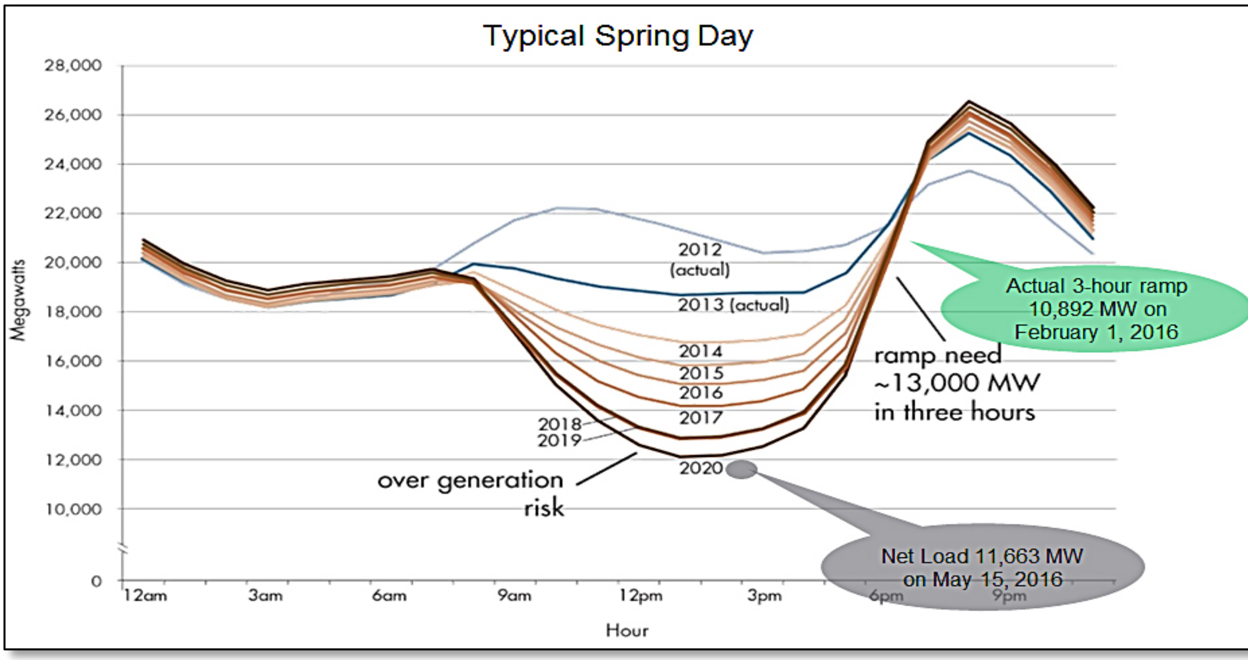
[10] According to conversations with the CAISO staff.

and California ISO are unique in this regard not just because of the 50 percent RPS but also the explosive growth of solar generation, which produces two thirds of its energy (unless it has a tracking system) during a period that ranges from 8 hours at the summer solstice to just 4.5 hours at the winter solstice. Except during the summer months, system load during these periods is flat. The result is that the net load goes into free fall.

Figure 27: The Duck Curve



Source: Onset, Inc.

The problem is that at the bottom of this free fall there is an unmovable set of non-VER resources that cannot be backed down. Some of this generation is kept online to be responsive to the rapid increase in net load in the afternoon hours. This means there is a floor below which the net load cannot go,[11] and consequently, VER generation is curtailed. UniGen is designed specifically to avoid the need for VER curtailment.

Several instances of overgeneration conditions already have occurred on the California ISO system. On May 15, 2016, for example, the net load dropped to 11,663 MW. Because such drops are happening much faster than anyone expected, adequate measures to manage or prevent these conditions have not been fully developed.

New Operating Conditions Emerge

When oversupply conditions do occur, operating the grid in accordance with NERC

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[11] That floor is about 12,000 and 14,000 MW according to CAISO reports, although it may be revised downward if, as expected, Diablo Canyon is closed.

reliability criteria[12] becomes a considerable challenge—namely, supplying enough generation in a timely manner to meet the unprecedented increases in net load (ramps) that begin around 3:00 pm and continue for several hours. If the controllable generation is insufficient or not timely, there is the threat that system frequency will fall below levels required by NERC. As depicted in Figure 27, ramps can be several thousand megawatts per hour and a collective ramp of as much as 13,000 MW from 3:00 pm to 6:00 pm could occur. California ISO has already reported ramps of nearly 11,000 MW during this time period occurred and projections for 2024 indicate 20,000 MW in three hours. For operators of the grid, these pose new and unprecedented challenges.

The amount of controllable generation required to meet these ramps can be met in part by dispatching fast-starting plants — namely, simple cycle combustion turbines (SCCT) or by increasing the output of slow-starting plants—namely, combined cycle combustion turbines (CCCT) already on-line.

The capacity of SCCTs in California ISO today is about 3,000 MW. As the Duck Curve shows, the afternoon ramps following an oversupply condition far exceed that capacity.

This leads to a derivative problem. To keep supply and demand in balance during these periods of extreme ramps in net load, the CCCTs must be kept online around the clock. Except for the afternoon hours when the output is higher, these plants will by necessity be operating at or near minimum power, which is the operating point where fuel efficiency is poor. This contributes to higher costs and more CO_2 emissions.

If the generation provided by flexible resources and on-line thermal generation lags behind the increases in net load, the frequency on the California ISO system and hence at the Western interconnections will fall. If this occurs routinely, it will draw unwanted attention from the Western Electricity Coordinating Council and NERC.

Solutions and Consequences

There are a number of ways to address the problems that accompany overgeneration.

One is to encourage or at least hope for an increase in system load. However, this has the potential to exacerbate the problem. The load increase would likely be disproportionally higher during the late afternoon to evening peak consumption hours. Illustratively speaking, the head of the duck would sit higher up. The amount of VER generation, which is linked to the increase in overall consumption, is disproportionately generated during the midday hours. Thus, the duck's belly gets bigger. The overall effect is to stretch the neck of the duck; that is, to make the afternoon ramps even higher.

Another option is to sell excess supply to Load Serving Entities in other balancing authorities within the Western Electricity Coordinating Council. This amounts to selling

[12] NERC operating standards, specifically, the 10 Resource and Demand Balancing (BAL) standards.

electricity during the hours of 11:00 am to 1:00 pm, Pacific Time, if it is to have any effect on oversupply conditions in the California ISO. But is this a dependable, long-term solution? The willingness of load-serving entities in the other balancing authorities to absorb excess electricity from California ISO at that time may well be influenced by factors other than favorable prices, including the predictability of that supply's availability and the operational effect on their own generation resources.

A promising solution is to change consumer tariffs, which have historically discouraged consumption of electricity during the midday (and formerly peak) hours. This would take the form of "matinee prices" as being discussed by the CPUC.[13] A pilot program is being developed that would provide financial incentives for certain commercial, agricultural, and industrial users to use electricity during the middle of the day. If this pilot program is successful, further work will be done to decide the particulars of a full-scale program, such as the change in the rates themselves and whether the tariffs are opt-in or opt-out.

More widespread use of plug-in electric vehicles (PEVs) also has the potential to change consumption patterns. The idea is to charge PEVs during periods of oversupply when wholesale prices are low or negative. PEVs would subscribe to the services of an aggregator, which would have the ability to access wholesale market prices. There is much work to be done on this option as well, and the number of PEVs actually bought and charged during the midday hours is hard to predict.

Meanwhile, the overgeneration problem is arriving ahead of schedule as reported in a number of articles such as "The Duck Has Landed."[14] "Grid operators are now seeing overgeneration beginning to manifest itself during the midday hours necessitating curtailments, just as the duck curve forecasted," said California ISO spokesman Steven Greenlee.

In addition to all of these measures, California ISO believes that an increase in energy storage and the flexibility of power plants to more quickly follow ISO instructions to change their output are potential solutions.[15] The high cost associated with transmission level storage solutions is a well-known problem. What is less known but coming to light is the lack of flexibility, as California ISO defines it, which exists with the current fleet of gas plants, particularly combined cycle resources. One way to look at these emerging issues is that the original design basis of the grid, which was based on slow-moving, predictable load and generation, has effectively changed to something almost the exact

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[13] Order Instituting Rulemaking into Policies to Promote a Partnership Framework between Energy Investor Owned Utilities and the Water Sector to Promote Water-Energy Nexus Programs, Rulemaking 13-12-011 (Filed December 19, 2013).

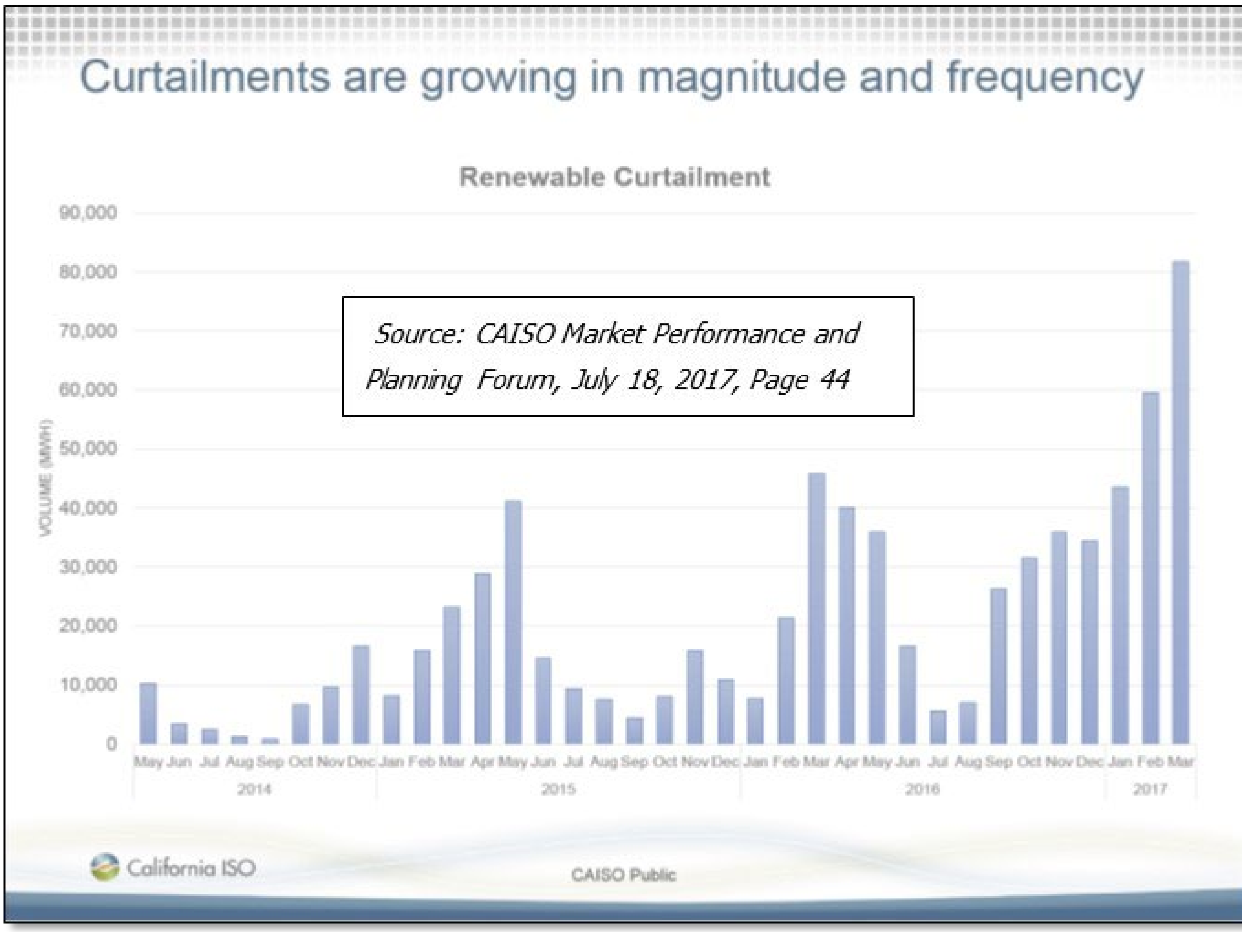
[14] The Duck Has Landed, posted on May 2, 2016 by Meredith Fowlie, Energy Institute at Haas.

[15] https://www.caiso.com/Documents/FlexibleResourcesHelpRenewables_FastFacts.pdf.

opposite. Resources and approaches that worked in the past are struggling to find a role now that the design basis has changed.

Finally, if the above options do not prove adequate, then the solution of last resort is probably curtailing VER generation. Some of that will be done voluntarily for economic reasons. Already, negative prices are resulting in sizable economic curtailment, as seen in Figure 28.

Figure 28: Voluntary Curtailment for Economic Reasons is on the Rise



Source: Onset, Inc.

However, if this is not sufficient, California ISO will almost certainly issue curtailment orders when necessary. As desirable as VER generation is, California ISO has a statutory obligation to ensure the reliable operation of its transmission grid in accordance with NERC Reliability Standards. This properly takes precedent.

The purpose of this research is to demonstrate that this last resort, curtailing VERS, is unnecessary if UniGen were to be used throughout the California ISO system.

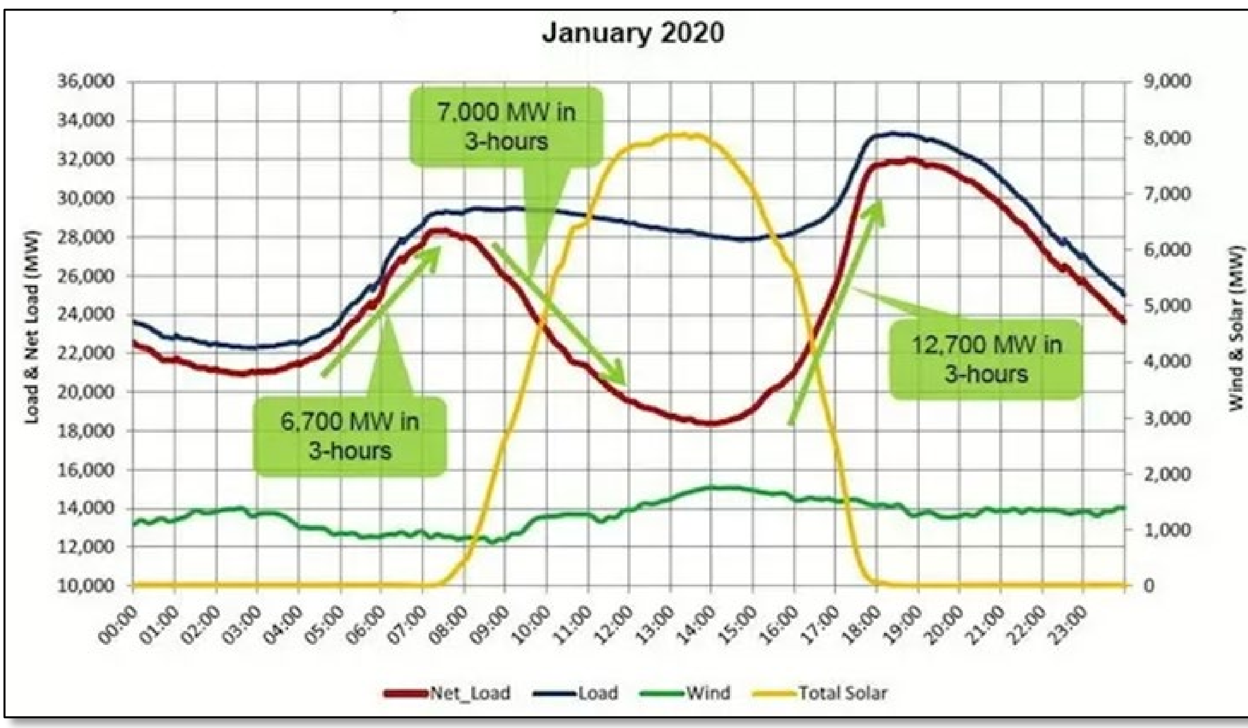
All of the proposed solutions, including UniGen, have merit and will mitigate the coming problems in varying degrees. However, most are outside the control of California ISO, either because the solution depends upon third parties (such as consumers or car buyers) changing behavior or upon yet-unidentified technologies and cost advancements. However, as will be discussed, implementing the UniGen solution is under the control of California ISO or its market participants, makes use of existing VER and non-VER resources, and requires only the development of a few software applications to play an important role in mitigating the effects of the overgeneration problem.

However, first it will be helpful to deconstruct the Duck Curve.

Deconstructing the Duck Curve

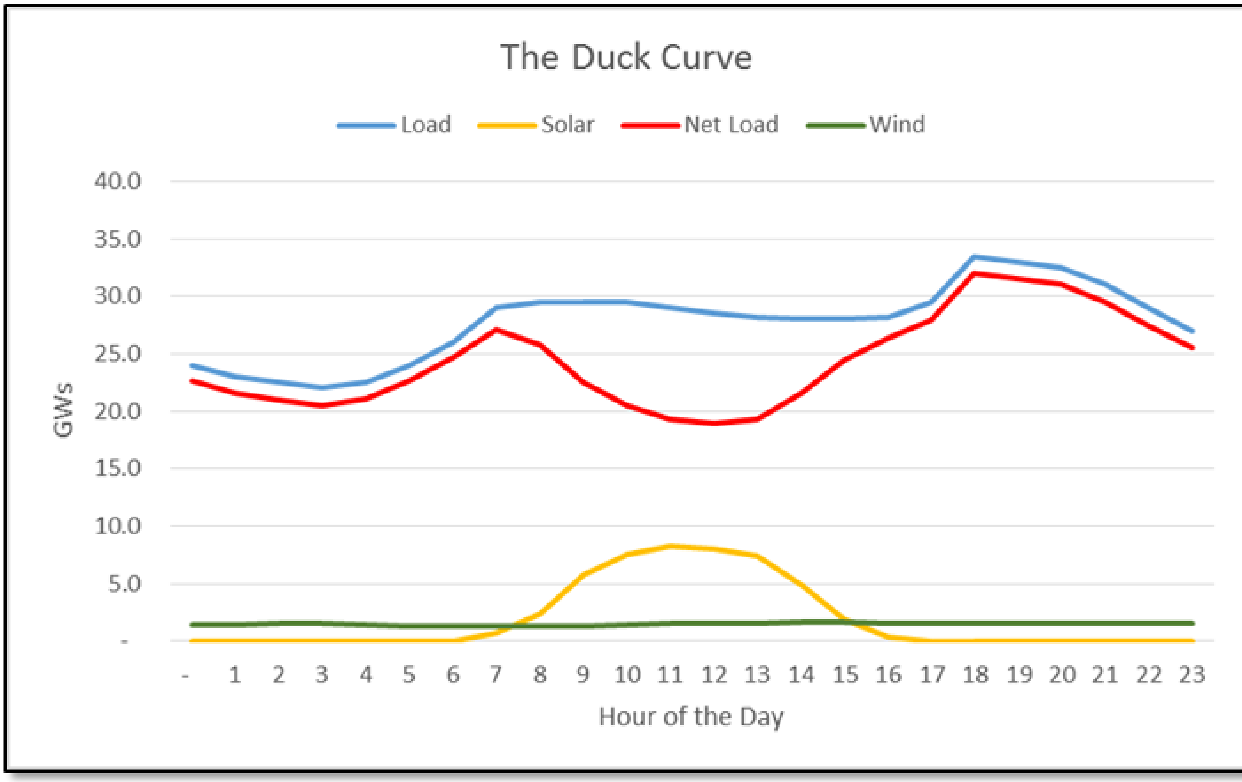
The Duck Curve, as it might be in 2020, is given in Figure 29. Note that these supply curves for wind and solar are not on the same scale as the system and net load curves. The authors found that by redoing this figure with all the data on the same scale, as shown in Figure 30, the problem and its solution became visually clear.

Figure 29: The Duck Curve in 2020



Source: Onset, Inc.

Figure 30: Deconstructing the Duck Curve



Source: Onset, Inc.

It is visually clear that wind generation varies within a narrow band and does not play a role in the hour-to-hour changes in net load (a condition unique to California). One can also observe that during the midday hours, system load is also constant. It is easy to see that the belly of the duck is determined almost solely by solar generation, in which there will be considerable increases over time. They are almost inverse images of each other.

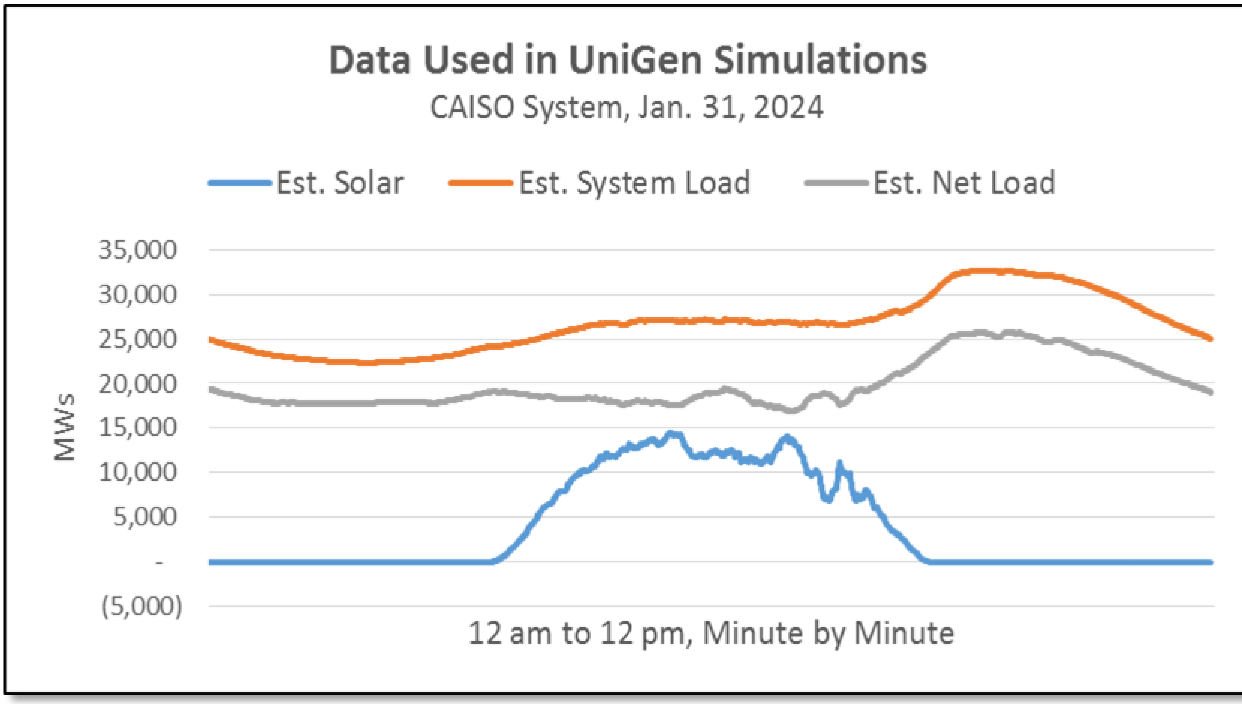
The solar generation hump can in effect be eliminated by directly pairing solar generation with that of dedicated gas plants and energy storage, as has been discussed earlier.

Reshaping the Supply Curve

For this analysis, the authors made use of the actual load, wind, and solar data for January 31, 2016, which were publicly available on the California ISO website. The data are given on a minute-by-minute basis, which provides a more insightful look into the dynamic interactions of load and generation.

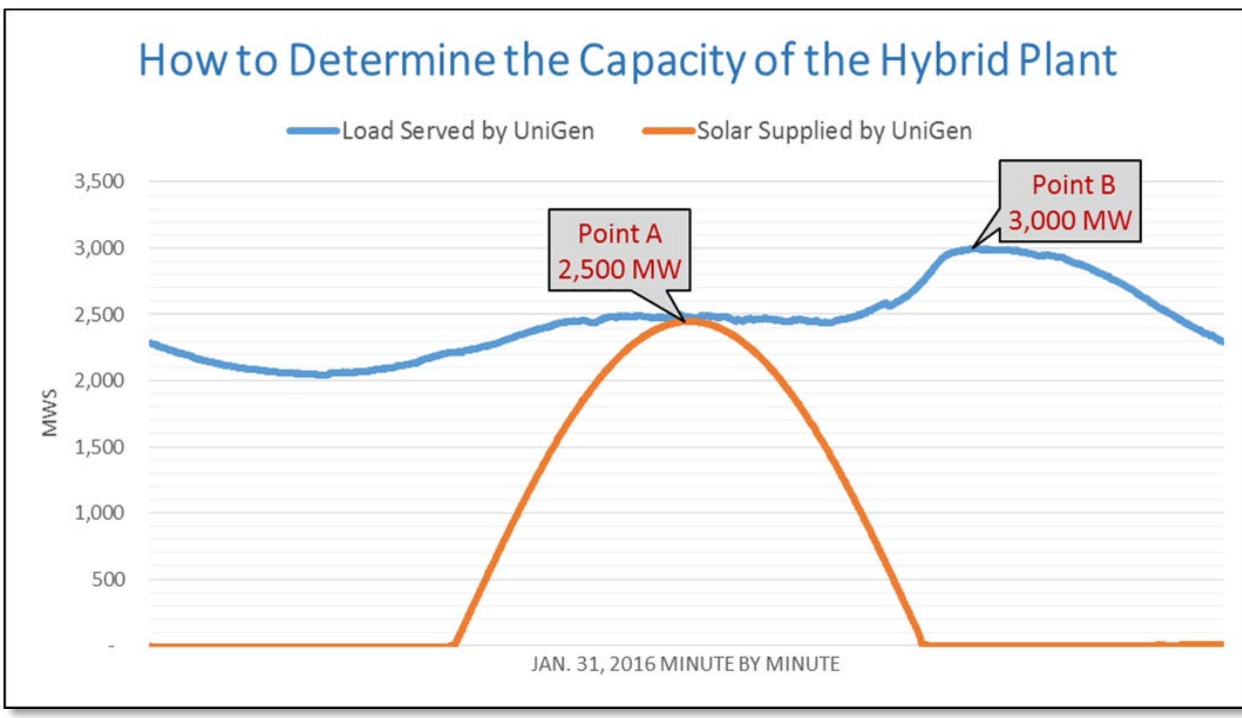
As documented in Figure 31 and Figure 32, the authors scaled these data to represent conditions expected in 2024. The scaling made use of California Energy Commission forecasts of load growth and Onset's estimate of the relative increases in solar and wind generation for the year 2024.

Figure 31: Data Used in Simulating Overgeneration with UniGen



Source: Onset, Inc.

Figure 32: Sizing the Capacity of the Hybrid Plant to Serve Load



Source: Onset, Inc.

The strategy is to schedule the output of several UniGen hybrid plants; that is, VERs coupled with controllable plants or storage. UniGen plants schedule their output in the day-ahead market to serve a portion of the California ISO system load. A two-step process determines the capacity of the controllable resources that must be paired with solar resource. The first is to determine the capacity of the solar resource by having the expected peak solar generation serve an equal amount of load that occurs at the same time. This is Point A in Figure 32 and results in a schedule whose main priority is to consume 100 percent of the solar generation available. That is, the schedule is designed specifically to avoid curtailment. Note that the solar output curve is based on a "perfect solar day"; that is, one with clear skies. For a day like this, solar generation can be readily predicted using well-known mathematical models.[16] Onset, Inc. developed its own model based upon these mathematical ones for purposes of calculating solar generation for the time of year (January 31), the latitude, and size of the project in acres.

The second step is to include SCCTs or CCCTs in the resource mix. The output of these power plants can be precisely controlled and is used to maintain schedule commitments when actual solar generation deviates from that forecasted or when it is not available at all. The capacity of these "controllable" power plants is determined by the peak load being served by UniGen. This is Point B in Figure 32.

The first case simulates the operations of a group of hybrid plants that consist of solar photovoltaic energy and an SCCT. To illustrate the impacts of using UniGen to mitigate the effects of overgeneration, the authors chose to repurpose all 3,000 MW (estimated) of SCCTs in California ISO and make them part of hybrid plants. This is a good first case because the SCCT is regarded as a superior flexible resource.[17]

As depicted in Figure 33, the UniGen plant is able to use the complementary aspects of solar and power plant generation to serve the load throughout the day. There is no requirement to curtail solar and the power plants start and stop only once per day. The schedule deviations are a concern and are present because while the plant is starting, the solar generation is steeply dropping to the point that even a fast-starting resource has trouble keeping up. The authors have developed a simple algorithm to address this problem and will discuss it shortly.

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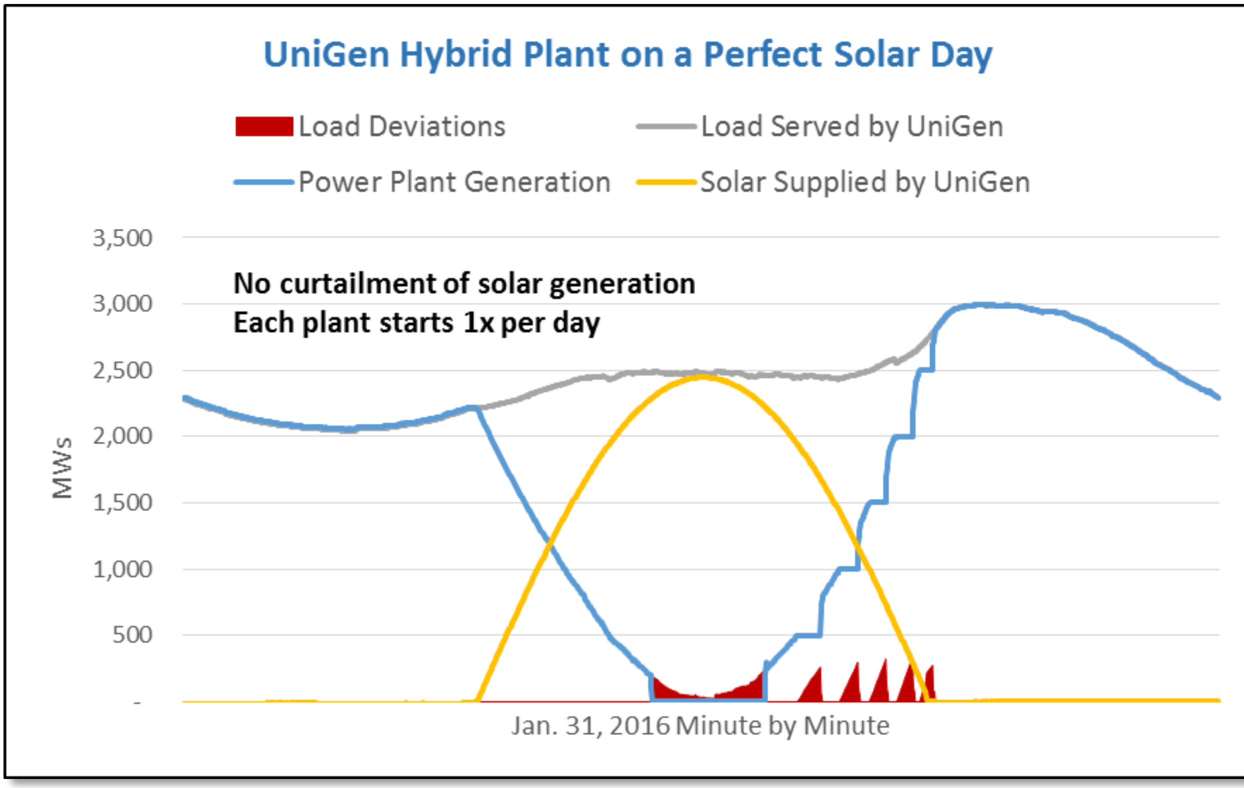
[16] One such model, developed at NREL, is the *Simplified Clear Sky Model for Direct and Diffuse Insolation on Horizontal Surfaces*, Technical Report No. SERI/TR-642-761, Golden, CO: Solar Energy Research Institute, 1981 by Bird, R. E., and R. L. Hulstrom.

[17] The term flexible resource appears throughout management and economic literature. It is generally defined this way: a flexible resource has the ability to make changes that are necessary to quickly adapt to different circumstances. Lean manufacturing, for example, is a process that strives for efficiency and limited waste and relies heavily on flexible resources.

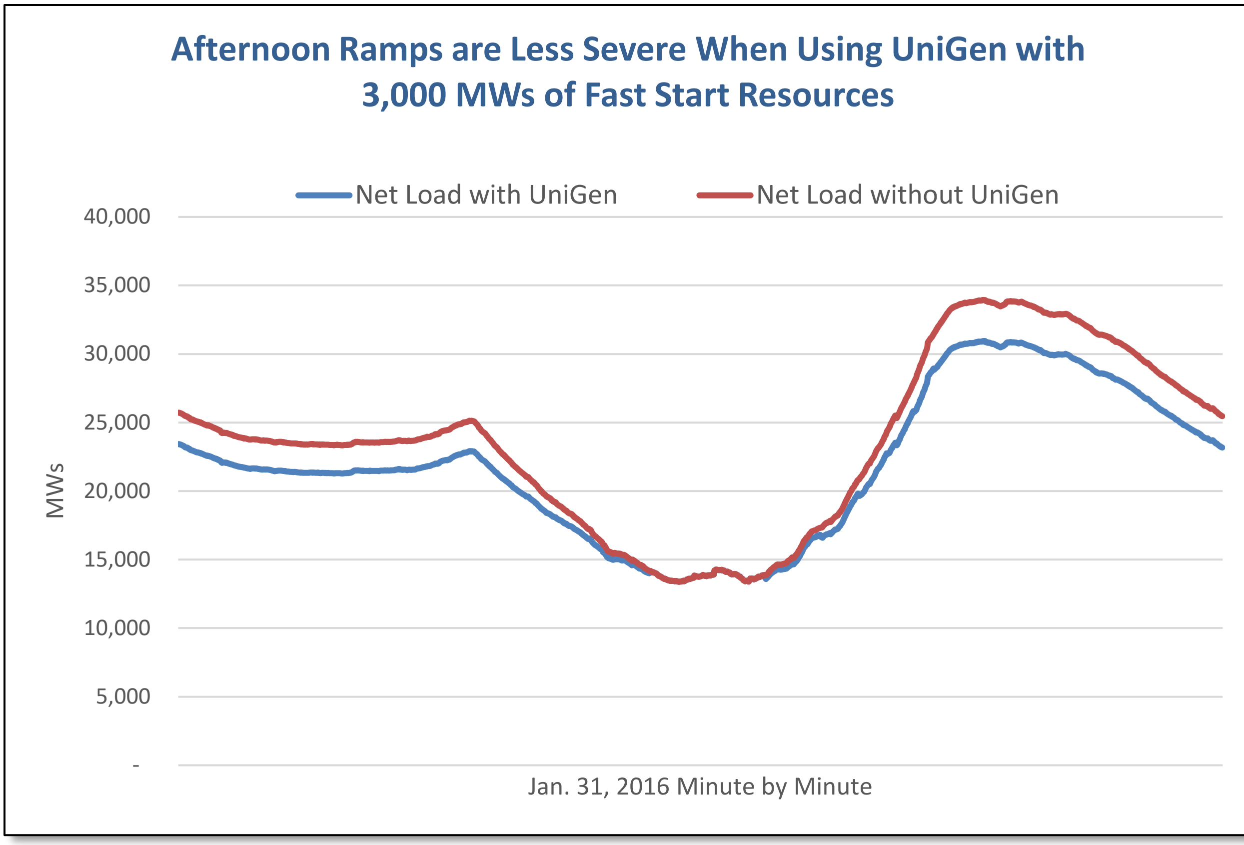
Figure 33: Results of Using UniGen to Meet Load with a Hybrid Plant



Source: Onset, Inc.

However, for now, the question is: Does this mitigate the size of the afternoon ramps as seen by the California ISO operators? As shown in Figure 34, the ramps occurring after the midday slump in net load are not as steep. A way to measure this impact is the ratio of peak net load to minimum net load, which declines by nearly 10 percent when UniGen is used with 3,000 MW of SCCTs. Simulations were done for even larger amounts of flexible resources and the results will be discussed later. Before that, however, a digression from the main topic to that of an example of how UniGen is a *Smart System*.

Figure 34: Reducing the Afternoon Peak and Ramp



Source: Onset, Inc.

Making UniGen Smarter

The reduction in solar generation that occurs in the late afternoon happens quickly. Even fast start power plants that are dispatched to offset this loss have trouble keeping pace. The result is that while the plants are starting up, deviations from the generation schedule mount quickly. This can be seen by looking again at Figure 33. The red areas represent deviations from the generation schedule.

A UniGen hybrid plant is able to exactly meet its schedule and operating plan throughout the day, except for the several 10-minute periods during which the fast start resources (there are six in the model used in this research) are undergoing startup (the red blips that occur in the afternoon.) For the resource owner, schedule deviations are a concern because they represent a financial cost that if not managed for California ISO may lead to NERC violations.

The solution is to make UniGen smarter so that it knows when to start the plants so that schedule deviations are kept to a minimum. The authors developed the "Early Mover" algorithm that starts controllable power plants earlier in time and puts the output of these units on an upward trajectory that runs exactly counter to the falling solar supply curve.

The algorithm takes advantage of the fact that mathematical models can predict solar generation on a day with clear skies with a high degree of certainty. Subtracting the predicted solar generation from the expected load (which is also very predictable and mostly flat during the afternoon) results in a reliable prediction of the exact time that power plant generation will be needed.

Details of the Early Mover algorithm that is embedded within the UniGen control system to proactively start controllable plants are found in Appendix C.

A side-by-side comparison of the schedule deviations for controllable plants that use the Early Mover algorithm and those that do not is shown in Figure 35. The algorithm is very effective and eliminates almost all of the schedule deviations. By the way, the deviations that occur at the bottom of the net load curve result from the fact that a single SCCT cannot generate less than its minimum load (assumed to be 40 percent). The authors intend to further explore if energy storage could be used to make up for this deficiency.

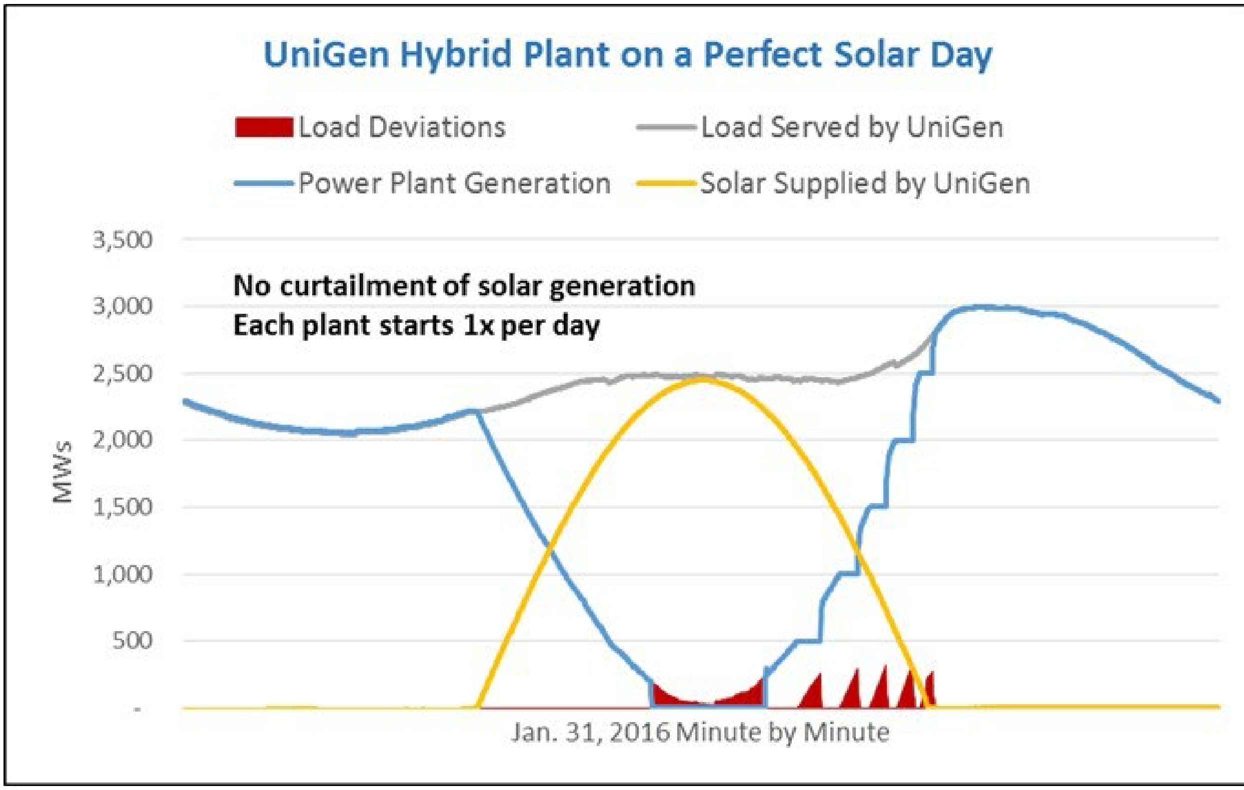
The system load profile changes appreciably over the course of year. The result is a net load curve that changes as the seasons change. The impact of overgeneration and the size of the ramps is therefore greater in some months than others. The authors analyzed four cases, one for each afternoon season, to see how the net load and ramps changed during the year. Each case was characterized by different load and solar generation curves. The results are found in Appendix D. The following two panels of Figure 35 contain the results of model simulations of overgeneration conditions for increasing numbers of UniGen hybrid plants and illustrate the flattening effect of UniGen on the Duck Curve.

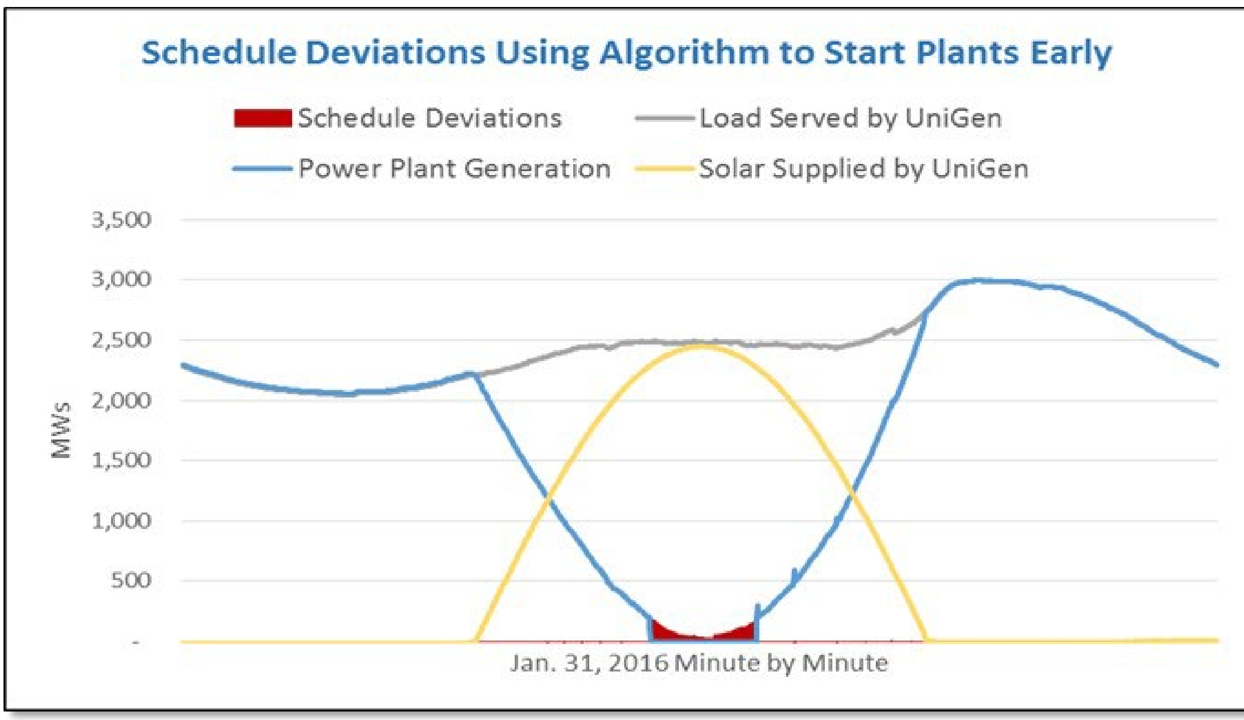
The Early Mover algorithm is a good example of what the smart grid should look like. Early Mover makes use of mathematics and data to make decisions in real time. It then takes proactive steps to optimize the use and cost of the resources.

How Much Flexible Capacity Is Needed?

There is an ongoing and spirited debate regarding how much flexible capacity is needed as the grid continues its transformation. The authors' studies indicate that UniGen plants with 6,000 MW of fast start SCCTs would reduce the afternoon ramps by close to 20 percent, as measured by reductions in peak to minimum megawatts or reducing the size of the average afternoon ramp (Figure 36) This is a more manageable problem for the grid operator. It should be noted that expecting the controllable generating capacity to perform at maximum ramping to meet the steep afternoon load curve day after day without failure might be unrealistic without a control scheme like UniGen.

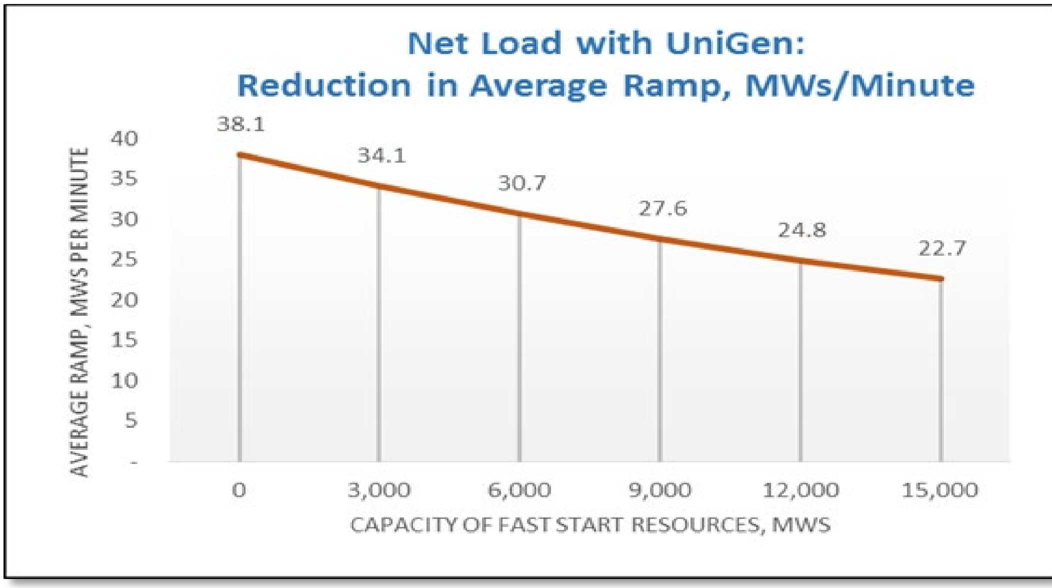
Figure 35: An Example of the Smart Grid in Action





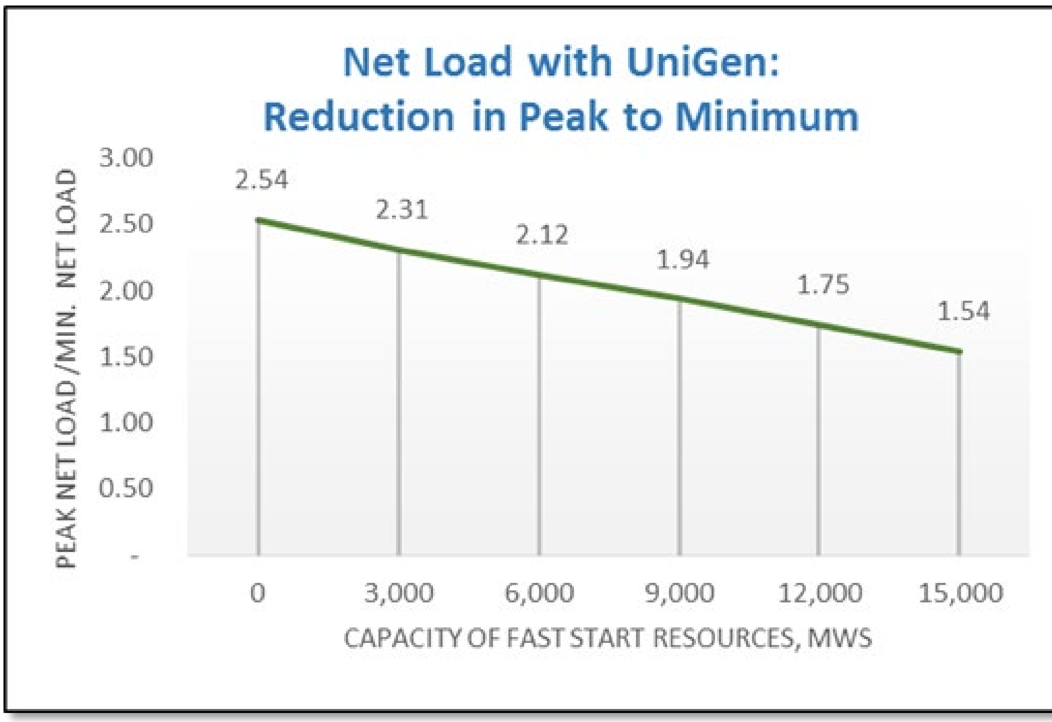
Source: Onset, Inc.

Figure 36: Reducing the Afternoon Ramps



Source: ___

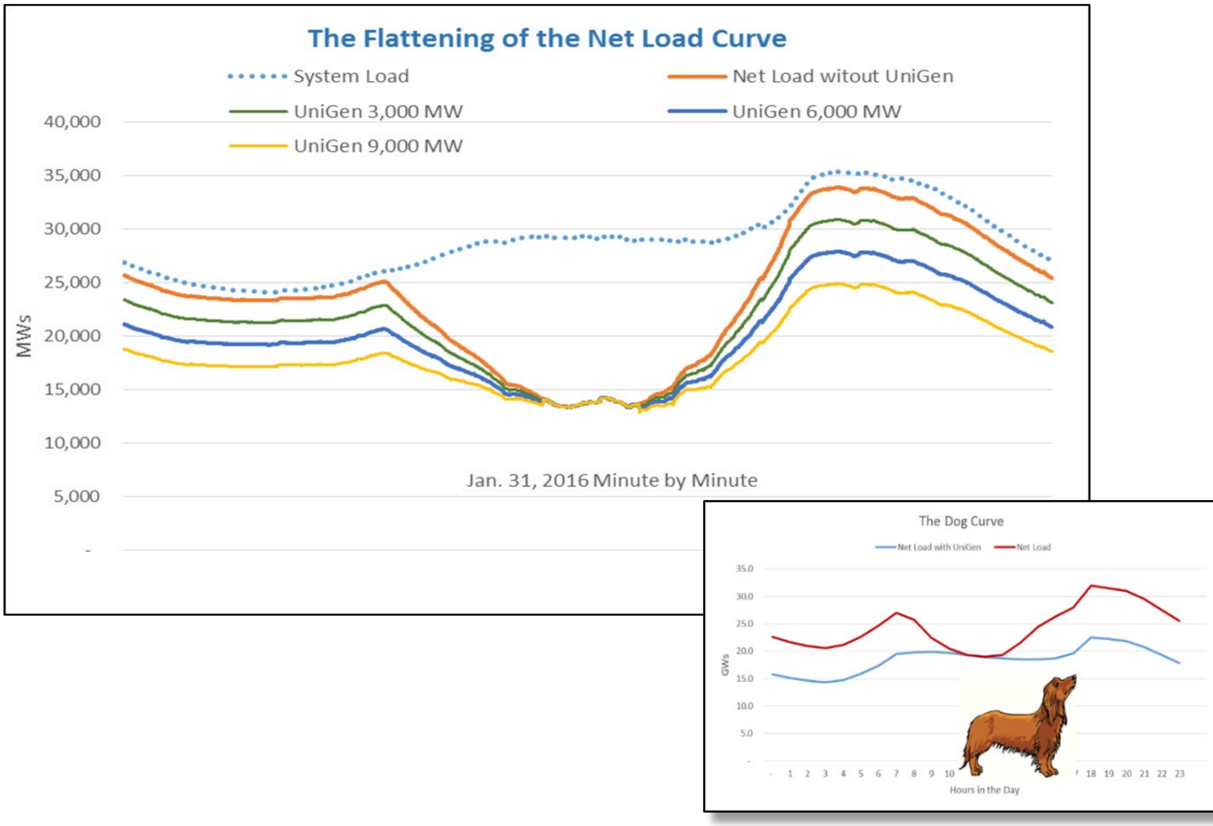
Figure 37: Flattening the Net Load Curve



Source: Onset, Inc.

Figure 38 illustrates the extent to which the afternoon ramps are changed, as more resources are made available for UniGen plants. The Duck Curve is transformed into what is affectionately called the Dog Curve.

Figure 38: The Dog Curve



Source: Onset, Inc.

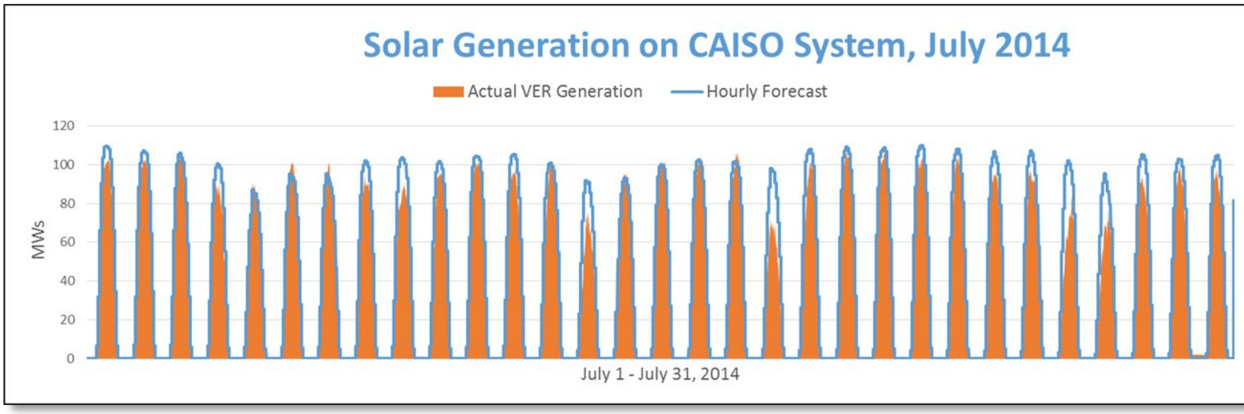
When Solar Generation is Not Perfect

Over the years, the authors have worked with numerous data sets that characterize the expected and actual generation from solar resources. These data sets reveal that there are many more perfect solar days than perhaps expected. In the summer, for example, there are numerous such occurences. This is illustrated in Figure 39. So, it makes sense to switch on the Early Mover algorithm during summer months, unless forecasts predict a day without clear skies. (A future task is to develop an algorithm that makes use of short-term forecasts to decide when it is appropriate to use Early Mover.)

During the winter months, solar generation obviously deviates from perfect solar conditions, as Figure 40 illustrates. It is the variability, whether it occurs in winter or summer, that UniGen is designed to manage. The question is if UniGen can manage (that is, smooth out) this variability and achieve the reductions in the afternoon ramp that it does for perfect solar days.

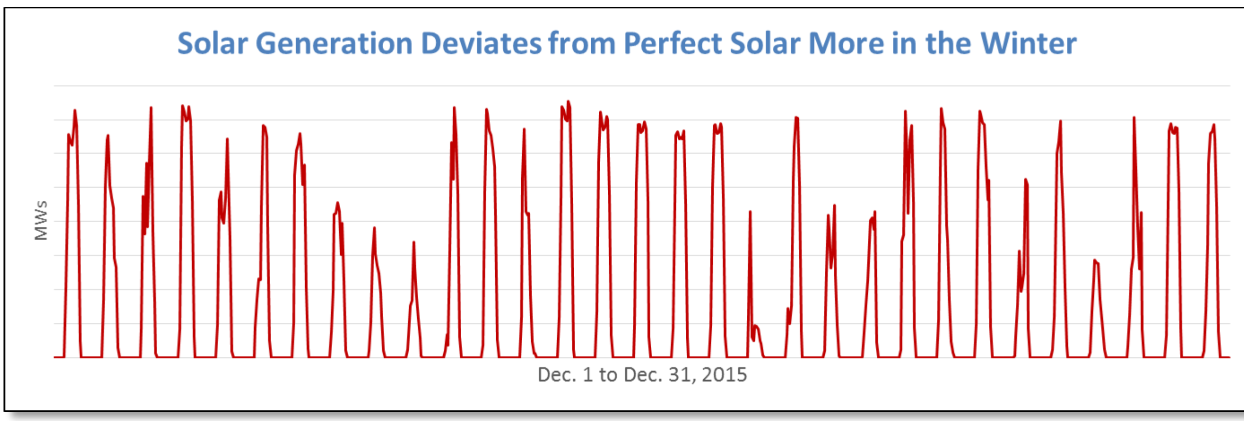
The true variability of solar (and wind) is masked by the use of hourly averaged data. Therefore, the authors' analysis uses minute-to-minute data for load, wind generation, and solar generation that was made public by California ISO. This makes sense because data are scaled downward. California ISO operators must process and manage the minute-to-minute data to meet the NERC standards for the grid.Important NERC reliability standards are stated in terms of 10-minute compliance periods so the use of subhourly data was a vital component of the analyses.

Figure 39: Variation in Actual Solar Generation (Summer)



Source: Onset, Inc.

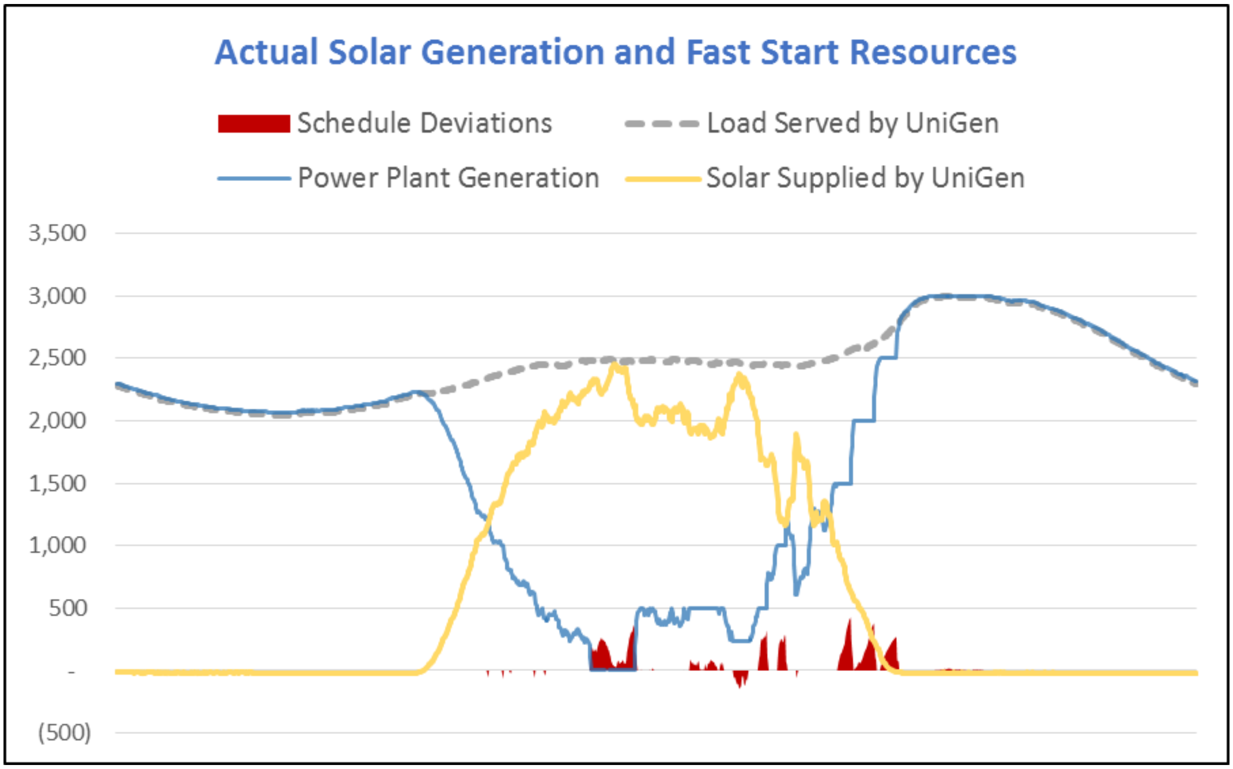
Figure 40: Variation in Actual Solar Generation (Winter)



Source: Onset, Inc.

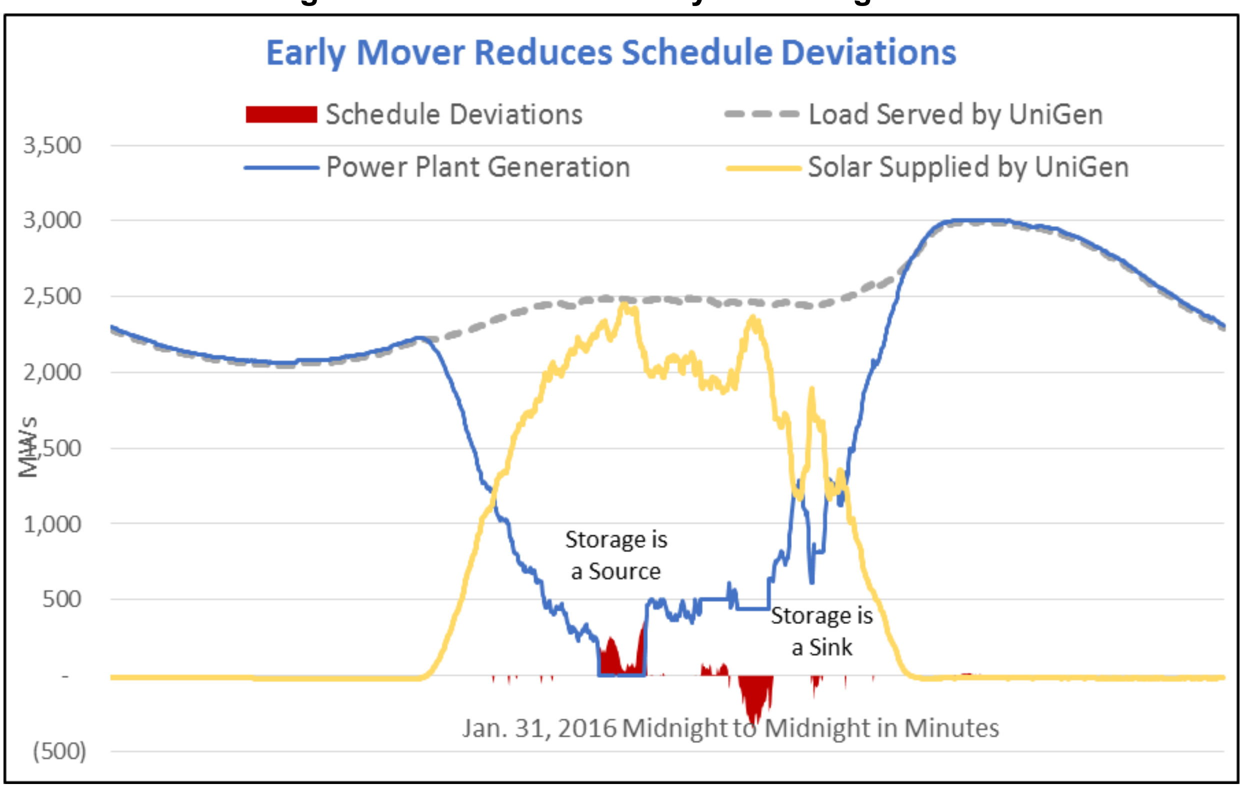
The purpose of Figure 41, Figure 42, and Figure 43 is to demonstrate that UniGen, especially with the Early Mover algorithm, manages the combined outputs of the solar resources and the power plants with a minimal of schedule deviations. With further work on the algorithm, it is possible to reduce the deviations to near zero. There are other options to reduce schedule deviations. Advanced VER generation forecasts would improve the effectiveness of Early Mover.Energy storage, when added to the mix of resources, could alternately act as a sink or a source for generation, depending on the demand. It is possible to customize the schedule to optimize the results as defined by the resource owners, including reducing schedule deviations to near zero, which might involve a tradeoff in the costs of maintaining one plant at minimum load versus the cost of schedule deviations (balancing costs).

Figure 41: UniGen with Fast Start Combustion Turbines



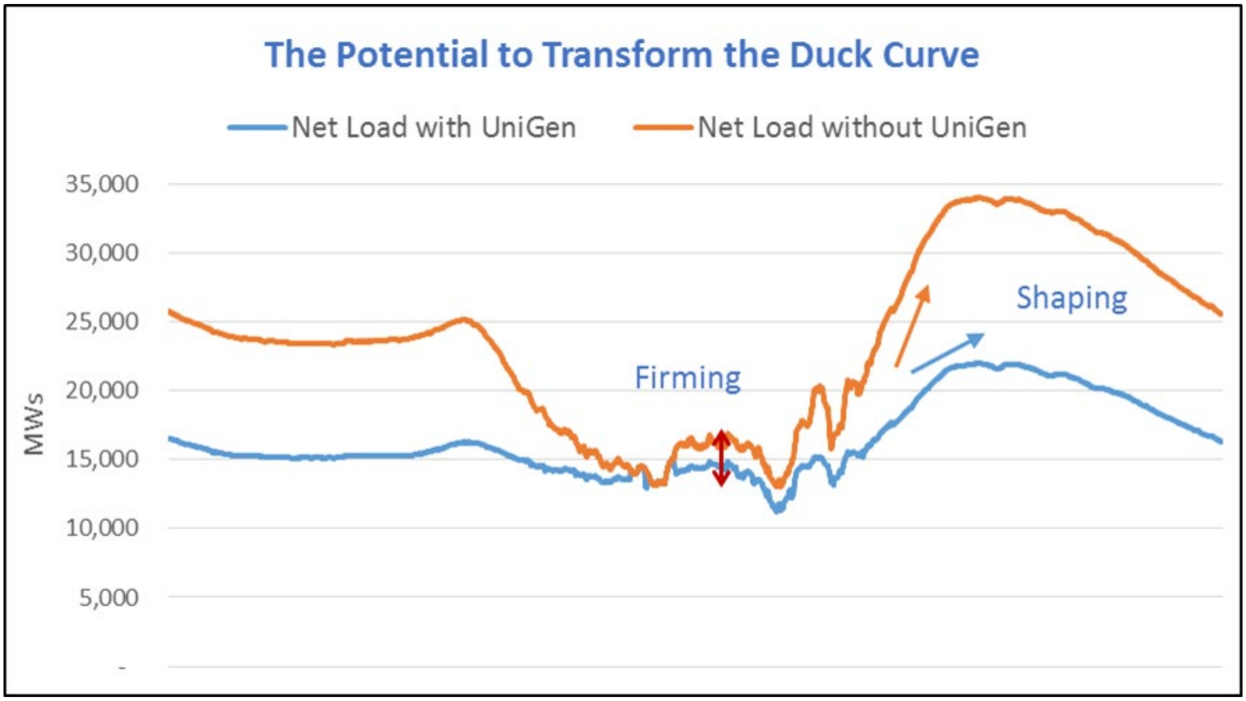
Source: Onset, Inc.

Figure 42: Results with Early Mover Algorithm



Source: Onset, Inc.

Figure 43: UniGen and the Transformation of the Duck Curve



Source: Onset, Inc.

This particular analysis demonstrates that UniGen can appreciably reduce the ramps caused by overgeneration and VER forecast errors. Said differently, it can firm and shape the generation supply curve to support California ISO's efforts to integrate higher levels of VERs. It provides market participants with financial incentives to change behavior by cooperating to turn individual resources into a UniGen plant. Those incentives are the abililty to schedule all of the VER output in the day-ahead market, thereby avoiding negative prices, for its asset to become part of a UniGen hybrid plant and earn a steady revenue from large energy sales (capacity factors are over 50 percent in these analyses.)

Can Combined Cycle Plants Help?

One of the side effects of overgeneration is the requirement to keep slow start resources, such as a CCCT, at minimum load.[18] These are referred to as "minimum dispatchable thermal units." Because these units take 60 to 90 minutes to start up and

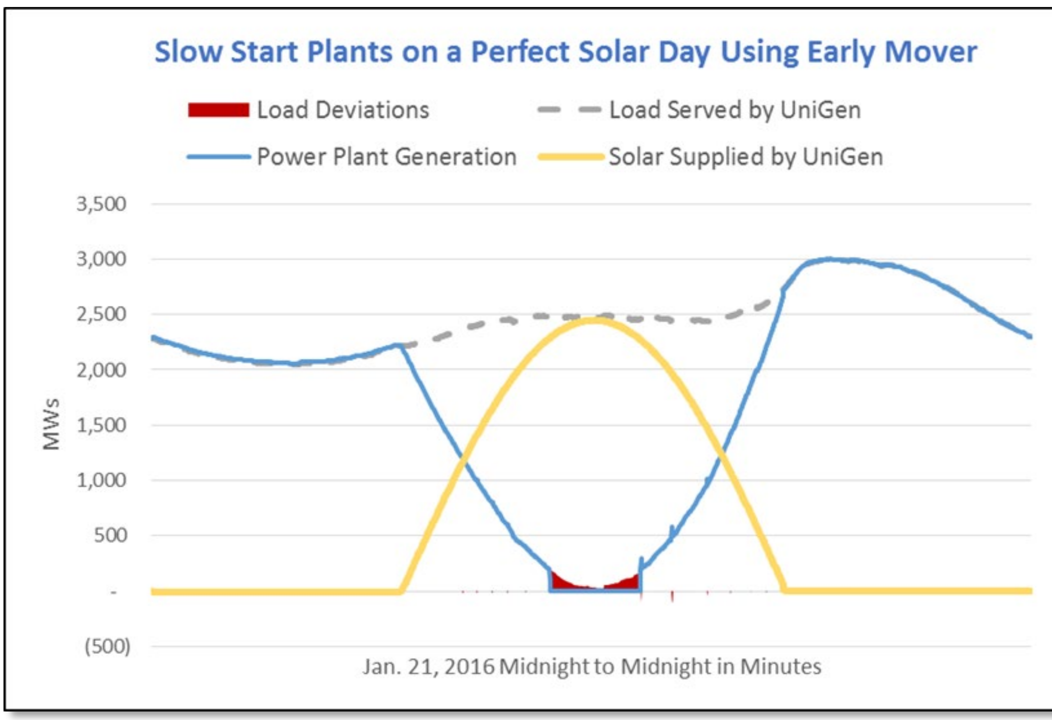
[18] Typically, minimum load or Pmin is 40 percent of full load. This limit is set not by any mechanical or physical constraints but by air emission restrictions. Emissions, especially CO_2, which cannot be captured by catalysts like other pollutants, increase sharply as the plant decreases its output and 40 percent has generally been the point at which the level of emissions becomes unacceptable. It has been reported that perhaps Pmin as low as 20 percent may be achieved, but the authors are unfamiliar with the details to know if this is credible, and use 40 percent in these analyses.

synchronize with the grid, the current thinking is that they should always be on-line and therefore ready to chase the afternoon ramps. The downside is the amount of natural gas that must be consumed for this strategy to work, thereby incurring costs in terms of dollars and CO_2 emissions.

The requirement to keep these units at their minimum load set point instead of shutting them down until needed stems from the reactive nature of the California ISO market. Dispatch orders are issued by the market only if deviations from expected generation occur and are issued only every five minutes. UniGen, however, operates differently. UniGen has intelligence embedded within it (the Early Mover algorithm being an example), which anticipates when the controllable plants will be needed, starts them accordingly, and then manages their output in real time. As a result, the slow start plants can be shut down when not needed.

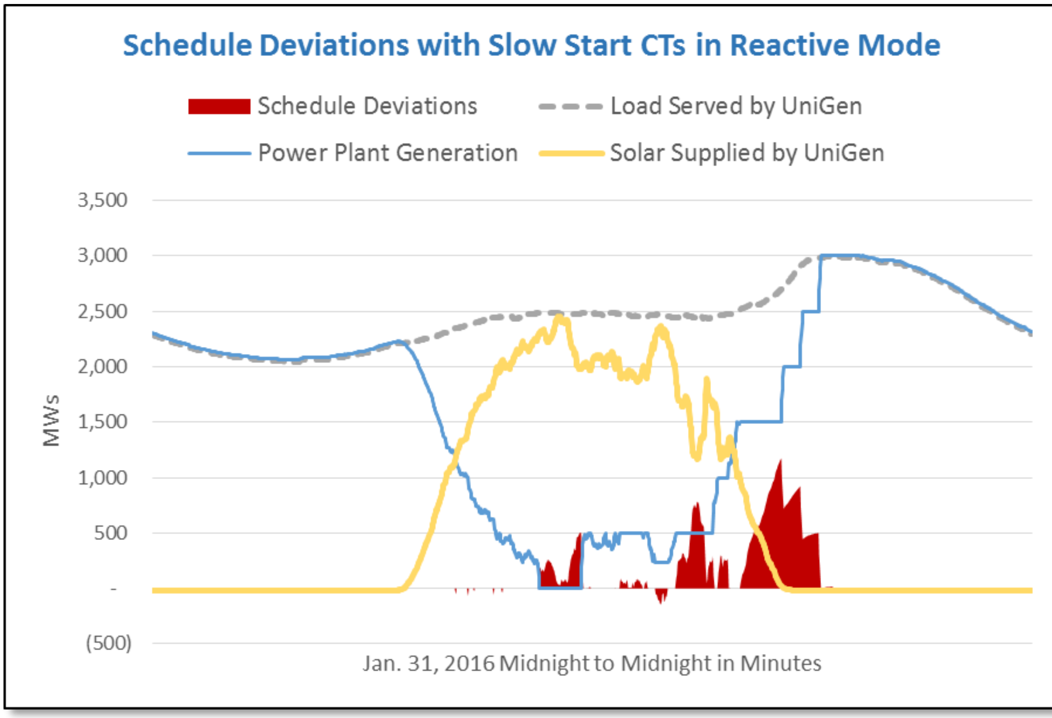
The results of the simulations confirm this as depicted in Figure 44, Figure 45, and Figure 46.

Figure 44: Combined Cycle Plants with UniGen on a Perfect Solar Day



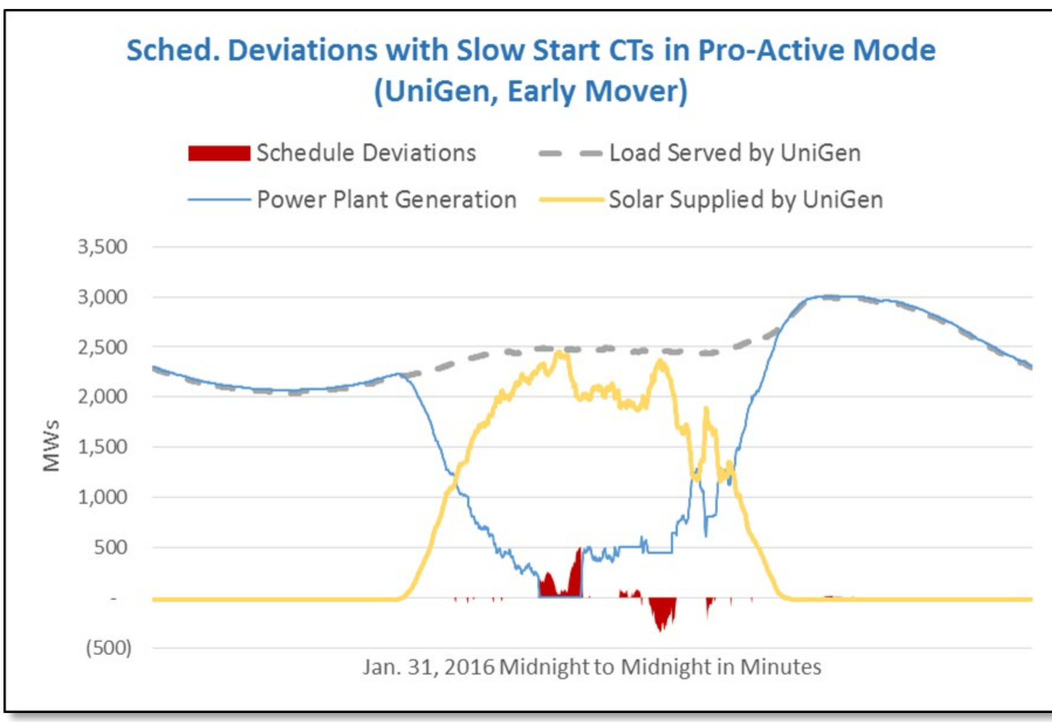
Source: Onset, Inc.

Figure 45: Using Combined Cycle Plants to Maintain the Schedule



Source: Onset, Inc.

Figure 46: Using Combined Cycle Plants and UniGen to Maintain the Schedule



Source: Onset, Inc.

For example, Figure 46 shows the results of a simulation in which the CCCTs were in shutdown mode, were then issued a dispatch order when the deviations exceeded their minimum load, after which they took 60 minutes to synchronize to the grid. The schedule deviations in the afternoon are unacceptably high because the slow start units cannot keep pace with the rapidly increasing demand for power.

However, UniGen correctly anticipates when the plants are needed. The schedule deviations are minimal for slow start plants just as they were for fast start ones.

This is a happy result. There is much more capacity in California ISO that is slow start. The fact that smart control systems make these resources just as effective as fast start ones means more capacity can be brought to bear (converted to UniGen plants) on the overgeneration issues. As an added benefit, the heat rate of combined cycle plants when used in a UniGen plant is quite good (7.5 MBTU/MWh). This means that fuel cost and CO_2 emissions will be less than simple cycle plants used in the same way.

This illustrates the benefits of transitioning from a supply management process that is reactionary, which all centralized markets seem to have, to a proactive process such as UniGen. Moreover, scheduling in the day-ahead market provides a predictable plan—that is, information — to California ISO. All of these features will transform the grid into one with less CO_2 and other emissions, which is the objective of the RPS directed by the state.

What Was Learned

The purpose of this study was to see if UniGen could have a positive and important effect on system reliability during conditions of overgeneration. A second purpose was to investigate the feasibility of implementing UniGen as a renewable integration tool. This study shows that:

- The rapid growth of solar on the California ISO system and the resulting "generation hump" of midday supply is the primary determinant of the Duck Curve. UniGen plants, which consist of solar and controllable power plants working together, mitigate the effects of overgeneration conditions by diminishing the magnitude and shape of the afternoon ramps. The Duck Curve can be transformed into a different shape that the authors call the Dog Curve, which does not have the large afternoon ramps that are very difficult to manage, at least within the bounds of reasonable costs and CO_2 emissions. The number of flexible resources, an estimate of which was made in this study, determines the extent to which this transformation can be accomplished. The impact of UniGen was measured by reductions in the ratio of peak-to-minimum generation (the trough to the crest of the wave of generation), and by average ramps. For example, 6,000 MW of UniGen plants would reduce these measures by 20 percent.
- The UniGen strategy is to schedule the combined output of the two resources in the day-ahead market to serve load with a typical profile. A central feature of the

UniGen hybrid strategy is to create a schedule that ensures 100 percent of the solar generation is delivered (no curtailment). This helps advance the goals of the RPS while minimizing the impact on schedules and system reliability.

- The UniGen strategy results in important financial benefits that would motivate market participants (that is, resource owners) to change their behavior and adopt the UniGen approach. This change in behavior would directly benefit California ISO by supporting its efforts to maintain system frequency during conditions of overgeneration.
- Because it is a *Smart System*, UniGen uses algorithms to manage and optimize the resources. The Early Mover algorithm, for example, reduced schedule deviations from levels that were unacceptable and undermined the strategy. These reductions were demonstrated to be minimal and in some cases near zero.
- UniGen proved to be successful in reducing schedule deviations for perfect solar days and days when the actual solar generation differed substantially from forecasts. This is an important finding because it means UniGen addresses two problems: firming the generation supply when VERs deviate from forecasts, in addition to reducing the afternoon ramps.
- Another important finding is that slow start plants can be just as effective as fast start ones in terms of reducing the afternoon ramps with a minimal amount of schedule deviations. This means that simple cycle and combined cycle plants can be used to flatten the belly of the Duck Curve.

It is generally acknowledged that the emergence of the smart grid must be supported by new technologies and, more importantly, changes in behavior and business practices. UniGen, for example, requires resource owners to cooperate instead of individually bidding into the market, a change in business practices that have been in place for years. UniGen is a distributed, market-based solution that identifies schedule deviations and makes corrections in real time so that the problem does not propagate into the California ISO control room. It is a solution used by private parties instead of the California ISO, which requires a change in thinking that solutions should be centralized and under the control of one party.

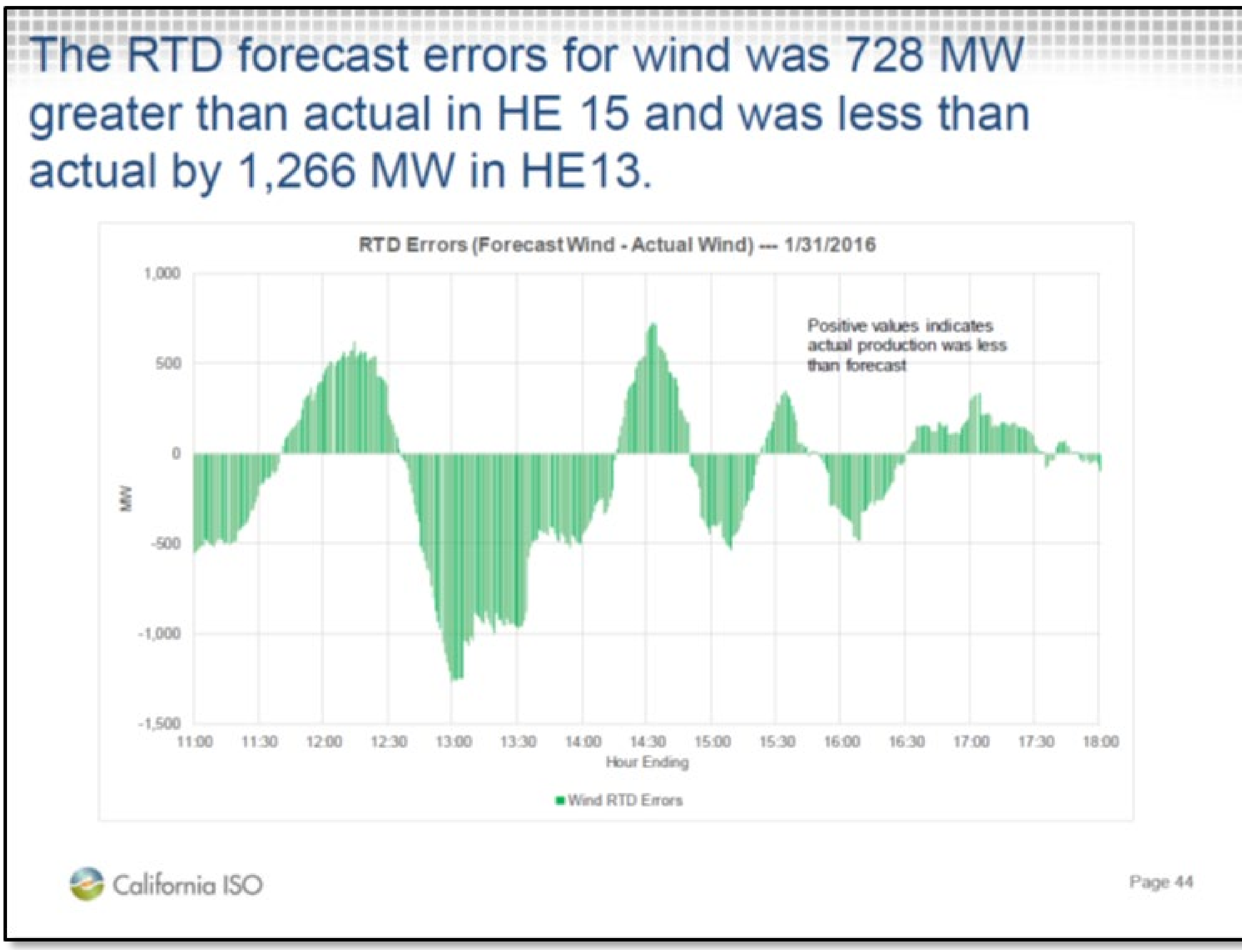
Change is good but not easy. To paraphrase Charles Darwin, it is not the strongest or most intelligent species that survive; it is the one most adaptable to change.

CHAPTER 4: Enhancing the Primary Frequency Response Using the UniGen Smart System

Introduction

In 2014, the Federal Energy Regulatory Commission approved a new grid reliability standard, BAL-003-1. The standard stipulates that each balancing authority, including California ISO, demonstrates it has sufficient capability to respond to grid disturbances resulting in the decline of system frequency. Examples of grid disturbances requiring an appreciable response include the loss of a major power plant or transmission line (contingency events) and considerable deviations in actual VER generation compared to forecasts (or schedules). A recent example of the latter is shown in Figure 47.

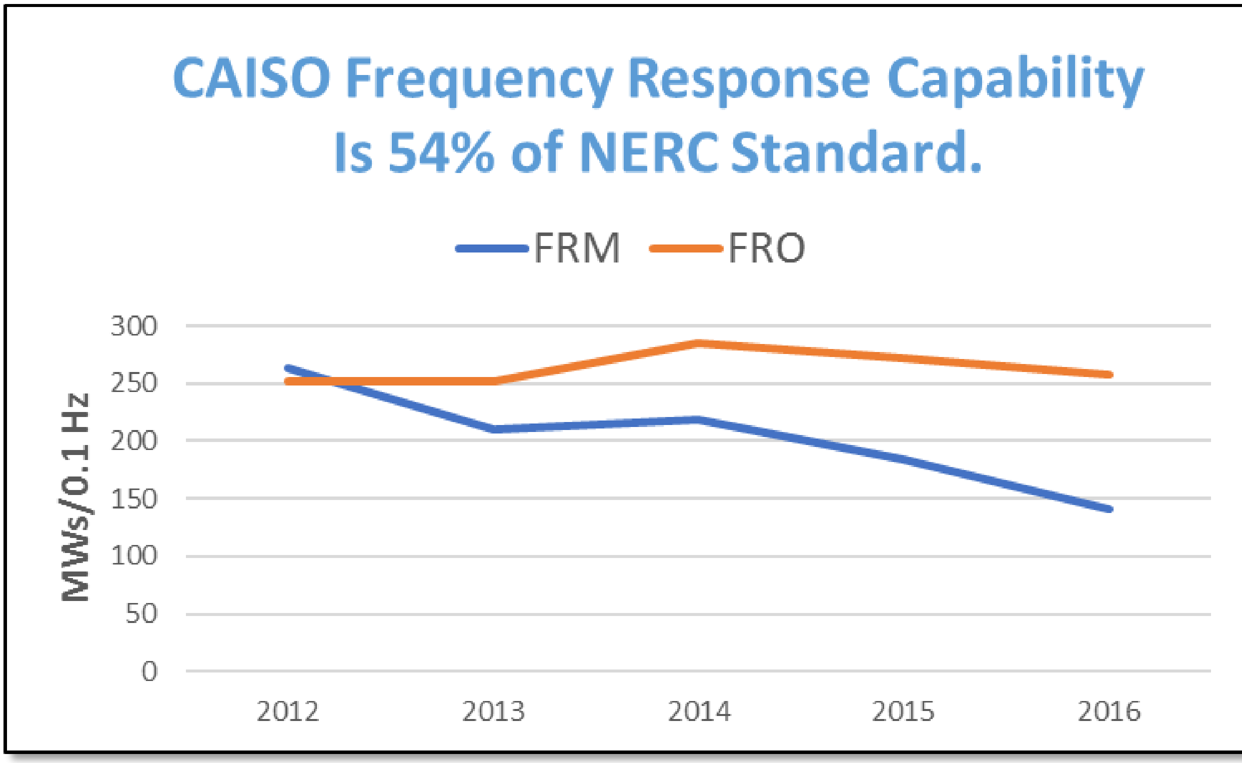
Figure 47: Forecast Errors Are Equivalent to a Contingency Event



Source: Onset, Inc.

As part of the new standard, balancing authorities are required every year to calculate their frequency response obligation and frequency response measure. These metrics are shown in Figure 48.[19]

Figure 48: Frequency Response Capability for California ISO



Source: Onset, Inc.

According to California ISO, the decline results from the increase in renewable generation, which does not provide primary frequency response:

> *Operations identified the main driver of this trend is largely the result of the increased proportion of renewable generation. Renewable generation amounts will continue to increase as California reaches its renewable goals. Given this trend, the ISO finds its projected performance insufficient to meet BAL-003-1 or support system reliability. Phase 2 of the initiative will evaluate a market mechanism to ensure sufficient primary frequency response performance in long-term."*[20]

UniGen is a market mechanism that enhances primary frequency response and the day-to-day regulation management.

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[19] Frequency Response, Draft Final Proposal, February 4, 2016, p. 10.<authors?>

[20] http://www.elp.com/articles/2016/02/california-iso-to-address-frequency-response-amid-renewable-power-gains.html

In the bulk power system, forecasting and scheduling demand and generating resources are the initial steps in maintaining power system frequency. Controllable generating resources then provide adjustments to ensure that supply equals demand in real-time operations and the system stays in balance. This existing process is currently being challenged by the use of intermittent sources such as wind and solar, which can affect total supply and demand forecasts. More flexible resources and more dynamic control schemes are clearly needed to adapt the system design to meet the disruptive renewable sources being put into use in large numbers.

In this report, the goal is to demonstrate how UniGen can potentially enhance the frequency profile of a multi-area system, such as the system under control of California ISO. For this purpose, the following sections will be further explained and discussed in this report:

- Frequency control in multi-area systems with no renewable generation.
- Effect of uncontrolled renewable generation on system frequency.
- Contribution of UniGen to improvement of system frequency.
- Enhanced control of frequency with UniGen using a "Renewable Generator Governor."

In the upcoming sections, results of all discussions have been demonstrated through modeling of a multi-area system with Matlab/Simulink simulation software. All data and parameters used for simulations are based on historic data received from California ISO as well as opinions of experts in the field.

Assumptions

The following assumptions have been made in the analysis:

- Interactions between load frequency control and automatic voltage regulator control systems have been assumed to be noninterdependent. This assumes that in bulk generation transmission systems, changes in active power will primarily affect system frequency; whereas changes in reactive power will mostly affect the local system voltage profile.
- Simulation of supply deviations and the resulting frequency deviations is conducted under steady-state conditions on a 1-minute sliding-window period. This means that after new supply schedule deviations are introduced to the system at the beginning of each time interval (1-minute scale), accumulative behavior of system design components will take the system to another level of frequency well before the next set of schedule deviations is introduced. Under these circumstances, transient (less than a minute) frequency deviations have been ignored.
- Active power, MW, transmission losses are negligible throughout the system.

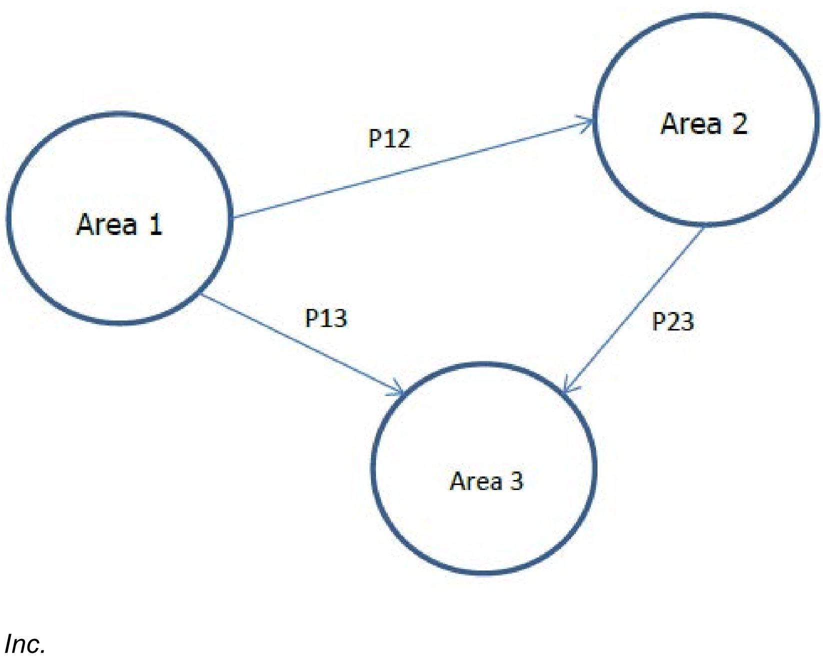
Frequency Control in Multi-Area Systems With No Renewable Generation

Figure 49 depicts a three-area study system with interconnecting tie-lines and power transactions scheduled between the areas shown by P_{12}, P_{13} andP_{23}. All generators in a single area of the system have been combined to form three equivalent synchronous generators in the whole system. As known, frequency of the generated power for a synchronous generator is directly dependent on its rotor speed through the following equation:

$$n = \frac{120 \times f}{P} \qquad (1)$$

where *n* is the rotor speed in rpm, *f* is the frequency in hertz (Hz) and *P* is the number of poles of the machine. As the balance between mechanical power and electric power of the generator is compromised, speed of the rotor and consequently frequency of the machine will deviate from its rated value. When multiple machines are interconnected as shown in Figure 49, schedule deviations inside one of the areas will produce a response by all areas of the system until the frequency of the whole system reaches a new steady-state value. Transition of the frequency from one state to another state, however, will be different for each individual area of the system, which depends on the dynamics of the components inside each individual area.

Figure 49: Schematics of Multi-Area System

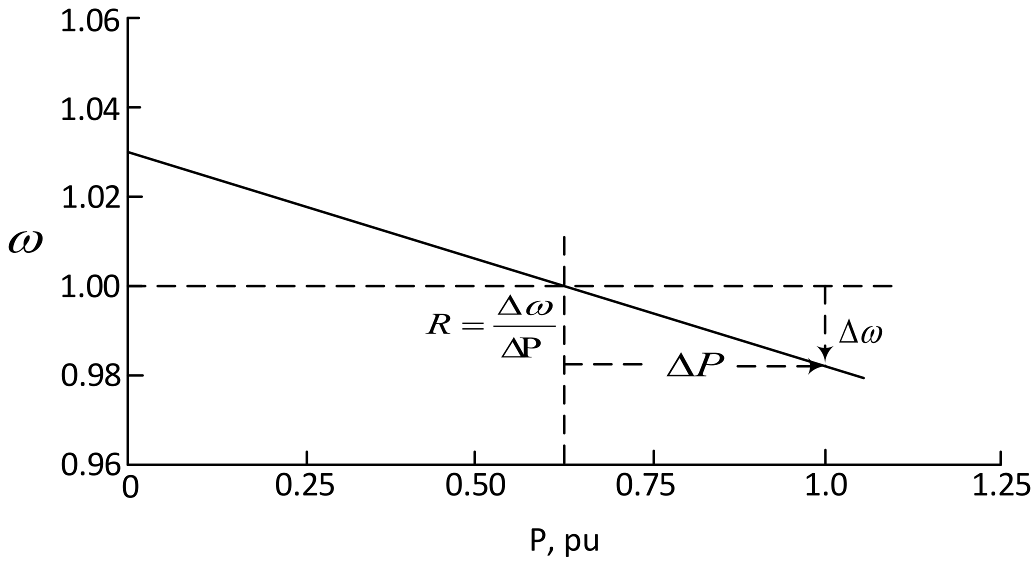


Source: Onset, Inc.

Load Frequency Control

The first stage of frequency control for a synchronous machine is accomplished through load frequency control based on the speed droop line shown in Figure 50. Load frequency control means that if a turbine's load (or in other words, the electric power demand) is suddenly increased relative to supply, the supplying generators will naturally decrease their rotational speed. The generator governor senses this decrease in synchronous speed and its controls respond individually based on the droop line of Figure 50. It is assumed for this study that when more power is released from the generator, its speed or frequency will drop with a slope of $R = \Delta\omega/\Delta P$. (R is commonly referred to as the generator droop.) Therefore, load frequency control will be needed to counteract to increase the mechanical power by $\Delta P = \Delta\omega/R$.

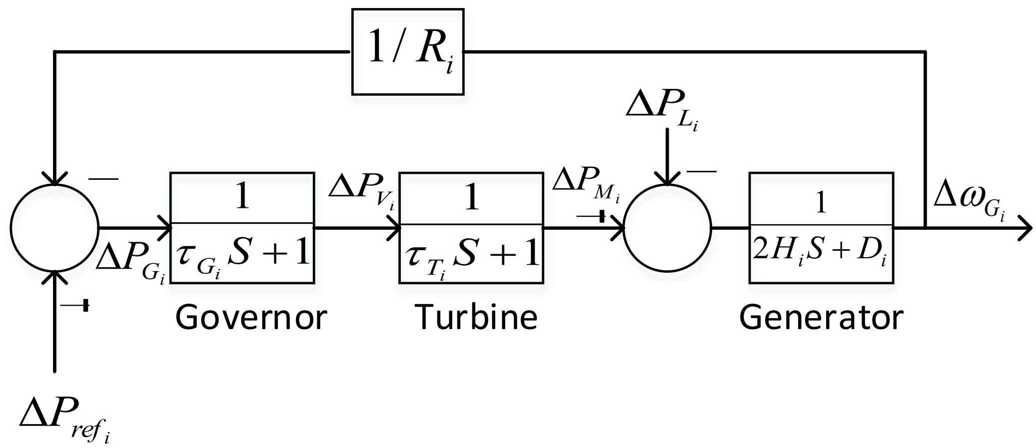
Figure 50: Load Frequency Control Based on Droop Line



Source: Onset, Inc.

Figure 51 shows a simple block diagram associated with load frequency control. In the diagram, $\Delta\omega$ and ΔP_L are the changes in frequency and electric load, respectively. Changes of frequency will feedback through droop control to the governor, which will further change the valve position and mechanical power. In this figure, ΔP_g, ΔP_V, and ΔP_m are the changes to power generation, turbine valve position, and mechanical power in the Laplace domain (where S is the Laplace operator), respectively. Other parameters in this block diagram are τ_g and τ_T, which are the time constants of the governor and turbine. Finally, H is the constant of inertia and D is the damping coefficient of the generator.

Figure 51: Load Frequency Control Block Diagram for Single-Area System



Source: Onset, Inc.

It can be shown that in steady state, the change in frequency associated with the change in electric load can be written as:

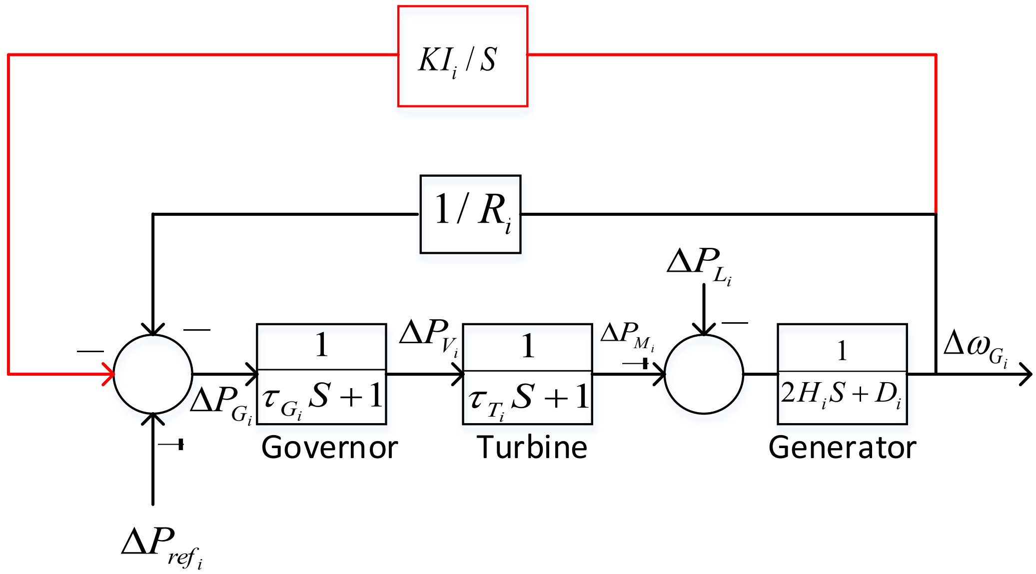
$$\Delta f_{ss} = -\Delta P_L \left(\frac{1}{D + \frac{1}{R}} \right) \qquad (2)$$

where Δf_{ss} and ΔP_L are the changes in steady-state frequency and electric load, respectively. The minus sign in equation (2) indicates that an increase in electric load will result in a decrease in frequency. It can be seen that if $D + 1/R$ is big, error on frequency will be small. Moreover, from equation (2) it can be seen that the droop control alone cannot set the error of frequency to zero. As a result, further control is needed to minimize the error of frequency.

Automatic Generation Control

The next stage in controlling the frequency of a generator is through automatic generation control (AGC). In AGC, a change in the setting of the generated power (ΔP_{ref}) is commanded to set the error of frequency back to zero. It can be shown that if the changes of frequency are fed back through an integrator with gain k_I, the resulted ΔP_{ref} signal can change the generation of power to bring the steady-state frequency back to its nominal value. Figure 52 depicts this scheme, where the red path is associated with AGC.

Figure 52: AGC Block Diagram for Single-Area System



Source: Onset, Inc.

AGC in Multi-area Systems

In a multi-area system under control of a balancing authority, when an imbalance occurs between load and generation in one of the areas, not only the frequency of the whole system, but also scheduled transactions of power between areas of the system will be affected. To maintain the frequency in such a system, an AGC scheme called tie-line bias control is used. Figure 53 depicts the block diagram of area *i* of the system and its relationship to other areas. Subscripts *i* in this figure indicate that the parameters are associated with area *i* of the system. The red paths in this figure are associated with AGC. To reduce the error in frequency, each area calculates an area control error based on the following:

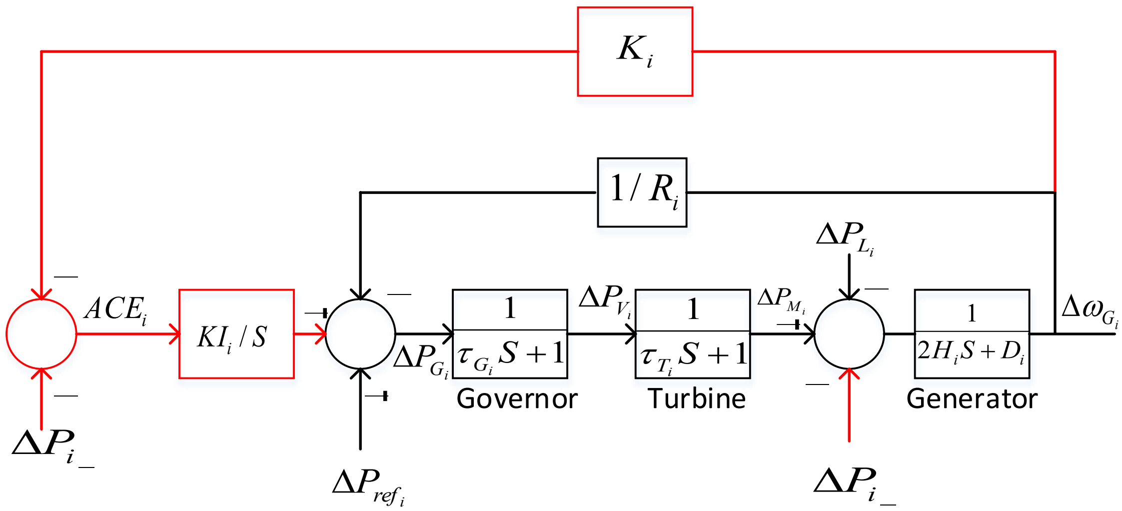
$$ACE_i = K_i \Delta\omega + \Delta P_{i\_} \tag{3}$$

where K_i is a gain specific to area *i* and $\Delta P_{i\_}$ is the change in power transactions between area *i* and other areas of the system. To be more specific:

$$\Delta P_{i\_} = \sum_{\substack{j=1 \\ j \neq i}}^{n} \Delta P_{ij} \tag{4}$$

where *n* is the number of areas in the system and ΔP_{ij} is the transaction of power from area *i* to area *j*. If the losses are negligible, it can be assumed that $\Delta P_{ij} \approx \Delta P_{ji}$.

Figure 53: AGC in Multi-Area System



Source: Onset, Inc.

In a multi-area system, load frequency control is the fastest control to respond to system needs. Depending on the parameters of the generator and turbine-governor, load frequency control can take from a few seconds up to a minute to affect the system. For certain types of power plants, such as nuclear, it is not implemented at all (that is, $R = \infty$), since it is not feasible to vary power generation.

The next stage of control (that is, AGC) is a slower control loop, which affects the system in a matter of few minutes. In California ISO, only a small fraction (1 to 2 percent) of the whole capacity of generation is dedicated to AGC.

The third and slowest loop that affects system frequency is associated with the changes in generator settings ($\Delta P_{ref,i}$) raised by market activities. This loop can usually impact the system in a matter of 30 minutes to a few hours.

Impact of Uncontrolled Renewable Generation Production Variation on System Frequency

To quantify the impact of over- or underproduction deviation from scheduled generation of an equivalent renewable source on system frequency, a simple transfer function based on the following is used:

$$\Delta\omega_{R,i} = K_{R,i}.\Delta P_{R,i} \qquad (5)$$

where:

$$K_{R,i} = \frac{\partial \omega_{R,i}}{\partial P_{R,i}} \qquad (6)$$

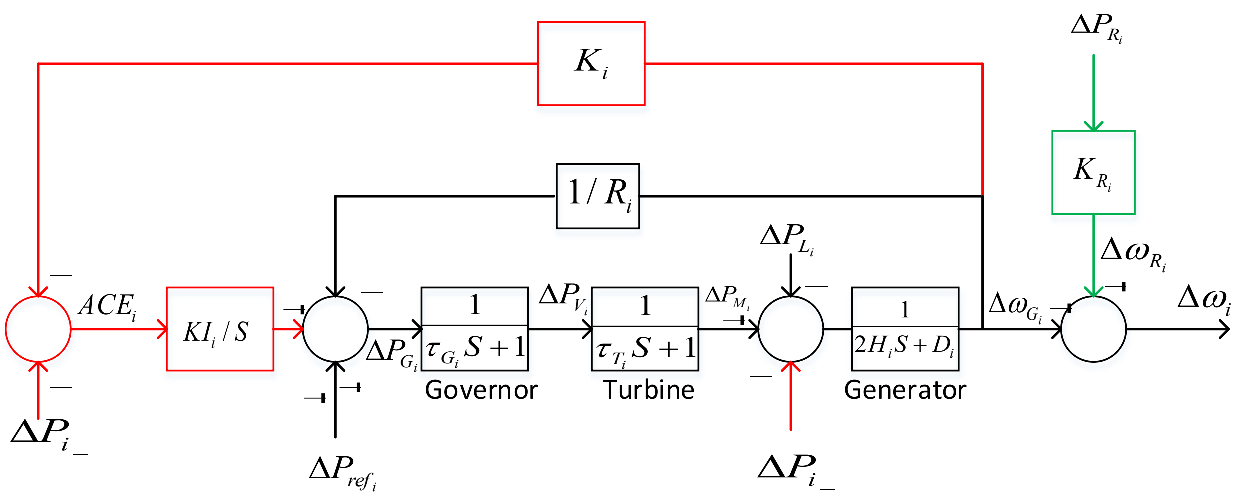
In (5), $\Delta P_{R,i}$ is the schedule deviation of the equivalent renewable source in area *i* and $\Delta\omega_{R,i}$ is the resulting deviation of frequency in area *i* contributed by the renewable source. $K_{R,i}$ is a coefficient defined by (6) and is derived from empirical data. In this study, an overfrequency of 0.1 Hz caused by 750 MW of overgeneration in a 30 GW-rated system has been considered to find $K_{R,i}$.

Frequency deviation of area *i* based on combined contribution of the equivalent generator and the equivalent renewable source can be written as:

$$\Delta\omega_i = \Delta\omega_{G,i} + \Delta\omega_{R,i} \qquad (7)$$

Figure 54 shows the block diagram of frequency deviations in area *i* caused by an equivalent conventional and an equivalent renewable source.

Figure 54: Block Diagram of Frequency Impacted by Renewable Generation



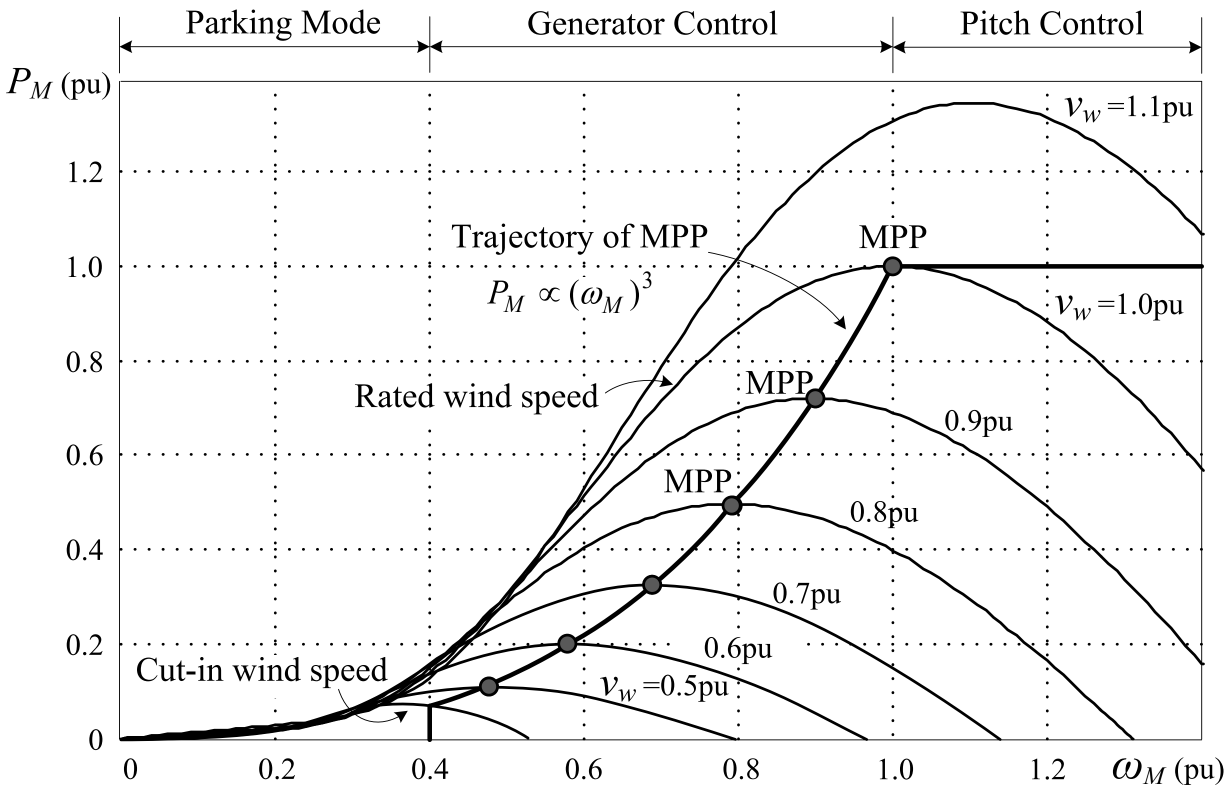
Source: Onset, Inc.

In this figure, the path associated with renewable generation is shown in green. When studying the impact of schedule deviations on system frequency, depending on the area of the system, some of the components in Figure 54 may or may not exist. For example, if no renewable generation exists, $K_{R,i}$ and as a result $\Delta\omega_{R,i}$ will be zero. Similarly, if the generator does not participate in AGC, K_i and $K_{I,i}$ will be zero. Finally, if the generator does not provide load frequency control, then $R_i = \infty$.

Impact of Controlled Renewable Generation on System Frequency

In this section, the authors provide a method to calculate the impact of controlled renewable generation on system frequency. "Controlled renewable generation" indicates responsible release of renewable energy to reduce negative impacts of overgeneration or undergeneration on frequency variations. Under normal conditions, independent power producers will try to maximize the generation of renewable energy sources based on maximum power point tracking methods. This is because independent power producers are paid more when they generate more. To provide a background to maximum power point tracking, it needs to be noted that based on characteristics of a renewable source (for example, a wind turbine) in a particular situation (for example, wind speed); it is possible to control the source of power through power electronic converters in a way to extract the maximum power. In the case of wind power, this happens when the turbine's speed is controlled as a function of the wind's speed. In other words, while wind speed changes during different hours of a day, it is possible to maximize the extracted power if the turbine's rotational speed also changes according to a nonlinear power curve (Figure 55).

Figure 55: Wind Turbine Power Speed Characteristics and Maximum Power Point (MPP) Operation



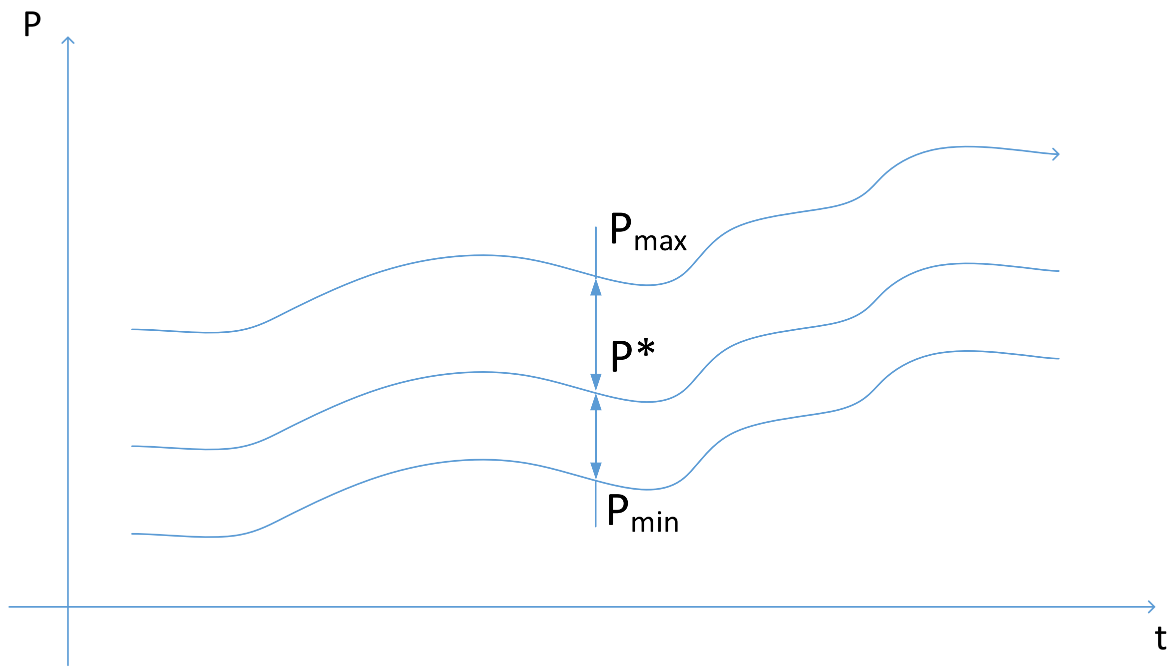
Source: Onset, Inc.

In Figure 55, a collection of $P_M - \omega_M$ curves at different wind speeds is shown, where P_M is the power extracted from the turbine and ω_M is the turbine's rotational speed. For example, when wind speed is at $v_W = 1.0$ pu, the maximum possible extracted power will be at $P_M = 1.0$ pu, if the turbine's speed is controlled at $\omega_M = 1.0$ pu. Therefore, independent power producers will try to maximize power generated through maximum power point tracking control.

On the contrary, it has been observed that overgeneration of power during peak-generation periods can result in overfrequency. The goal in this section is to provide a method that can enhance system frequency using a governing system similar to droop control in synchronous generators.

To explain this concept, Figure 56 shows the forecast of power generation associated with a renewable source over a certain period of time. The upper graph (P_{max}) shows the maximum predicted generation based on maximum power point tracking. Based on the renewable generation governing concept, however, a lower value (P^*) will be generated under normal frequency conditions. This is to provide some room ($P_{max} - P^*$) in case more generation is needed when system frequency is low. On the other hand, the renewable source will be allowed to generate less (up to P_{min}) in case system frequency is too high.

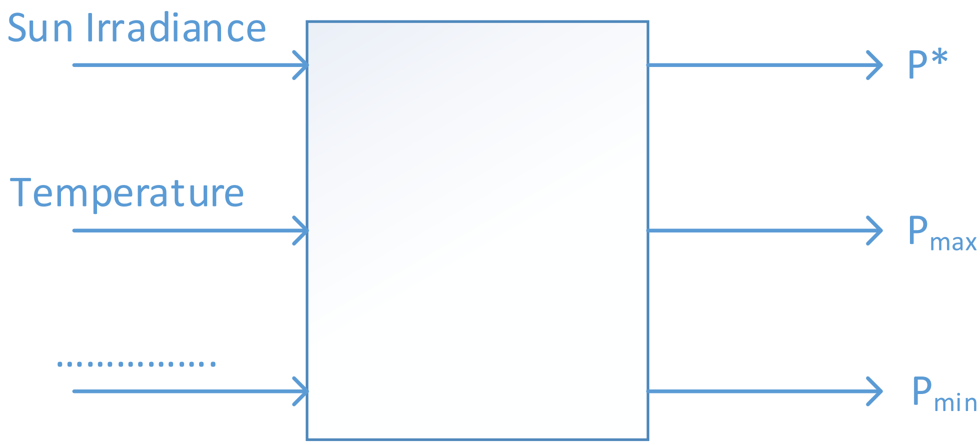
Figure 56: Scheduled, Minimum and Maximum Generation of Renewable Source



Source: Onset, Inc.

In general, to determine the upper and lower bands, a decision-making block similar to Figure 57 will be used. In the case of solar generation, elements such as sun irradiance and temperature, and in the case of wind generation, elements such as wind speed will be the inputs to the block. On the output, the block will then determine the minimum, maximum, and scheduled power generations specific to the conditions of the moment.

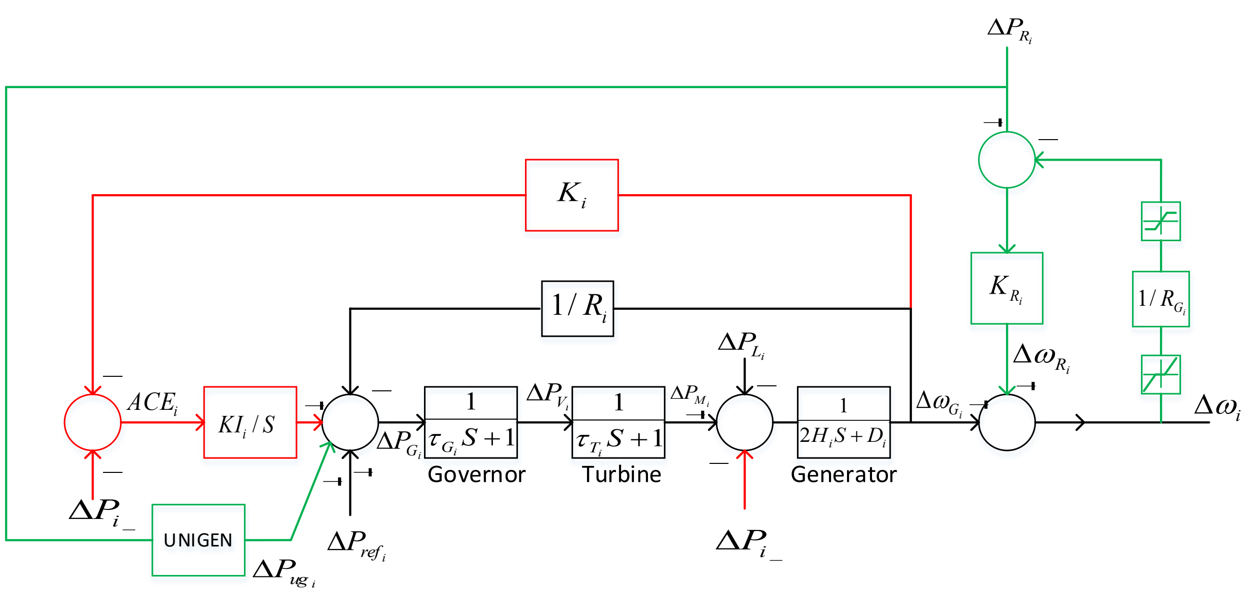
Figure 57: Decision-Making Block to Determine Renewable Generation Limits



Source: Onset, Inc.

The renewable generation governing system, similar to the droop control in synchronous generators (Figure 50) will receive system frequency as its input and will determine the change in active power (ΔP) required to be added to P^*. In practice, a dead band will be applied for frequency inside which no action will be considered as necessary. Figure 58 shows schematics of a renewable frequency governing system embedded in AGC block diagram. From this figure, it can be seen that the output of the governing system will be limited to the upper and lower limits (P_{max} and P_{min}) to ensure proper operation.

Figure 58: Schematics of Renewable Generator Governor Embedded in AGC



Source: Onset, Inc.

Steady-State Solution for Frequency in a Multi-area System

To quantify the impact of schedule deviations on frequency during steady-state conditions, the combined algebraic equations of the areas are solved for the following unknowns:

$$\begin{aligned} &\Delta P_{M,i} = \Delta P_{V,i} = \Delta P_{G,i} \\ &\Delta P_{i\_} \qquad\qquad i = 1,2,\dots,n \qquad (8) \\ &\Delta\omega = \Delta\omega_i \end{aligned}$$

Where inputs to the above problem are denoted as "schedule deviations," including deviations of electric loads, renewable generations and settings of the generators:

$$\begin{aligned} &\Delta P_{L,i} \\ &\Delta P_{R,i} \qquad\qquad i = 1,2,\dots,n \qquad (9) \\ &\Delta P_{ref,i} \end{aligned}$$

To find the unknowns in (8) based on Figure 57,the following equations can be written in steady state:

$$\Delta P_{M,i} - \Delta P_{i\_} - \Delta P_{L,i} - D_i\left(\Delta\omega - \Delta\omega_{R,i}\right) = 0 \qquad i = 1,2,\dots,n \qquad (10)$$

$$K_{I,i}\left[-K_i\left(\Delta\omega - \Delta\omega_{R,i}\right) - \Delta P_{i\_}\right] = 0 \qquad i = 1,2,\dots,n \qquad (11)$$

Assuming system lossless, then:

$$\sum_{i=1}^{n} \Delta P_{i\_} = 0 \qquad i = 1,2,\dots,n \qquad (12)$$

If $K_{I,i} \neq 0$ (that is, when generator does not participate in AGC), then from (11) it can be concluded that:

$$\Delta P_{i\_} + K_i.\Delta\omega = K_i.\Delta\omega_{R,i} \qquad i = 1,2,\dots,n \quad K_{I,i} \neq 0 \qquad (13)$$

where:

$$\Delta\omega_{R,i} = K_{R,i}\left(\Delta P_{R,i} - \frac{\Delta\omega_i}{R_{u,i}}\right) \qquad i = 1,2,\dots,n \qquad (14)$$

Substituting (14) into (13) gives:

$$\Delta P_{i\_} + K_i \left(1 + \frac{K_{R,i}}{R_{u,i}}\right) \Delta\omega = K_i . K_{R,i} . \Delta P_{R,i} \qquad \begin{matrix} i = 1,2, \dots, n \\ K_{I,i} \neq 0 \end{matrix} \qquad (15)$$

When $K_{I,i} = 0$, then from the block diagram of Figure 58:

$$-\frac{\Delta\omega - \Delta\omega_{R,i}}{R_i} + \Delta P_{ref,i} + \Delta P_{ug,i} = \Delta P_{M,i} \qquad i = 1,2, \dots, n \qquad (16)$$

Substituting $\Delta P_{M,i}$ from (10) into (16) gives:

$$\Delta P_{i\_} + B_i \left(1 + \frac{K_{R,i}}{R_{u,i}}\right) \Delta\omega = B_i . K_{R,i} \Delta P_{R,i} + \Delta P_{ref,i} + \Delta P_{ug,i} - \Delta P_{L,i} \qquad \begin{matrix} i = 1,2, \dots, n \\ K_{I,i} = 0 \end{matrix} \qquad (17)$$

where:

$$B_i = \frac{1}{R_i} + D_i \qquad i = 1,2, \dots, n \qquad (18)$$

Algorithm for Finding Frequency Deviations in a Multi-area System

Based on (8) through (18), the algorithm for finding frequency deviations in a multi-area system can be described as follows:

$$\Delta\omega = \frac{\sum_{i=1}^{n} b_i}{\sum_{i=1}^{n} a_i}$$

where:

$$b_i = K_i . K_{R,i} . \Delta P_{R,i} \qquad \text{if } k_{I_i} \neq 0, \text{ or}$$

$$b_i = \Delta P_{ref,i} + \Delta P_{ug,i} - \Delta P_{L,i} + B_i . K_{R,i} . \Delta P_{R,i} \qquad \text{if } k_{I_i} = 0$$

$$a_i = K_i \left(1 + \frac{K_{R,i}}{R_{u,i}}\right) \qquad \text{if } k_{I_i} \neq 0, \text{ or}$$

$$a_i = B_i \left(1 + \frac{K_{R,i}}{R_{u,i}}\right) \qquad \text{if } k_{I_i} = 0$$

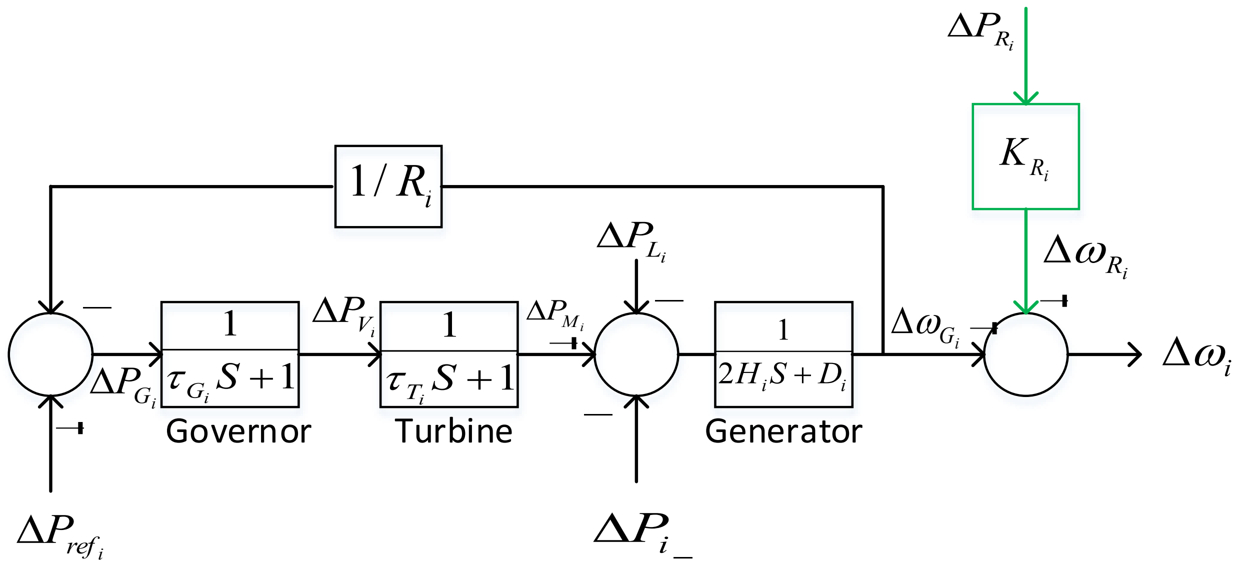
Simulations and Analysis

In this section, frequency deviations have been simulated in a sample three-area system. The three areas are described in the following:

- AGC: Area representing synchronous and renewable generators participating in AGC. Figure 53 represents the block diagram of an AGC area.

- Non-UniGen: Area representing synchronous and renewable generators that are neither part of UniGen nor AGC. This area can be further divided into two subareas:
    - Subarea with synchronous generators that participate in load frequency control, as shown in Figure 59.

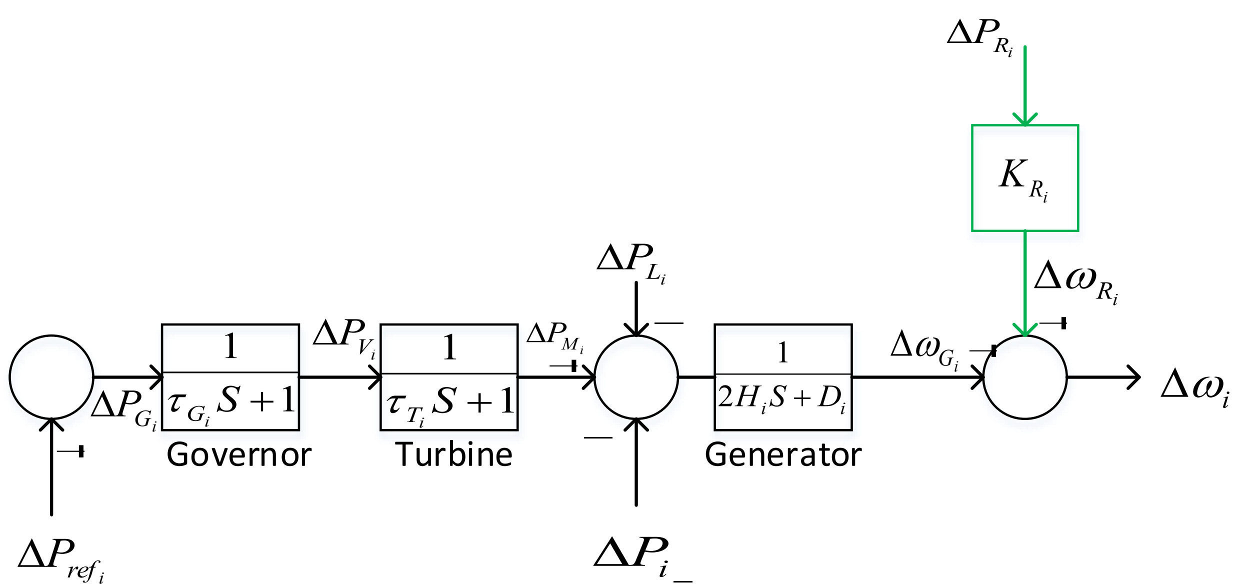
Figure 59: Non-UniGen Non-AGC Subarea with Load Frequency Control



Source: Onset, Inc.

- Subarea with synchronous generators that do not participate in load frequency control, as shown in Figure 60.

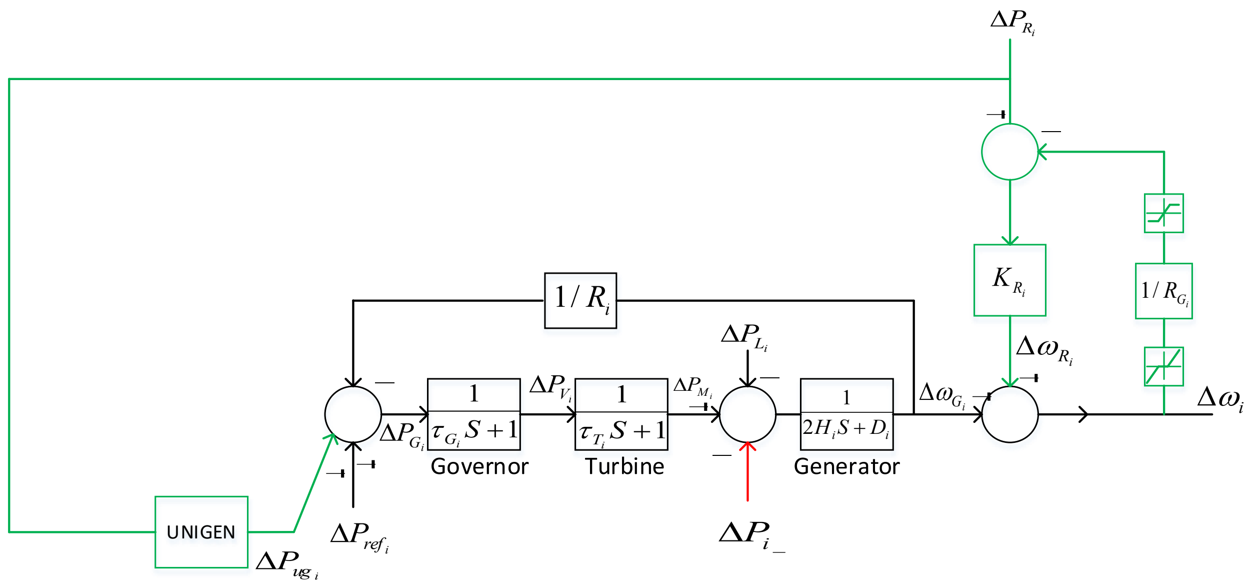
Figure 60: Non-UniGen Non-AGC Subarea Without Load Frequency Control



Source: Onset, Inc.

- UniGen: Area representing synchronous and renewable generators that are part of UniGen. Figure 61 represents the block diagram of a UniGen area. With respect to Figure 59, Figure 61 has an extra input signal ($\Delta P_{ug,i}$) generated by the UniGen logic to counteract schedule deviations.

Figure 61: UniGen Subarea



Source: Onset, Inc.

In the above block diagrams, $\Delta P_{L.i}$, $\Delta P_{ref.i}$ and $\Delta P_{ug.i}$ can be considered as inputs, $\Delta\omega_i$ and $\Delta P_{i\_}$ are outputs, and $\Delta P_{R.i}$ can be considered as noise.

Based on the above block diagrams and the explained method for steady-state analysis, several case studies have been simulated to demonstrate the impact of renewable schedule deviations on system frequency. In these simulations, the authors first demonstrate the effect of $\Delta P_{R,i}$ noises on $\Delta\omega$, and then show how UniGen ($\Delta P_{ug.i}$ inputs) can enhance system frequency by counteracting intermittency of the renewables. Therefore, in the following examples, all other inputs, including load changes ($\Delta P_{L,i}$), as well as the changes associated with market signals ($\Delta P_{ref,i}$), have been ignored. In the following examples, the input data associated with renewable schedule deviations are based on the historic data received from California ISO for a complete year. These data have been scaled to fit the size of a 30 GW system. Based on this, the maximum deviation of the renewables in the upcoming examples is 750 MW. All other parameters, including equivalent generators' parameters that represent different areas of the system, are arbitrary values. These parameters have been tabulated in Table 2. For this table, in the Non-UniGen and UniGen plants, K_i and $K_{I,i}$ parameters are zero, meaning that these plants do not participate in AGC. Moreover, in the following examples, it is assumed that 90 percent of schedule deviations associated with renewable generation inside the UniGen area have been counteracted (compensated) by the generator inside that area.

Table 2: Equivalent Synchronous Generator Parameters Representing Areas of Simulated Examples

Example	Parameter
AGC	Rating: 600 MVA R = 5% (on its own base) D = 0.6 (on its own base) K = D + 1/R KR = 0.0867 pu KI = 0.01 pu $\tau_G = 0.20$ s $\tau_T = 0.52$ s H = 3 s
Non-UniGen	Rating: 27000 MVA R = 10.0% (on its own base) D = 0.6 (on its own base) K = 0 KR = 0.0867 pu KI = 0 $\tau_G = 0.25$ s $\tau_T = 0.50$ s H = 120 s
UniGen	Rating: 2400 MVA R = 5% (on its own base) D = 0.6 (on its own base) K = 0 KR = 0.0867 pu KI = 0 $\tau_G = 0.23$ s $\tau_T = 0.48$ s H = 27 s

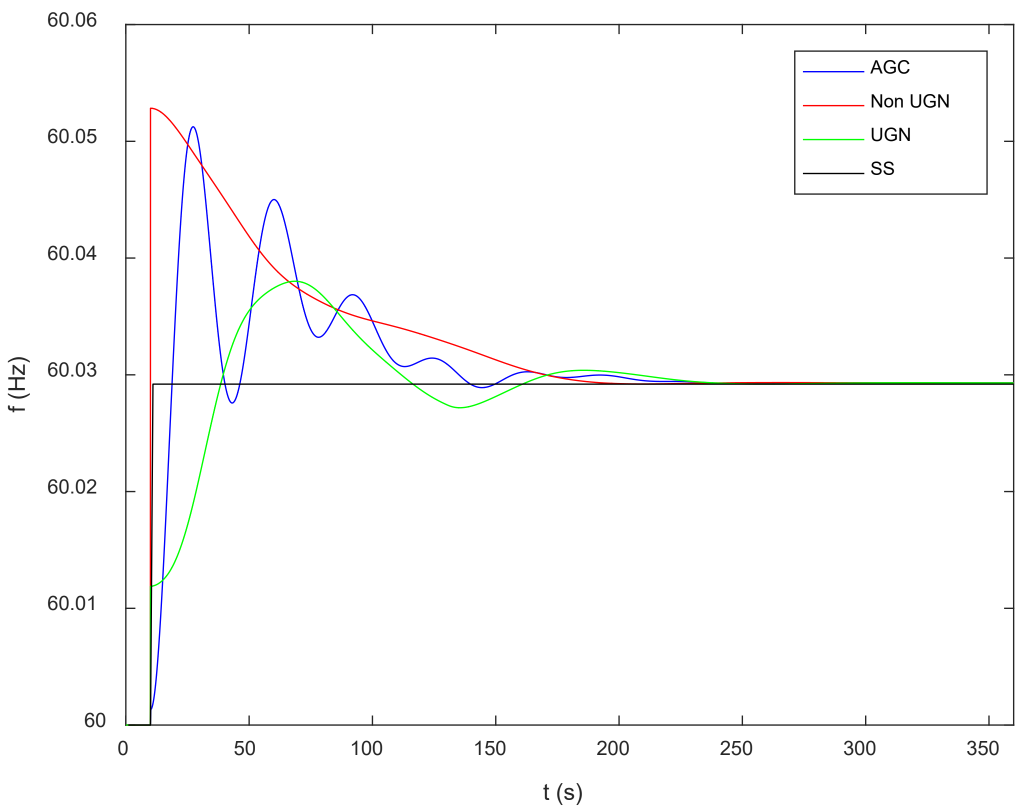
Source: Onset, Inc.

In the following examples, when renewable generator governor is used, it will only be applied in the UniGen area, with 5 percent droop on a 1200 megavolt ampere (MVA) base.

Transient Frequency Profile With No UniGen

In this simulation, transient frequency deviations are tested against steady-state values to determine whether a frequency profile will converge to its expected steady-state solution described in (8) through (18). For this purpose, Matlab/Simulink has been used to simulate a maximum of 380 MW overgeneration of renewables verified in an actual operating day in California ISO based on Table 3. In this simulation, typical values based on Table 2 associated with a 600 MW AGC plant, a 24 GW Non-UniGen plant, and a 5400 MW UniGen plant have been considered. It has been assumed that UniGen will counteract 90 percent (342 MW) of schedule deviations based on a two-minute ramp-up rate. Figure 62 depicts this case, where the "AGC," "Non UGN," and "UGN" plots show the transient frequency responses of the AGC, Non-UniGen, and UniGen areas and the "SS" plot depicts the steady-state response of frequency. As can be seen, transient frequencies of all system areas have been converged to the steady-state frequency of the system in approximately four minutes (240 seconds). This is a typical frequency response in an AGC-based system.

Figure 62: Transient Frequency Response of UniGen Compared with Steady-State Solution



Source: Onset, Inc.

Steady-State Frequency Profile With No UniGen

In this case, the total schedule deviations associated with renewable generations have been divided between the three non-UniGen areas, as shown in Table 3. Since the authors have assumed that renewable generations do not exist in AGC subareas, the corresponding coefficients in AGC subareas will be zero.

Table 3: Percentage of Renewable Schedule Deviations in Different Subareas in Simulation (2)

Simulation	Percentage
AGC	2%
Non-UniGen	98%

Source: Onset, Inc.

Steady-State Frequency Profile with 8 Percent UniGen

In this case, 8 percent of the total capacity of the system is associated with a UniGen area. Percentage of renewable generation schedule deviations for the three areas is tabulated in Table 4.

Table 4: Percentage of Renewable Schedule Deviations in Different Areas in Simulation (3)

Simulation	Percentage
AGC	2%
Non-UniGen	90%
UniGen	8%

Source: Onset, Inc.

Steady-State Frequency Profile with 18 Percent UniGen

In this case, the total schedule deviations associated with renewable generations have been divided between the three UniGen subareas as shown in Table 5.

Table 5: Percentage of Renewable Schedule Deviations in Different Areas in Simulation (4)

Simulation	Percentage
AGC	2%
Non-UniGen	80%
UniGen	18%

Source: Onset, Inc.

Steady-State Frequency Profile with 8 Percent UniGen and Renewable Governor Control

This case is similar to the case in Simulation (4) except that 5 percent of the capacity of the renewable generator has been used for frequency droop control.

A summary of the results associated with the above simulations is shown in Table 6. It can be observed that as the penetration level of UniGen plants in the system increases, frequency deviations become smaller and system frequency gets closer to 60 Hz.

Table 6: Summary of Results

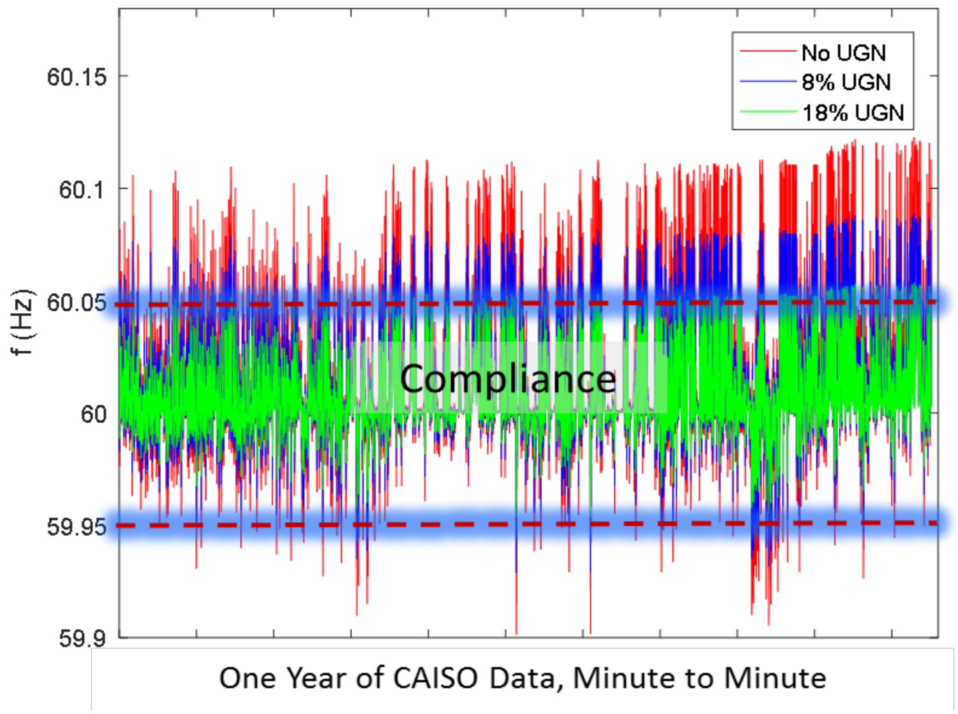
	min f (Hz)	max f (Hz)	mean f (Hz)	Std. dev. f (Hz)
Simulation (2)—No UniGen	59.9014	60.1226	60.0176	0.0335
Simulation (3)—8% UniGen	59.9288	60.0885	60.0127	0.0242
Simulation (4)—18% UniGen	59.9536	60.0577	60.0083	0.0158
0–18% UniGen with Renewable Governor	59.9608	60.0487	60.0070	0.0133

Source: Onset, Inc.

Figure 63 depicts the frequency profile of the system on a yearly basis using the simulated data. In this figure, the two thick red lines depict the under- and overfrequency limits of NERC (59.05–60.05 Hz). As can be observed, the "18% UniGen" case shows a remarkably better frequency profile.

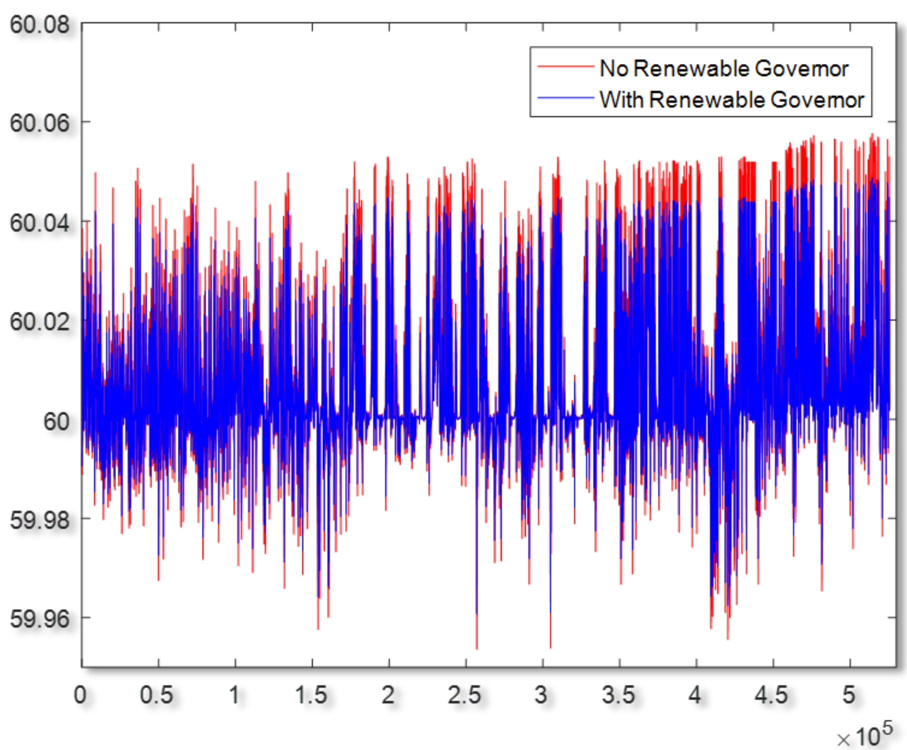
In Figure 64, a comparison between Simulation (4) and Simulation (1) has been made to show the contribution of the renewable governor in enhancement of frequency profile.

Figure 63: Yearly Profile of Frequency in Different Cases



Source: Onset, Inc.

Figure 64: Effect of UniGen Renewable Generator Governor on Frequency Profile



Source: Onset, Inc.

Conclusions

As a result of VER generation displacing fossil fuel power plants, power grids of the future will be more susceptible to frequency excursions, both in number and magnitude. The intermittent nature of VER generation makes it difficult to forecast and deviations from forecasts and schedules is a new and growing source of frequency disturbances.

With their inertial response and droop control characteristics, controllable power plants with large generators have been an important source of the grid's primary frequency response capability. VERs do not have this capability and as they populate the grid in growing numbers, frequency response measures have declined somewhat precipitously.

New technologies and approaches are needed to enhance the grid's primary frequency response. It was the purpose of this study to demonstrate that UniGen is one of these new approaches.

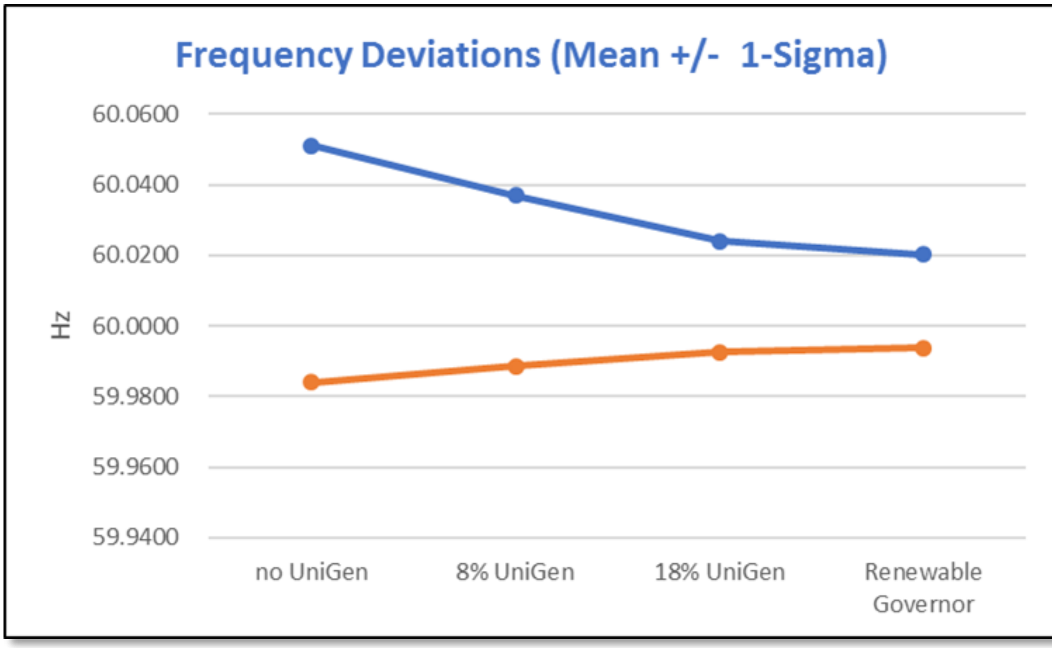
In this study, the frequency response of a typical three-area system, with characteristics closely matching those of the California ISO system, has been analyzed for a number of cases that show the impact UniGen has on the frequency profile.

In the base case, the transient frequency responses of the three areas were calculated using only controllable plants and AGC to provide primary frequency response. The second and third cases introduced an increasing number of UniGen plants.

These analyses show that it is possible to considerably improve the frequency profile of the system using UniGen. Furthermore, with a moderate penetration rate of the UniGen plants, it has been verified that it is possible to regulate system frequency within +/- 0.05 Hz as required by NERC. The results are summarized in Figure 65. This is due to the fact that reduction of schedule deviations by UniGen, which is its primary role, automatically complements AGC and other frequency response measures. UniGen's primary frequency response is always present, does not need to be procured or dispatched, nor require revenue enhancements from the California ISO market.

Also, in this report, it was verified that regulation of frequency can be improved through "renewable governing systems" similar to speed-droop control of the synchronous generators. Results of this study can undoubtedly motivate future research to understand more about the impact of extensive penetration of renewable systems in current grids. As a result, future studies will be needed, especially in areas associated with dynamic behavior of the system against schedule and frequency deviations using UniGen.

Figure 65: Managing Frequency Deviations with UniGen



Source: Onset, Inc.

CHAPTER 5: Applying the UniGen Smart System to Manage the Impact of Distribution Level Resources on the Transmission System

Purpose of This Study

"The state is under a significant shift from the classic grid configuration of a high concentration of larger central power plants to a new mixture of energy generation resources that includes a high amount of Distributed Energy Resources (DER). As a result of this shift, the systems and technology required to manage this grid will take new and improved grid monitoring, reporting, and management systems."[21]

The purpose of this study is to investigate the use of UniGen and its underlying principles to manage the impact of the intermittent nature of distributed energy resources on the transmission system. The work described in this report is supportive of the goals and efforts of the 2017 Integrated Energy Policy Report.

Introduction

According to Navigant Research,[22] demand response and solar photovoltaic are expected to be the predominant resources added to the distribution network. Storage, electric vehicles, and fuel cells are other distributed energy resources expected to play a role.

The amounts of solar photovoltaic and demand response expected on any given day are, of course, hard to predict and have the potential to deviate considerably from forecasts. The resulting distribution net load, which appears as a flow of power at the connection points between the distribution and transmission networks, represents a risk to the reliability of the transmission network. Complicating matters, distributed energy resources, unless they are participating in the wholesale market, are not visible to California ISO and cannot be directly controlled. In the so-called highly distributed energy resources future, use of considerable amounts of distributed energy resources and the obligation to maintain reliability to NERC standards is yet another challenge for those who are working to integrate renewables into the grid.

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[21] 2017 Integrated Energy Policy Report Scoping Order, p. 6, http://docketpublic.energy.ca.gov/PublicDocuments/17-IEPR-01/TN216389_20170306T111428_2017_Integrated_Energy_Policy_Report_Scoping_Order.pdf

[22] http://www.utilitydive.com/news/ders-in-2016-what-experts-expect-for-a-booming-sector/411141/

The CPUC has ordered California's three independently owned utilities to perform integration capacity analysis, the purpose of which is to ascertain distribution system limits to host distributed energy resources across the entirety of a utility's service territory. The independently owned utilities are doing some good work in this area, but it does not include possible effects on the transmission system. The unspoken assumption is, perhaps, that it is a problem for California ISO to solve.

Until recently, there has been scant attention to this issue. However, U.S. DOE's Electricity Advisory Committee hosted a panel discussion in late March 2017 to discuss how to manage the interconnection between the two systems. The name of the panel discussion says it all: *Panel: Transmission-Distribution Interface in the Context of Increasing Distributed Energy Resource Additions.*

Panelists represented several independent system operators, including California ISO. Their presentations can be found here: https://energy.gov/oe/downloads/electricity-advisory-committee-meeting-presentations-march-2017-wednesday-march-29-2017 .

Independent system operators (ISOs) are worried that distributed energy resources, which are not visible to or controllable by them, will create large fluctuations of power (and voltage) at the point of interconnection between the distribution and transmission networks (T-D points). The fundamental issue is a lack of predictability. As the California ISO presentation indicated,

> *ISO's primary DER concern is at the T-D interface … Predictability/confidence regarding DER responses to ISO dispatch instructions; and short-term forecasts of net interchange at each T-D interface.*

A good summary of the challenges and technology needs was given in a table from the California ISO presentation and is presented below.

The representative from PJM Interconnection expressed similar concerns:

> *ISO's Interest in Distributed Energy Resources*
>
> - Visibility for reliability
>
>   Today PJM has limited visibility into the operation of Distributed Energy Resources (DER).
>
> - Measure and forecast DER interaction with the grid
>
>   The ability to measure and forecast all DER would enable the grid operator to know the amount, timing, and location of generation injected into the grid and/or load reduced from the grid.
>
> 3. If possible, incent DER to interact for reliability and value.

This study will attempt to show that UniGen can satisfy the first two needs.

Table 7: Challenges Created by High Levels of Distributed Energy Resources

Area of Activity	Challenges of High DERs	What's Needed
System operations	• Diverse DER behaviors & energy flows, especially with aggregated virtual resources • Hard to forecast impacts at T-D interfaces • DO is not in the loop on DER wholesale market transactions • Multi-use DER may receive conflicting dispatches/signals (from DO and ISO)	• Distribution grid real-time visibility • Real-time forecasting of DER impact at each T-D substation • Coordination procedures between ISO, DO and DER re wholesale DER schedules & dispatches • Dispatch priority re multiple uses

Source: Onset, Inc.

Approach and Scope of the Analysis

In previous studies, UniGen was used to manage the combined outputs of transmission levels resources to maintain a day-ahead schedule. The forecasted generation of a wind or solar project was used, along with other factors, to prepare an optimal day-ahead schedule. When the actual generation deviated from the schedule, a dedicated firming resource (power plant or storage) was dispatched up or down to restore the schedule.

For this study, the aggregated generation of distributed energy resources will be treated as if it were a transmission-level variable energy resource. The forecasted aggregated generation of distributed energy resources is subtracted from the distribution system load to create a day-ahead schedule for the amount of power that will cross the T-D connection point. Using the day-ahead schedule as the set point for the UniGen control system, that schedule will be maintained by a firming resource located at or near the T-D intersection. The firming resources could be an existing power plant located at a substation or a fuel cell that could be sited at the substation.

DNV GL recommended this same approach to the New York ISO:

> Greater visibility and control ultimately increase the information that the system operator has to work with—allowing operators to prepare flexible resources for addressing aggregate variation in the load profile in a manner similar to approaches for integrating centralized variable supply resources.[23]

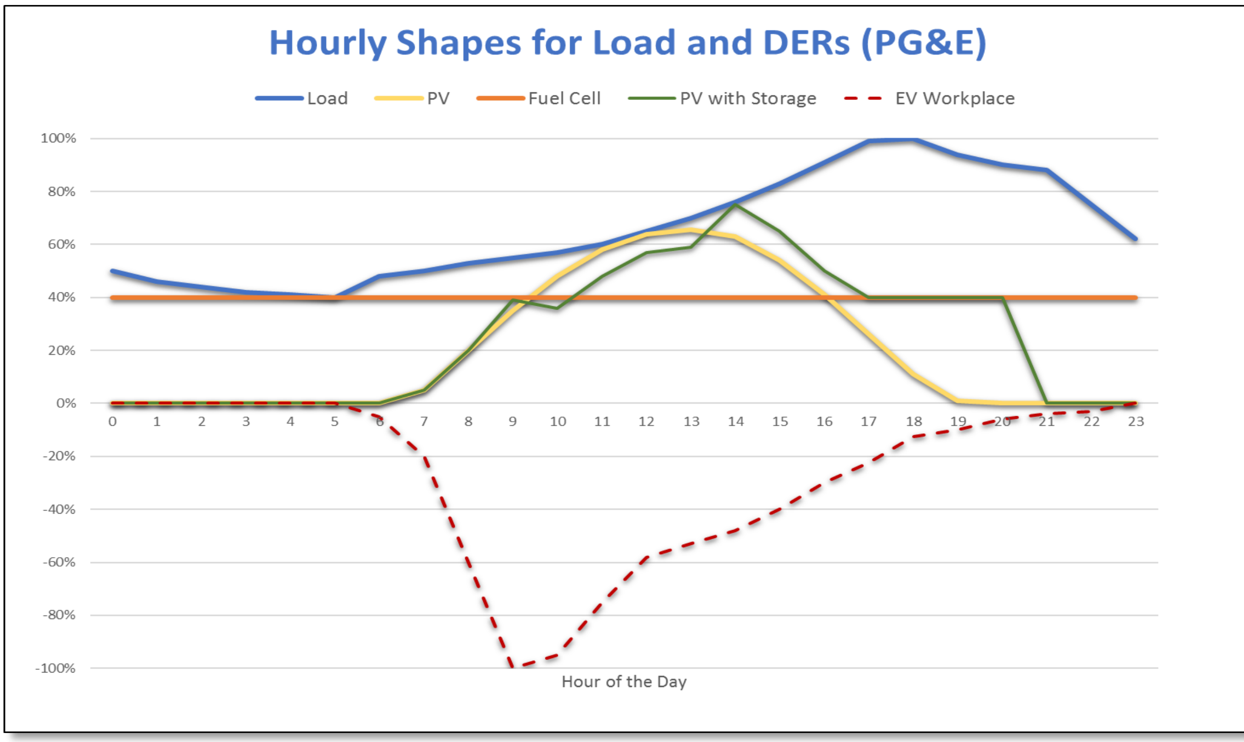
[23] Excerpted from page 12 of "A Review of Distributed Energy Resources," New York Independent System Operator, prepared by DNV GL.

Cases Studied

For these analyses, the authors assumed 100 MW as the projected peak load on a fictitious distribution network that is fed from a substation with at least that much transfer capacity.

The mix of distributed energy resources present on the distribution system influences the amount and timing of power flows across the T-D boundary. This is nicely illustrated by Figure 66, which depicts the hour-to-hour variation of the distribution system load and several types of distributed energy resources. The source of these data is PG&E's Integration Capacity Analysis done for the CPUC[24].

Figure 66: Daily Profiles for Distributed Energy Resources



Source: Onset, Inc.

Power flows are also influenced by the amount of generation by distributed energy resources on the distribution network as a percentage of the load. For this study, the authors assumed that distributed energy resource generation is heavily dominated by rooftop solar. This assumption is made for these reasons:

- Most of the increase in distributed energy resources on the distribution network is expected to come from rooftop photovoltaic systems; and

[24] Pacific Gas and Electric Integration Capacity Analysis for Distribution Resource Planning, September 2016.

- Actual solar generation has the most potential to deviate from that forecasted. This would happen if the amount of solar irradiation was less than expected (cloudy skies) or if homeowners used more solar generation than expected for their own use and put less into the system.
- The authors have data sets for day-ahead forecasts of solar generation and the corresponding actual generation, which can be used to make the simulations more realistic.

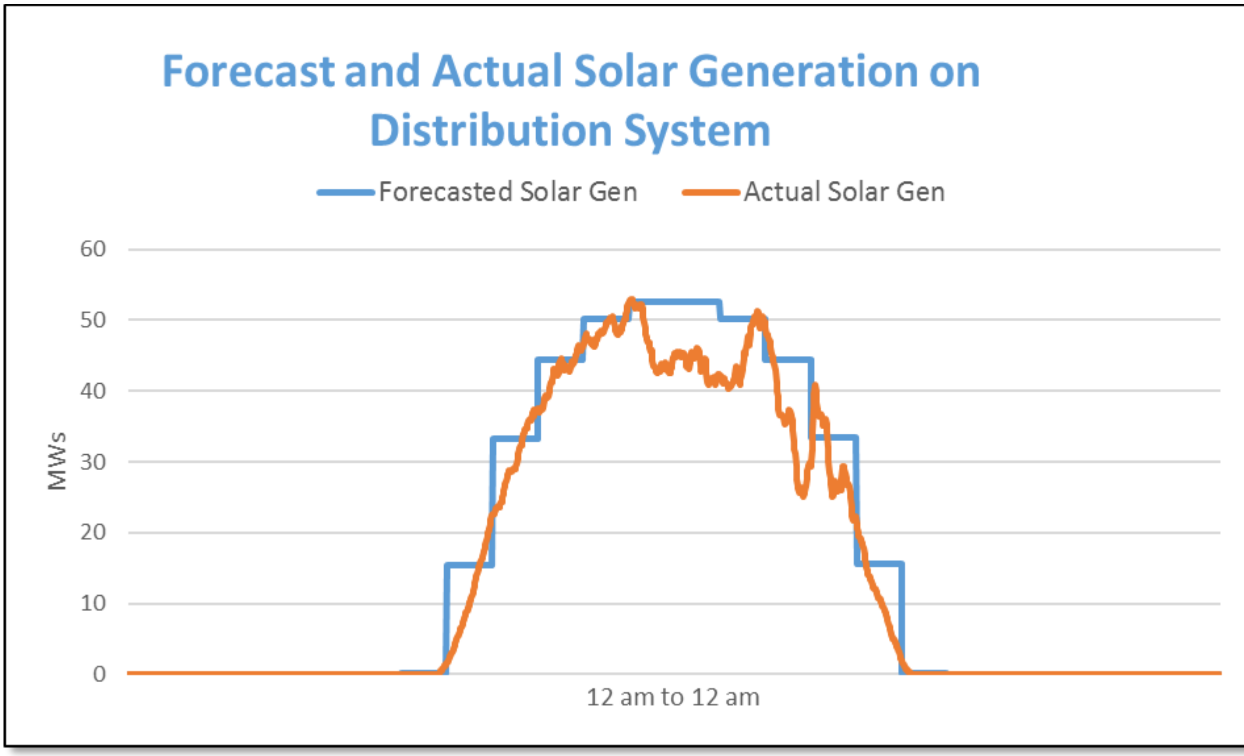
Base Case

For the analysis, the authors used the UniGen simulation model developed by Onset, Inc. prior to this study. This model calculates the interaction in time between the load, distributed energy resources, battery storage, and a power plant on the transmission side. The purpose of the analysis was to see if the expected distribution net load can be maintained with a battery storage system to an extent that an optimal amount of flexible resources can be lined up in the day-ahead market to meet the distribution net load.

The first case looks at the impact of distributed energy resources supplying 25 percent of the distribution load. This translates to 53 MW of solar capacity present on the distribution network for the day chosen for the analysis (March 21, the spring equinox). Solar generation is predicted by a version of NREL's Clear Sky Model, which produces a smooth, parabolic shape forecast of generation throughout a day with "perfect solar"[25] conditions. For purposes of this analysis, the day-ahead schedule is created by finding the average generation predicted for each hour. Historical data are used for actual solar generation. All this is shown in shown in Figure 67 and should realistically model the intermittent nature of distribution net load.

[25] Perfect solar is our term for a day without anything in the atmosphere (that is, clear skies) to block or dilute the amount of solar irradiance impinging on the solar panels.

Figure 67: Data Used in the UniGen Simulation Model



Source: Onset, Inc.

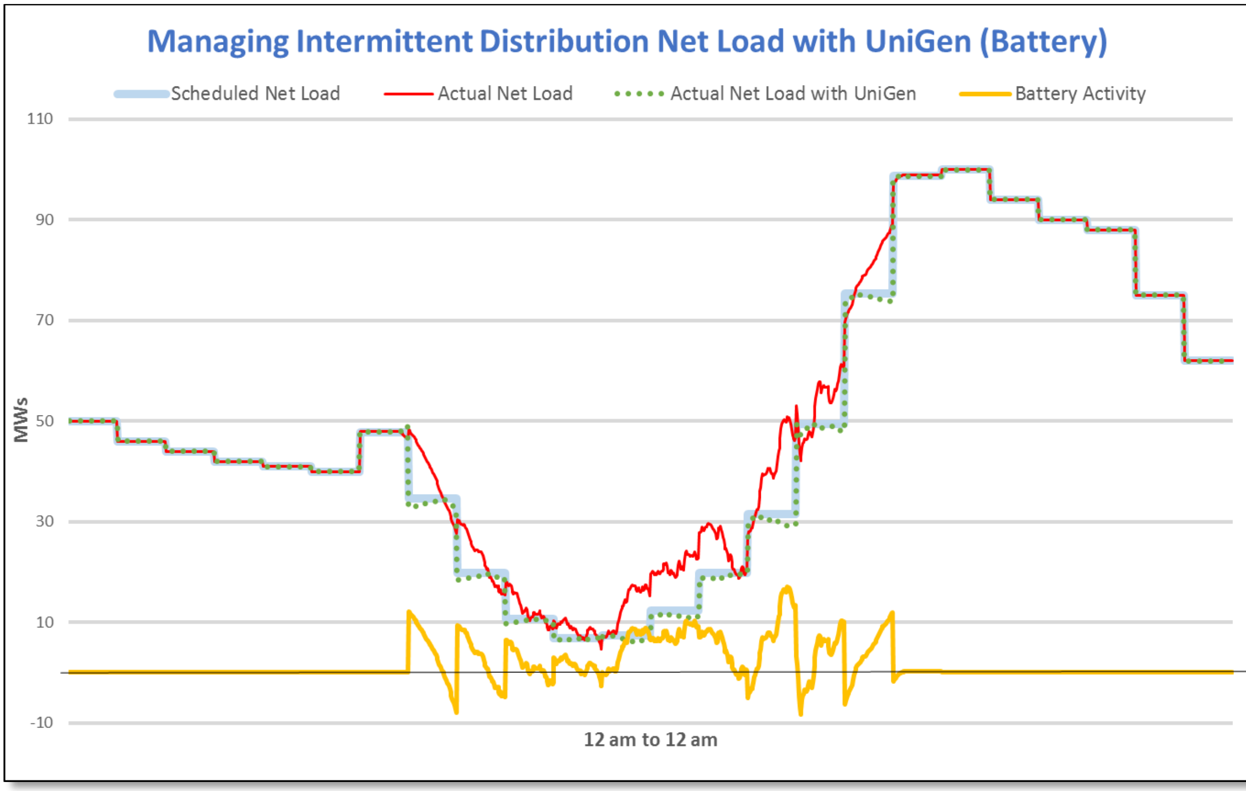
Results

The result of the base case analysis is shown in Figure 68. The deviation of the actual distribution net load from that scheduled (expected) is offset by a battery energy storage system, as more clearly shown in Figure 69. Eight batteries were used, each having a 4-MW discharge rate and 7 MWh of storage capability.

The simulation shows that UniGen is able to manage the storage resource so that it responds to changes in the distribution net load between the hourly changes in the schedule. As a result, the hourly schedule is predictable and transparent in the sense that it is known to California ISO.

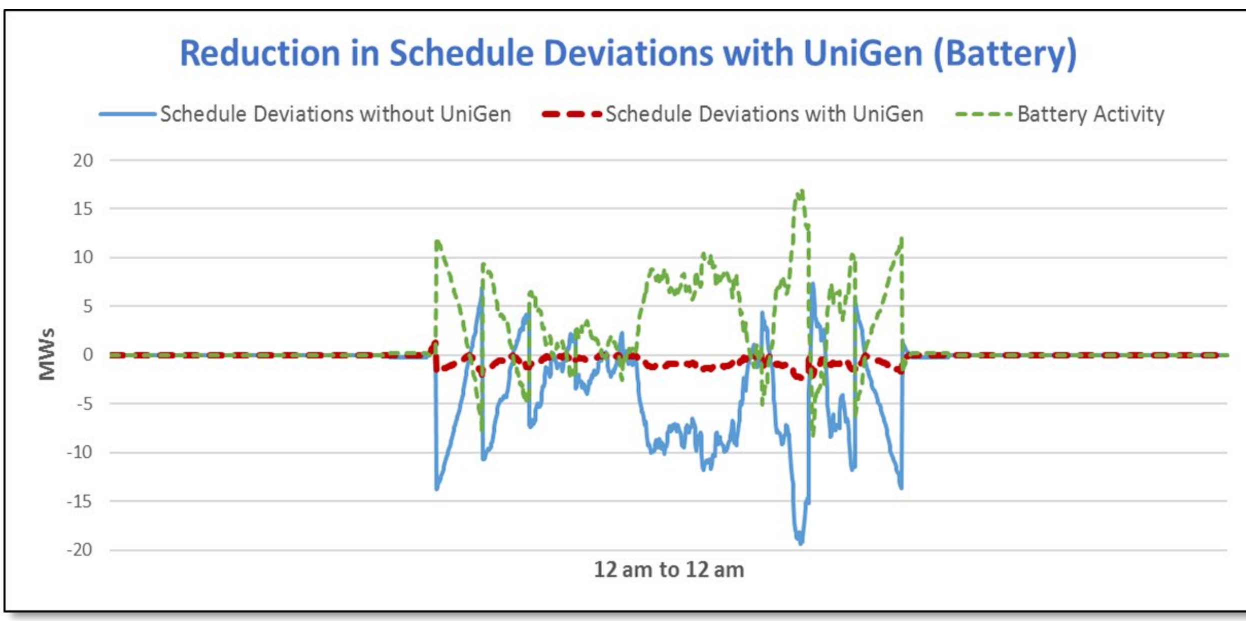
Whereas the storage resource manages changes between the hours, the power plant manages the step changes in the net load schedule.

Figure 68: Managing Intermittent Net Load on the Distribution System



Source: Onset, Inc.

Figure 69: Offsetting Deviations from Scheduled Distribution Net Load with Storage

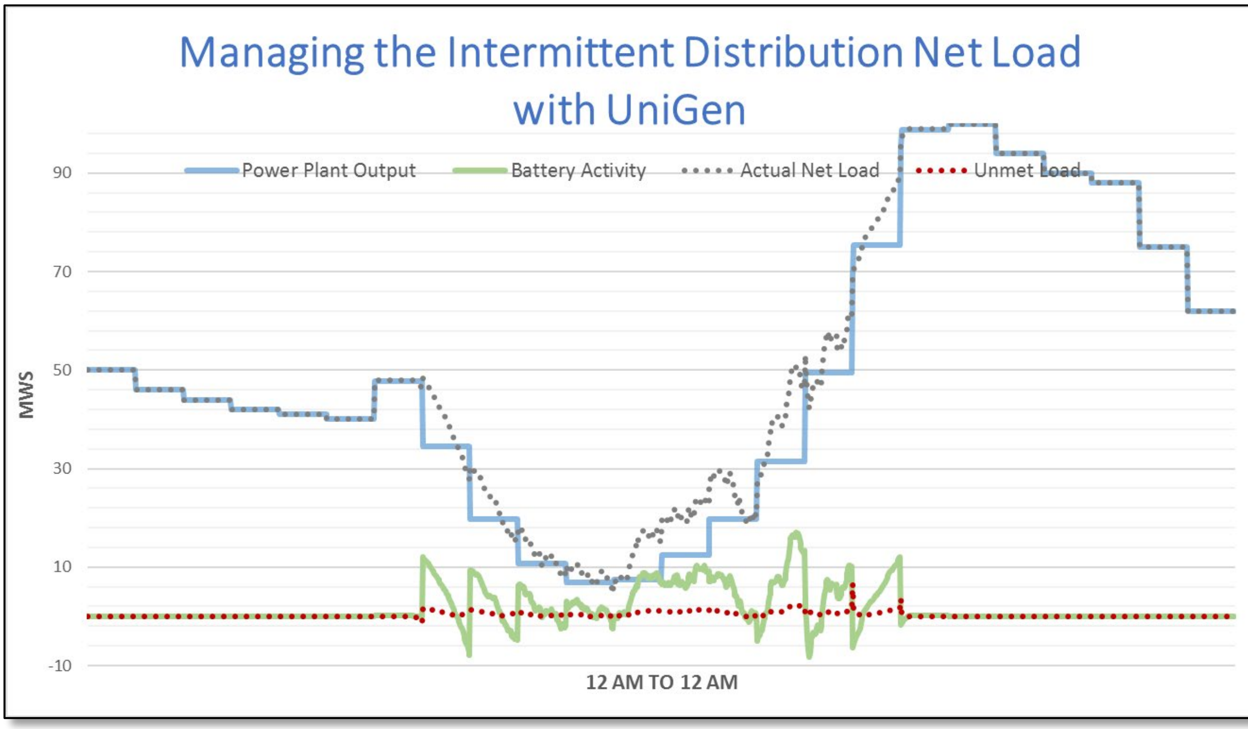


Source: Onset, Inc.

Discussion

This predictable net load schedule is important because it allows the output of a power plant to be procured in the day-ahead market using a set, predictable generation schedule. Indeed, a dedicated power plant could serve the net load on a day-to-day basis without, on some days, requiring shut down, as shown in Figure 70.

Figure 70: Regular, Manageable Power Flows from the Transmission to the Distribution Systems Using UniGen



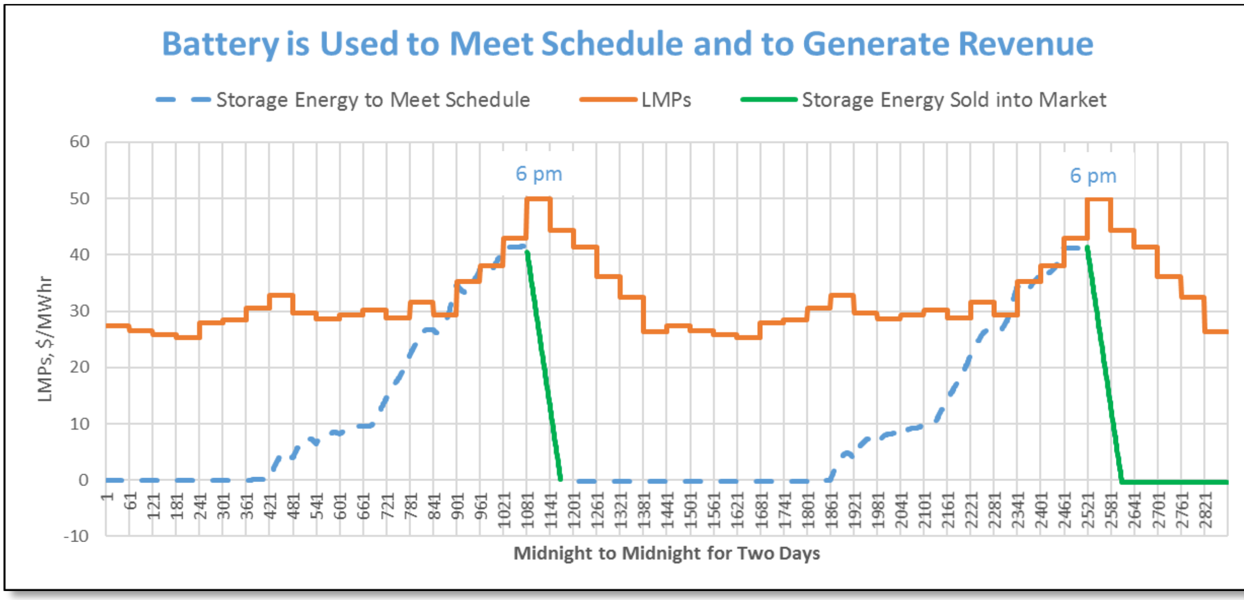
Source: Onset, Inc.

The storage battery obviously plays a key role. It acts as a shock absorber between the distribution and transmission systems, smoothing out the many intra-hour changes in net load.

The authors' analysis shows that to accomplish this, the battery must be discharged after the sun goes down so that it will be an empty reservoir the next day when the sun comes up. This is the result of basing the day-ahead schedule on the average value of solar generation for each hour. For this particular schedule, actual solar generation exceeds the schedule in the first part of the hour and the excess is stored. Later in the hour, the energy is released to maintain the schedule. For this particular set of data, the actual solar generation deviates from forecast during the middle of the day and the battery is used to regulate these deviations.

This strategic use of energy storage is economically advantageous. The battery is discharged during the time of day when market prices (locational marginal prices, as given in the Appendix) are at their highest. This is shown in Figure 71. Analysis suggests that this revenue would be ~$500,000 annually.

Figure 71: Revenues from Discharging Battery



Source: Onset, Inc.

Parametric Study

The strategy being studied is to schedule the distribution net load in the day-ahead market, and firm that schedule in real time with battery storage. The certainty of the firm distribution net load is sufficiently high that a generation schedule can be procured in the day-ahead market to serve this load.

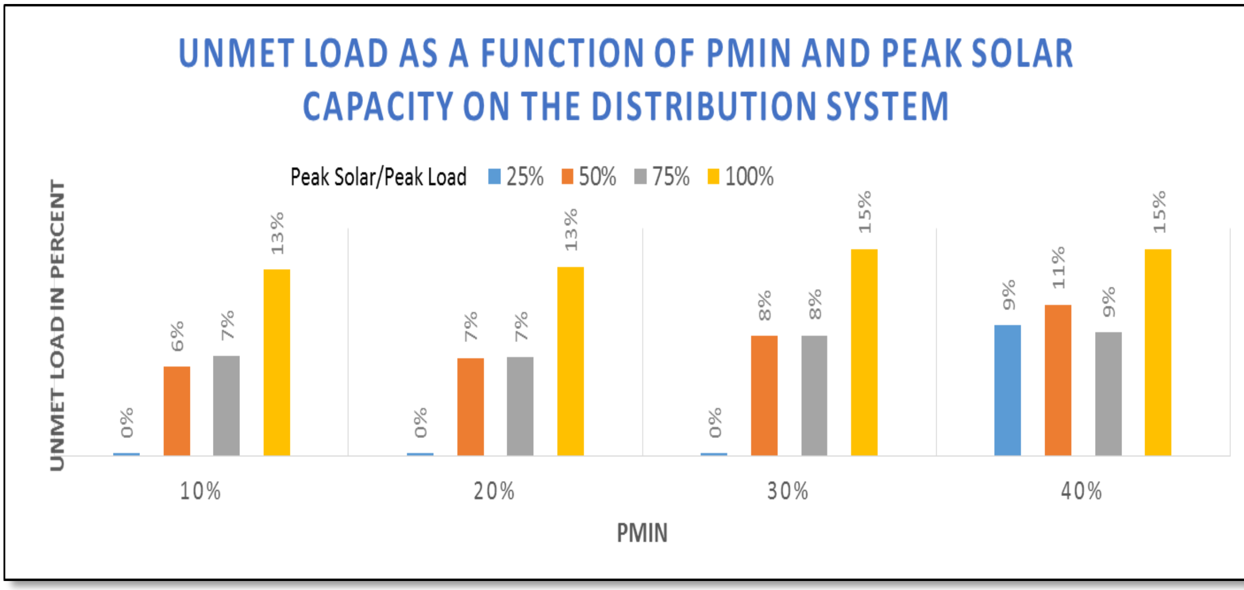
The effectiveness of this strategy can be measured by amount of residual load,[26] defined here as the difference between the firmed distribution net load and the output of the power plant.

The residual load is a function of the amount of distributed energy resource generation on the distribution system and the minimum load (or Pmin) of the power plant. In general, when distributed energy resource generation is a smaller percentage of the total load, the distribution net load does not fall below Pmin and the power plant can serve all the scheduled distribution net load. However, as the amount of distributed energy resource generation increases, the scheduled distribution net load falls below Pmin and during that time period the power plants will be shut down and unable to serve load. This is a case of generation oversupply, which is also occurring on the transmission system.

[26] This residual load would actually be served with balancing energy provided by the market.

The strategy is very effective when the solar capacity is relatively small and Pmin is 10 percent to 30 percent. There is no residual load. The strategy is moderately effective when solar capacity is 50 percent to 75 percent; better when Pmin is low. When the solar capacity is equal to the peak load, it is difficult to balance load and generation without using other means. This is summarized in Figure 72.

Figure 72: Measuring the Effectiveness of Scheduling Distribution Net Load in the Day-ahead Market



Source: Onset, Inc.

Finding a way to lower Pmin without violating air permit standards would be a valuable development, especially when distributed energy resources reach higher and higher levels.

However, in this strategy, the individual plant Pmin is not as important as the overall Pmin. If 10 MW are used to serve the distribution net load, then the least amount of power that can be generated will be between 2 MW (20 percent Pmin) and 4 MW (40 percent Pmin), which is considerably more useful in this strategy than one 100 MW unit with Pmin ranging from 20 MW to 40 MW. The amount of residual load is directly proportional to the total Pmin.

The following table shows the utility of the different sizes of power plants in minimizing residual load. An orange-colored Pmin means the plant is very effective, blue moderately so, and red means not effective. This holds for cases for solar capacities up to 75 percent.

Table 8: Effective Pmin by Type of Combustion Turbine

	Rating	Pmin in MW		# units needed [27]
IC Engine	10	2	4	10
LM2500	25	5	10	4
LM6000	50	10	20	2
LMS100	100	20	40	1

Source: Onset, Inc.

More Effective Use of Battery Storage

In the previous section, it was shown that the amount of residual or unmet load was highly dependent on the minimum load of the power plant. This deficiency can be corrected by using the battery in a more intelligent manner. Recall that for the strategy of scheduling the distribution net load to work, the battery is completely discharged after the sun goes down. This point in time was chosen because the variation in solar generation, which dominates the variability in the net load, is no longer present on the system. In other words, the battery was no longer needed to firm the scheduled distribution net load.

However, the algorithm that controls the use of the battery was rewritten so that energy was left in the battery in anticipation of using it to meet the residual load that the power plant could not because its output had dropped below its Pmin. Any remaining energy in the battery was later discharged to the market. Overall, this proved to be effective in reducing the amount of unmet load, provided the capacity of the battery was equal to the Pmin.

Another possibility is to keep the plant, when it reaches its Pmin, on-line and store the difference between its generation and the residual load in the battery. This algorithm was not written but should not be difficult to develop because the generation schedule, and hence the time periods when the schedule is below Pmin, is known well in advance.

The battery, in other words, can be programmed to do more than one job in this setting.

Conclusions

This feasibility study ascertained if the "UniGen Strategy" of scheduling the distribution net load in the day-ahead market, firming that schedule with an adequately sized battery storage system, and procuring generation in the day-ahead market or from a dedicated power plant based on an hourly schedule that is predictable, improves system reliability. The simulation studies have shown that this is a feasible strategy for maintaining regular power flows across from the transmission to the distribution

[27] To serve 100 MW peak load.

systems. It reinforces the authors' view that use of the day-ahead scheduling process is still the best tool for maintaining system reliability.

The study also shows that managing a mix of resources requires increasingly sophisticated algorithms. Future studies that develop these algorithms are highly recommended.

In the introduction to this report, the authors noted that when it comes to distributed energy resources, ISOs are interested in:

- Visibility for reliability (today, PJM has limited visibility into the operation of distributed energy resources).
- Measuring and forecasting distributed energy resource interaction with the grid.
- The ability to measure and forecast all distributed energy resources that would enable the grid operator to know the amount, timing, and location of generation injected into the grid and/or load reduced from the grid.

More study is necessary, but it appears that the UniGen Strategy informs the ISOs via the day-ahead schedule of what is to transpire on the distribution system so that the appropriate generation can be brought to bear.

CHAPTER 6: Results of UniGen Lab Testing

Introduction

Previous chapters have discussed the results of research studies performed to determine the technical and economic feasibility of UniGen as a potential tool to help integrate large amounts of renewable energy. Included in these studies were evaluations of the benefits to market participants and California ISO.

This chapter will discuss the second major research area, which is to develop the core UniGen software (Task 7 of the Agreement) and to test this prototype under laboratory conditions (Task 8). As stated in the EPIC agreement, the goal of these tasks is to advance the state of the art of the UniGen software technology to the point that it can be used in a laboratory test to verify, prior to use in the field with actual power plants, that it performs as expected.

Strong Force LLC was chosen to develop the software for the UniGen prototype. Strong Force was founded by former STEM employees who helped to develop the software that manages battery energy storage systems for commercial applications.

Description of the Test Plan

The basic functions of the UniGen software are to read high resolution data from the generation meter of the VER; run error checking routines to ensure the quality; compare actual generation data received to the manually preloaded day-ahead schedule; run algorithms that determine how to properly dispatch the firming resources to maintain the schedule as closely as possible; successfully transmit that dispatch signal to the firming resource; and receive data in return verifying that the order was received and followed.

For this project, the firming resource is a simulation model of a gas-fired power plant. The simulated power plant is able to receive the dispatch signal from UniGen over the chosen communication network and return data in the same way. The simulated power plant has internal logic similar to an engine control system used in actual power plants that governs the way a plant responds to a dispatch order.

In the absence of access to the actual generation of an operating wind or solar resource, the authors used historical data provided by California ISO. The data encompass one month (July 2014) and include the day-ahead generation forecast (which was used as the day-ahead schedule) and four-second data for the actual generation.

There were a number of tests, each lasting about one full day:

- Testing and debugging the communications system to ensure that UniGen and the simulated power plant are properly exchanging data.

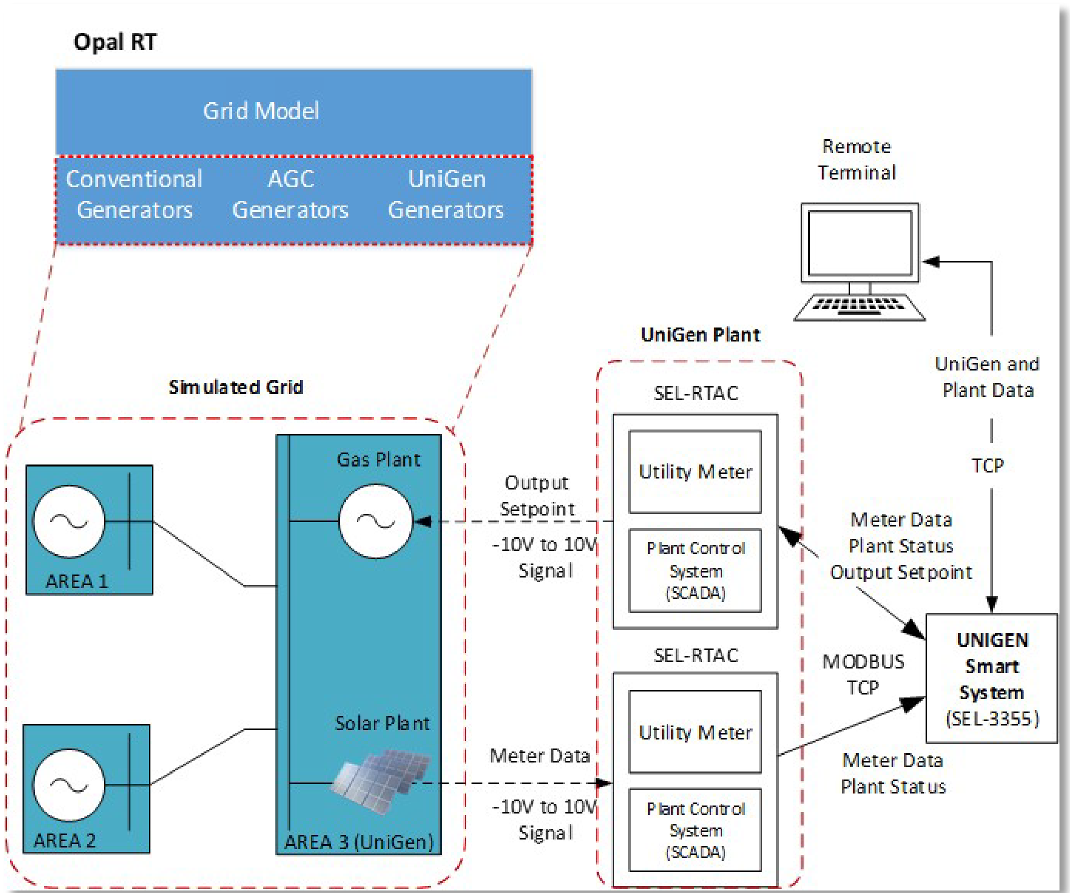
- Testing and debugging UniGen and the simulated power plant to ensure that the day-ahead schedule is being maintained with a minimum of schedule deviations.
- Repeating the tests in step two with the code revisions that resulted from the earlier tests.
- Performing a number of tests to statistically evaluate the reliability of UniGen.
- Connecting UniGen and the simulated power plant to the multi-area model described in Chapter 4. Run several cases to show how UniGen improves primary frequency response and frequency regulation in general.

Design of Test

To verify the functionality and effectiveness of UniGen in real world situations, real-time, hardware-in-the-loop testing was used. This type of testing enables the UniGen power plant and its controller (the UniGen Smart System) to be tested against a simulated model of the grid using the same interfaces in the real world. For the test, a model of the grid was developed in a real-time simulation environment, while the UniGen Plant as well as the UniGen Smart System were modeled externally. This enables the grid model to be directly controlled or affected by external components. Furthermore, testing was conducted under actual communication protocols and interfaces used in the real world. Not only can this type of testing verify the functionality of UniGen, but also it can show its potential impacts on the grid.

To perform a comprehensive test, three different components were set up and integrated. These components include the Grid Model, the UniGen Plant, and the UniGen Smart System, as depicted in Figure 73.

Figure 73: Test Setup Diagram



Source: Onset, Inc.

Grid Model

To verify UniGen's potential impact on the grid frequency, a model of the power grid was built. This model was developed and implemented in OPAL-RT OP-5600 hardware-in-the-loop (HIL) simulator. OPAL-RT OP5600 is a real-time target capable of interfacing with external hardware in real time. The interface between the real-time target and external hardware was handled using -10V to 10V voltage loops.

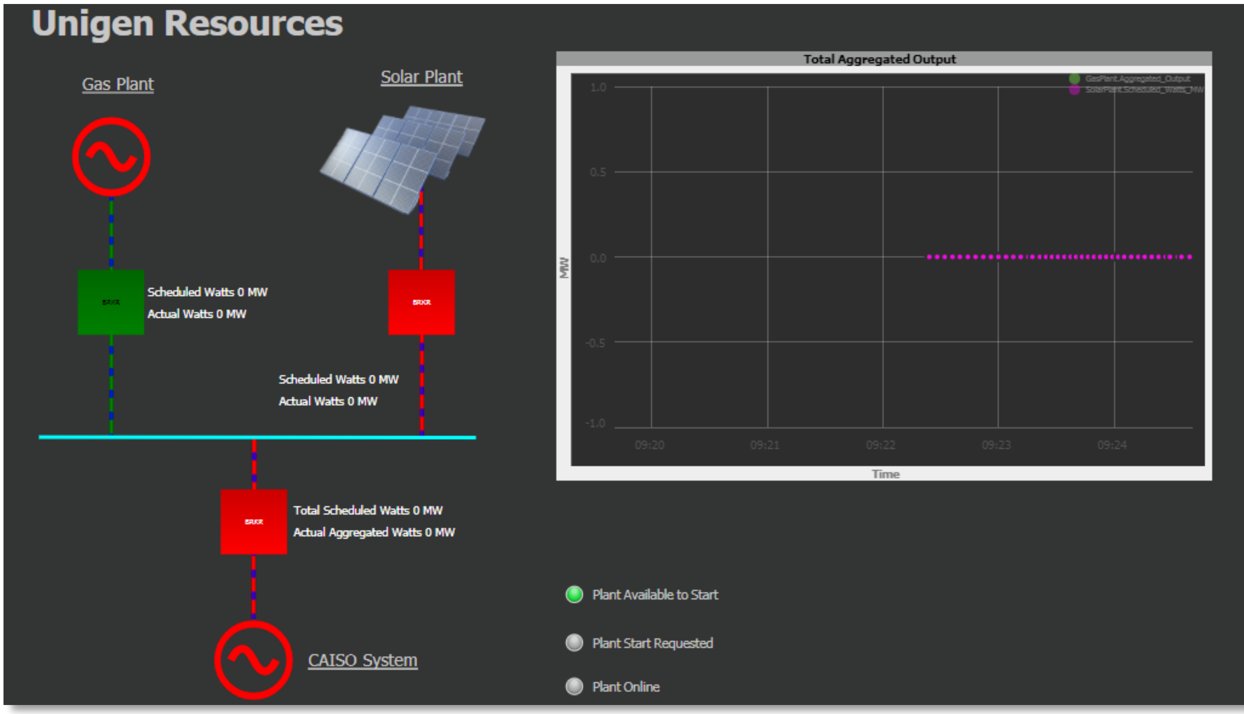
In the OPAL-RT simulator, a three-area system was modeled to represent the dynamics of the power grid under the control of California ISO. Area 1 represented the generators participating in AGC, which is a supervisory control system to regulate a system's frequency by adjusting power outputs of the generators inside this area. This area represents 2 percent of the whole capacity of the system. Area 2, the majority of the system (80 percent of the capacity), is comprised of the synchronous generators that neither participated in AGC nor were operated with UniGen logic. The majority of these generators (50 percent), however, responded to load changes through droop control, which is considered as a primary frequency control method. The rest of the system, Area 3, represented the generators governed by UniGen. These generators not only respond to load changes through droop control, but also through changes in power levels as commanded by UniGen (see Figure 61). In the test, the total renewable generation has been divided proportionally between the three mentioned areas based on their generation capacity (2 percent, 80 percent, and 18 percent, respectively).

The UniGen plant's behavior has been implemented through external hardware (to be discussed in the next section) to create an accurate representation of the UniGen plant and its relationship with the UniGen Smart System and the rest of the grid in real world. The grid model in OPAL-RT has been interfaced with the UniGen plant via -10V to 10V voltage signals. During the simulation, certain quantities, such as total gas and renewable generations have been scaled from megawatts to -10V to 10V voltage values. These values are then outputted from OPAL-RT simulator to the UniGen plant. The input to the OPAL-RT from the UniGen plant has also been interfaced via -10V to 10V voltage control loops to change the power settings of the simulated system inside OPAL-RT.

UniGen Plant Model

To simulate the processes taking place in the UniGen plant, a detailed model of the plant has been developed and implemented in the Schweitzer Engineering Laboratory Real-Time Automation Controller (SEL-RTAC). This allows the dynamics, characteristics, and parameters of the generators to be mimicked on an external device. These models have been developed based on IEC61131, the standard for programmable logic controllers. This has enabled dynamic characteristics such as start-up, shutdown, and ramping at different set-points to be simulated. Essentially, programs were written inside the automation controller that simulated the output of the power plant in real time. In the absence of real generators, this would be the most accurate method to mimic the behavior of an actual UniGen plant. Furthermore, to test the physical communication protocols and UniGen's capability to interface with various remote sites, the RTAC was programmed to communicate via MODBUS TCP. For this purpose, a program was written in RTAC to mimic the supervisory control and data acquisition (SCADA) system of a typical power plant. This allows UniGen to access certain information such as metered data, time to start, time to stop, and various plant statuses for its decision-making logic. A human machine interface was also developed in RTAC (Figure 74) to visualize the processes and outputs of the plant along with the commands received from UniGen.

Figure 74: Human Machine Interface of the UniGen Plant



Source: Onset, Inc.

UniGen *Smart System*

The UniGen login has been implemented through software in the Schweitzer Engineering Laboratory (SEL) 3355 Rugged Computer. The SEL-3355 is a commonly used computer for control and data acquisition of processes in industrial and power facilities. The UniGen software features a human machine interface that allows users to quickly change the parameters of the system and gain visibility into data from the UniGen plant(s) during control. In the testing phase, UniGen interfaced with the UniGen plant model through the typical MODBUS TCP communication protocol. This method tested UniGen's ability to communicate with and command remote UniGen plant(s).

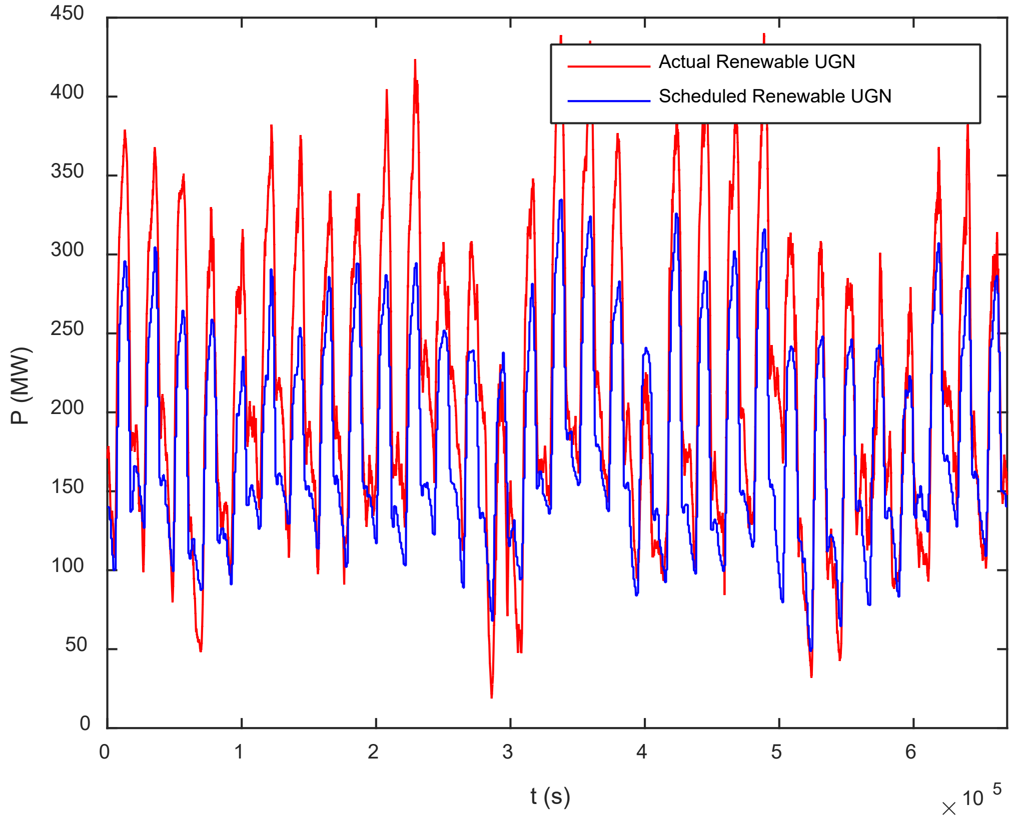
During the testing, the model of the grid ran continuously on the real-time target (OPAL-RT) while sending/receiving data to/from the external automation controller simulating the UniGen gas and renewable plants. UniGen continuously monitored and collected data from the UniGen plant(s) to verify meeting the schedule. In the situations of deficiency in generation, based on its logic, UniGen would send control commands via Modbus TCP to the UniGen plant to modify its generation. These commands included start, stop, and/or change of the setpoints for the generator(s) inside the UniGen plant. Once the UniGen plant (automation controller) received the commands, it would internally ramp up/down the simulated generator(s) based on the commanded setpoints and parameters of the plant. During this process, the output of the UniGen plant would be passed to the OPAL-RT simulated to update the generations in the simulation model. Once the simulation was updated, the impact of UniGen on the whole power system could be analyzed through indices such as frequency. Figure 73 shows the test setup, devices, and interfaces.

Test Results

This section discusses the test results based on the testing platform described above. The data used in this section are based on SCADA data of California ISO in July 2014, with a four-second interval. Modeling of the grid has been based on the same parameters used in Chapter 4 of this report. Several sessions were spent on setting up the test platform based on the schematics shown in Figure 73. Several hours had to be spent for coordination between the team members to calibrate and troubleshoot the flow of communicated data between OPAL-RT, the UniGen plant, and UniGen *Smart System*. After these initial steps, rigorous testing was implemented to ensure that UniGen could correctly operate to minimize schedule deviations based on existing capacity in the UniGen gas plant. In the testing, a gas-fired generator with a capacity of 220 MW was considered in the UniGen plant with a 2.66 MW/sec ramp date. Moreover, the minimum generation of this generator under regular conditions was considered to be at 45 MW. Since it was not practical to show the test results for the whole one-month duration of the SCADA data, it was decided to focus on the periods with the most undergenerated and overgenerated schedule deviations.

Figure 75 depicts the actual versus scheduled renewable generation in the UniGen Area (Area 3) of the test model in the whole one-month period.

Figure 75: Actual vs. Scheduled Renewable Generation in the UniGen Area



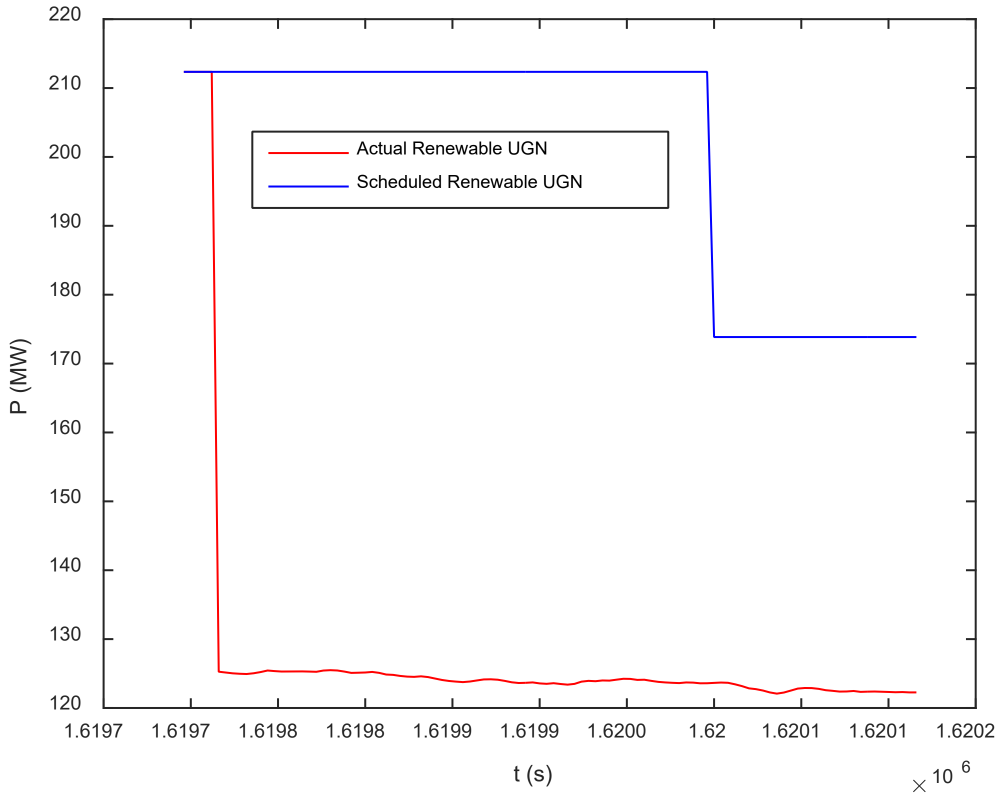
Source: Onset, Inc.

Among these data, results associated with selected periods of undergeneration and overgeneration have been shown in the following examples: simulations start and continue to be in steady state for the first 20 seconds, meaning that from 0–20 seconds there will be no schedule deviations. This ensures proper response of the UniGen plant and the UniGen Smart System to the changes that happen to the grid.

Maximum Undergeneration

Figure 76 shows the period of maximum undergeneration in the test data. In the first half of this figure, schedule deviation is more than 80 MW. In the second half, schedule deviation is reduced to approximately 40 MW.

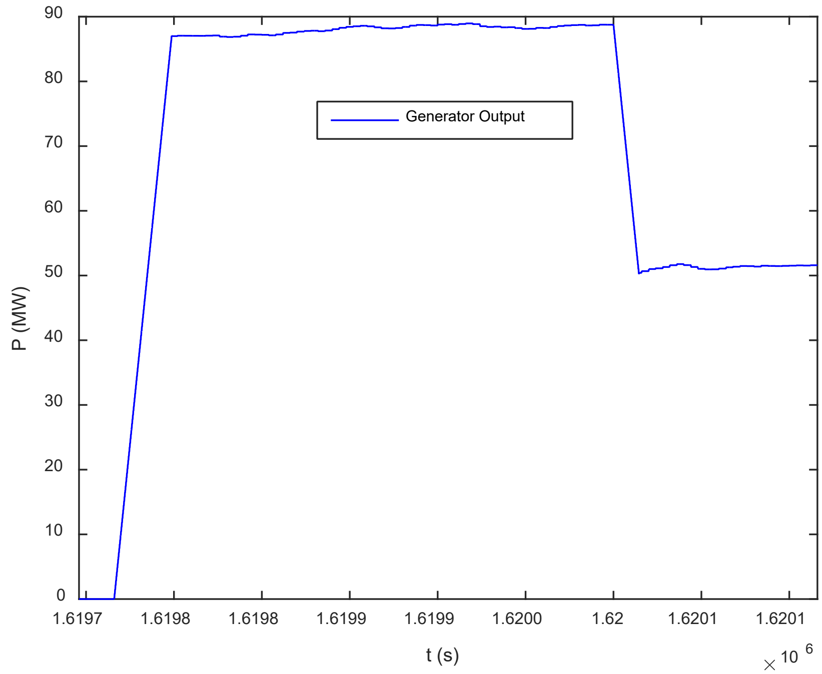
Figure 76: Maximum Undergeneration Period



Source: Onset, Inc.

Figure 77 shows the response of the generator in the UniGen area to reduce schedule deviations. Ramp-up and ramp-down periods based on 2.66 MW/s can be seen in this figure.

Figure 77: Generator Output in the UniGen Area Under Maximum Undergeneration

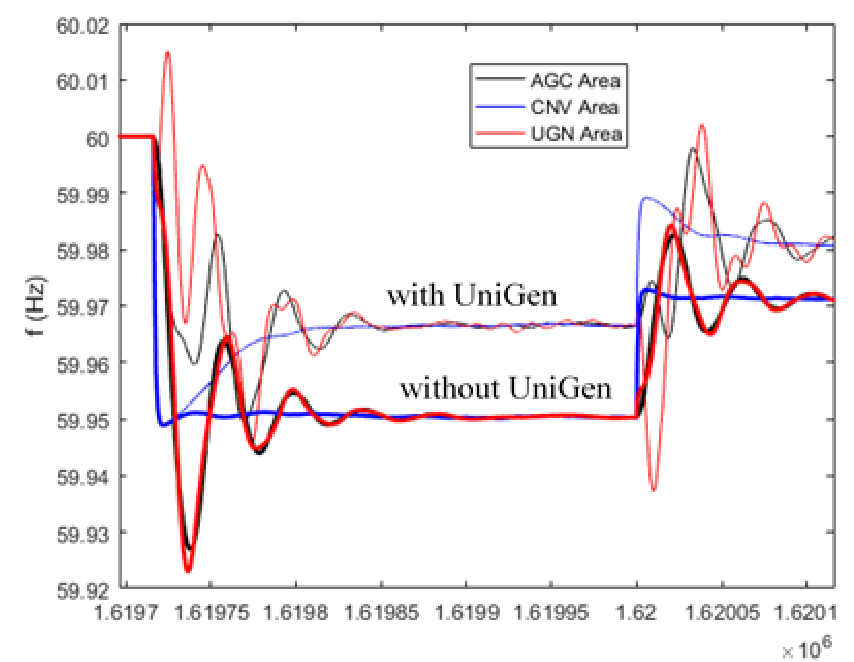


Source: Onset, Inc.

In Figure 78, the frequency response in the three areas of the system including AGC, CNV (conventional), and UGN (UniGen) are shown. It can be seen in this figure that due to the response of UniGen, all areas will go under transition periods for frequency. These different frequencies, however, will all converge into certain values, which represents the frequency of the whole system.

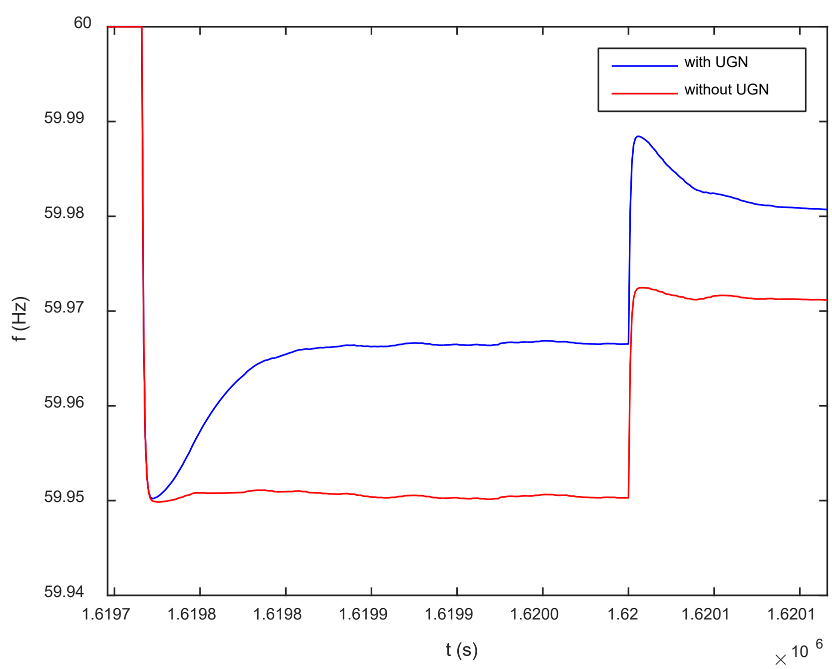
To compare the frequency response of the system under UniGen with the case when UniGen logic is not used, separate simulations have been carried out with and without UniGen's impact. The results are shown in Figure 79, where weighted frequencies in the two cases have been plotted side by side. The weighted frequency in each case has been found by considering the prorated impact of the equivalent inertias of the synchronous generators in the three areas. It can be seen from this figure that UniGen has been able to improve the frequency profile of the system in the simulated period. Therefore, it can be concluded that UniGen can improve the primary frequency response of the system in the case of undergeneration by commanding the synchronous generators under its territory to modify their output settings.

Figure 78: Frequency Response of the Three Areas with and without UniGen



Source: Onset, Inc.

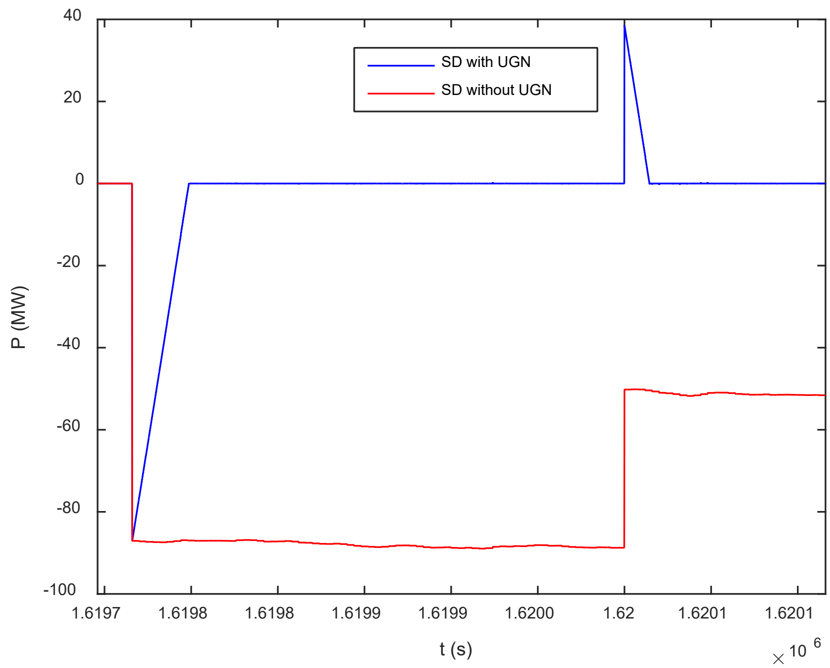
Figure 79: Comparison of the Weighted Frequency Response between Systems with and without UniGen



Source: Onset, Inc.

In Figure 80, a comparison has been made between the cases with/without UniGen when undergeneration exists. It can be seen from this figure that schedule deviations have been minimized overall by using UniGen.

Figure 80: Comparison of the Schedule Deviations With/Without UniGen in the Undergeneration Case



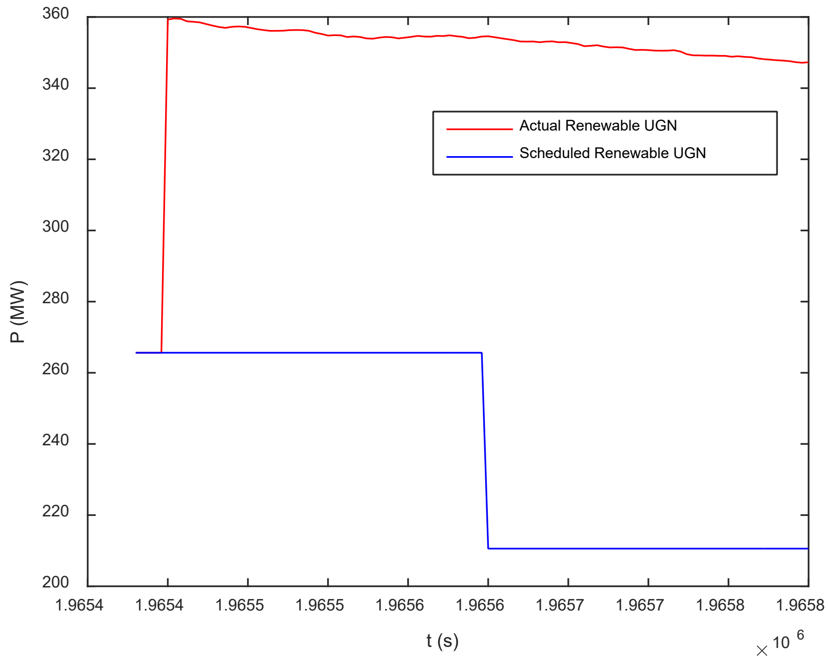
Source: Onset, Inc.

Maximum Overgeneration

Figure 81 shows the period of maximum overgeneration in the test data. It can be seen that in the first half, schedule deviation is more than 80 MW, while in the second half, schedule deviation becomes more than 120 MW.

During overgeneration periods, the only means to reduce schedule deviation would be either through reducing the gas plants' output or using storage to absorb extra generation of the renewables. In this study, since the authors started simulations from steady-state conditions when overall output of the synchronous generators was zero, two separate case studies were considered. In the first case study, the authors assumed the UniGen plant to only include synchronous generators, while in the second case study, the authors considered synchronous generators and a storage unit with -100/+100 MW range to absorb/generate power.

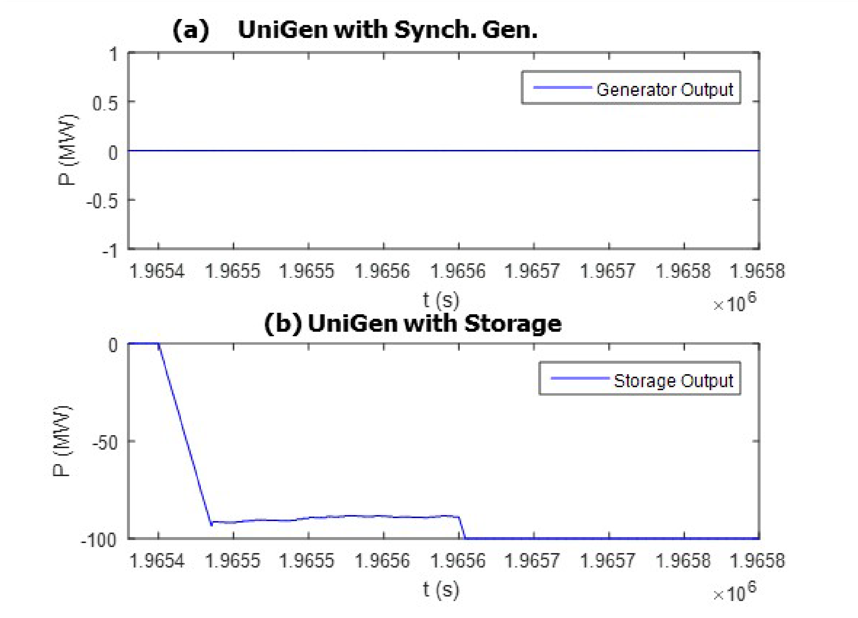
Figure 81: Maximum Overgeneration Period



Source: Onset, Inc.

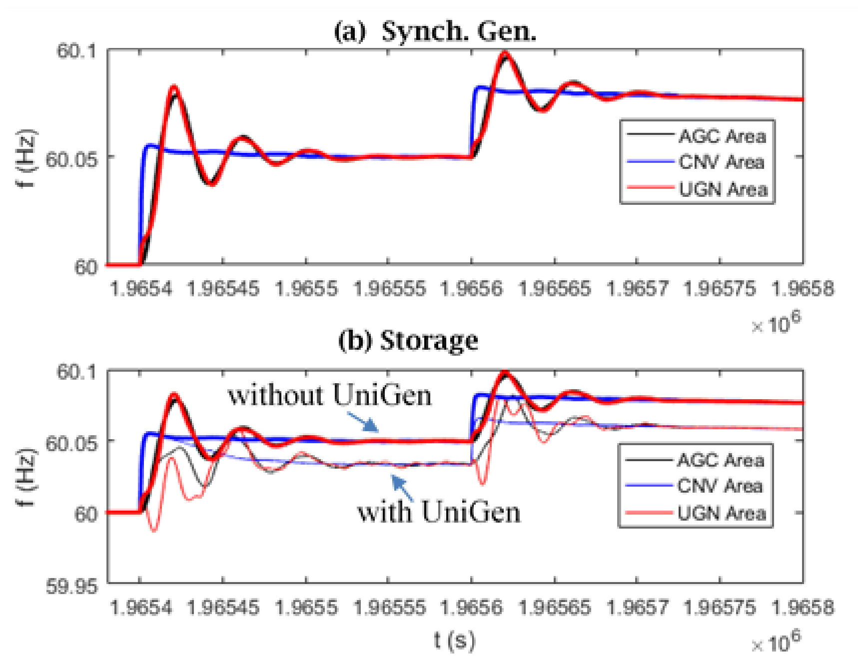
Figure 82 depicts the results of these two case studies. During overgeneration periods, the only means to reduce schedule deviation would be either through reducing the gas plants' output, or using storage to absorb extra generation of the renewables. In this study, since the authors started simulations from steady-state conditions when overall output of the synchronous generators was zero; two separate case studies were considered. In the first case study, it was assumed that the UniGen plant included only synchronous generators; while in the second case study, a storage unit with -100/+100 MW range to absorb/generate power with 2.66 MW/s ramp-up/down rate was considered. As can be seen from Figure 82 (a) (case with only synchronous generation), UniGen has not responded to this case since it does not have enough resources to reduce schedule deviations. In Figure 82(b), however, it can be observed that the storage unit has successfully absorbed the extra generation in the first half of the simulation, while in the second half it has kept the absorption of power at 100 MW due to the limitation of the storage unit. In Figure 83, the frequency responses of the three areas can be observed in the two mentioned case studies, while Figure 84 demonstrates the weighted frequencies. It can be seen from Figure 84 that in case (a) (without storage), the frequency response has not changed, while in case (b) (with storage), UniGen has successfully improved the primary frequency response of the system. This fact has been reiterated in Figure 85, which shows a comparison between schedule deviations with and without UniGen.

Figure 82: Generator/Storage Output in the UniGen Area Under Maximum Overgeneration



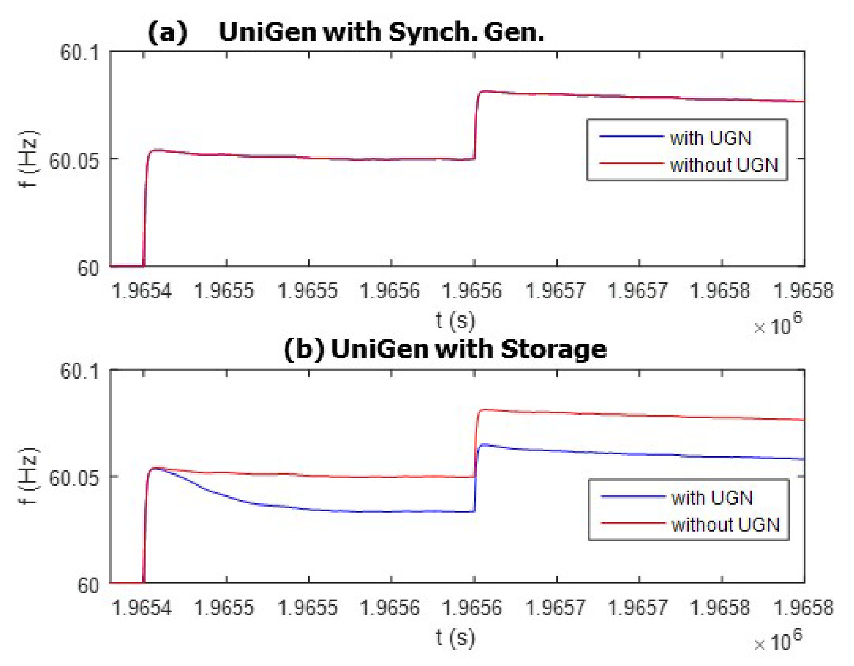
Source: Onset, Inc.

Figure 83: Frequency Response of the Three Areas With and Without UniGen



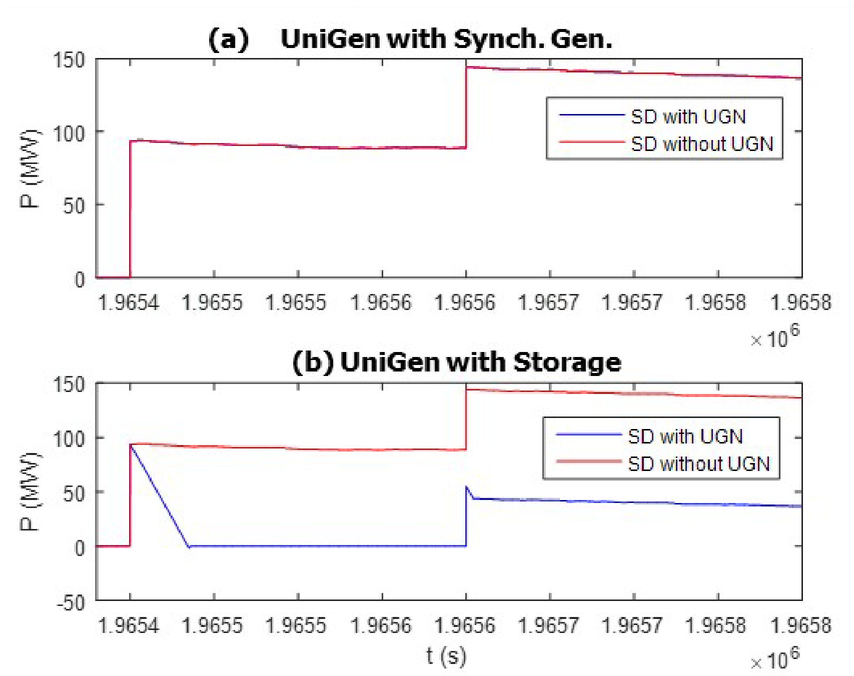
Source: Onset, Inc.

Figure 84: Comparison of the Weighted Frequency Response Between Systems With and Without UniGen



Source: Onset, Inc.

Figure 85: Comparison of the Schedule Deviations With/Without UniGen in the Overgeneration Case



Source: Onset, Inc.

In conclusion, during the testing procedure, successful operation of UniGen was verified. One important consideration for future research is optimum combination of synchronous generators and storage units to minimize schedule deviations.

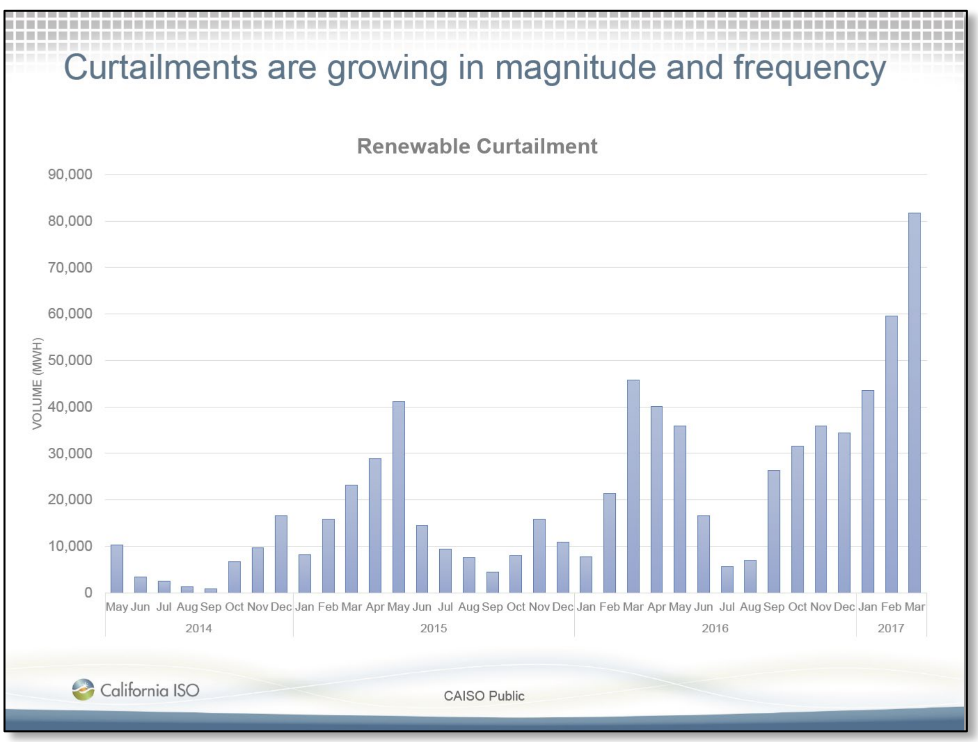
CHAPTER 7: Benefits to California

Discussion

The primary purpose of UniGen is to provide the technological means and financial incentives that will encourage VER generation to be scheduled in the day-ahead market. Currently, most VER generation is scheduled in the real time market (also known as the five-minute market), which effectively means it is not scheduled at all.

The day-ahead schedule is a historically proven tool for balancing demand and supply, thereby ensuring grid reliability. Scheduling VER generation in the day-ahead market and using UniGen to ensure that schedule is met is equivalent to integrating renewables into the grid. Thus, the overarching benefit to California will be a new technology for integrating the large amounts of new VERs envisioned by the 50 percent RPS. Currently, VER generation is scheduled in the real-time market but the increasing presence of negative prices in that market (11 percent of the time in the first half of this year, shown in Figure 87) has caused VER curtailment to jump, as seen in Figure 86: VER Curtailment on the Rise.

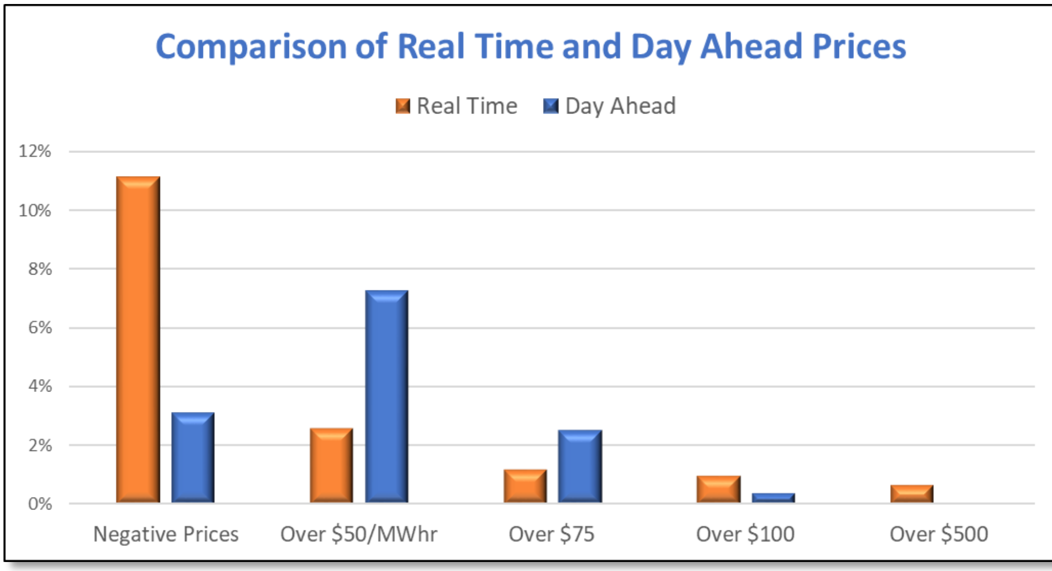
Figure 86: VER Curtailment on the Rise



Source: California ISO Website

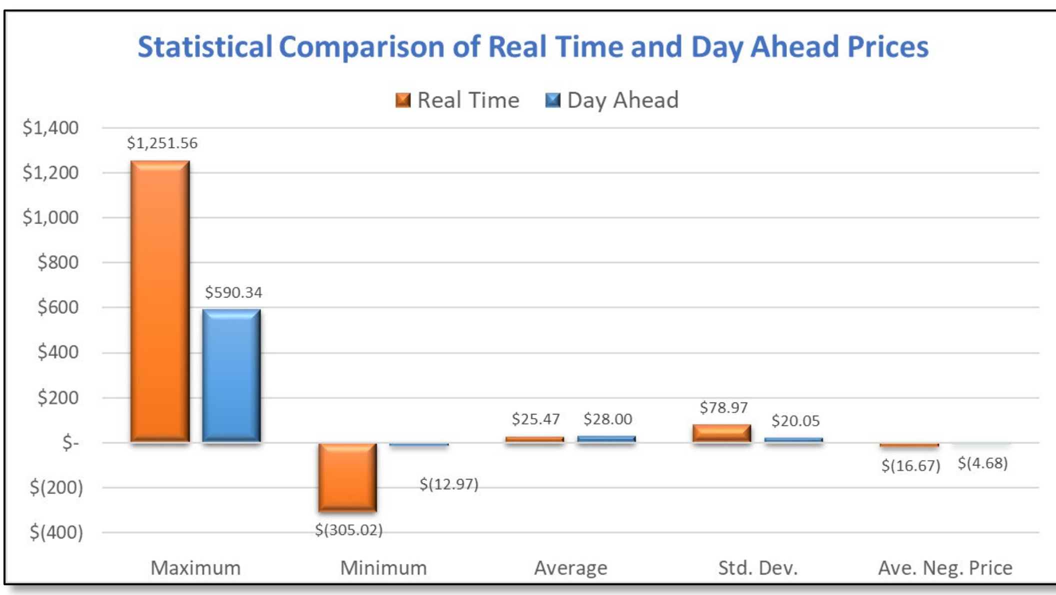
In comparison, there were far fewer instances of negative prices in the day-ahead market (3 percent). Moreover, the average negative price in the day-ahead market was $4.68/MWh versus $16.70/MWh in the real-time market, an important difference. In addition, the day-ahead market is much more stable with smaller extremes, as shown in Figure 87 and Figure 88.

Figure 87: Comparison of Prices in Real-Time Market and Day-Ahead Market



Source: Onset, Inc.

Figure 88: The Day-Ahead Market is More Stable



Source: Onset, Inc.

Summary of Benefits

There are, therefore, economic incentives for VER owners to use the day-ahead market, as discussed in Chapter 2.

- Revenues will be greater because day-ahead market prices are 10 percent higher on the average and avoiding economic curtailments results in an 11 percent increase in generation. The combined effect is a 21 percent increase in revenue.
- Revenues (and therefore cash flows) are considerably more stable, which in turn increases the asset's value.
- Reduction in balancing costs when actual VER generation deviates from schedule because the cost of the firming resources (gas plant or storage) is, over the course of the year, cheaper than the balancing costs purchased in the spot market. This incentive was determined by the studies described in Chapter 2 to be $200 million per year per 1000 MW of installed VER capacity. Over the course of 10 years, this is over $2 billion in cost savings that will help reduce rates for California consumers.

When VER owners are encouraged to use the day-ahead market, California ISO also benefits without any requirement to change its market or operations.

- The California ISO market would be more efficient because there would be less dependence upon the spot market.
- Lesser amounts of regulation services, which are purchased in the residual unit commitment market,[28] will be needed because dependable day-ahead schedules provide valuable information. In other words, California ISO would not pay to have power plants online and generating GHG emissions to account for the uncertainty in VER generation. (This is discussed in detail in Appendix E, Reducing GHG Emissions by Reducing the Number of Thermal Units Running at Part Load). This is a cost benefit for ratepayers, estimated by California ISO to be up to $36 million per year (based on information presented by California ISO at the Market Performance and Planning Forum on July 21, 2016). This is a savings to ratepayers of nearly $500 million over a 10- to 15-year period.
- Mitigation of the Duck Curve; that is, the steep afternoon ramps that occur in oversupply conditions. By flattening the Duck Curve, the number of gas-fired plants that are needed to be on-line to respond to the ramps is potentially far fewer. It is estimated, as described in Appendix E, that the number of combined cycle plants that are running at minimum load (at which point natural gas consumption and GHG emissions are the highest) would potentially be 2 GW less, a 10 percent reduction.

[28] The residual unit commitment market takes place after the day-ahead schedules are submitted and before the real-time market opens.

- Frequency regulation is enhanced at no cost to California ISO and without its intervention because UniGen hybrid plants automatically keep demand and supply in balance. Conceptually, AGC plants and those with droop controls respond to changes in grid frequency and take actions that attempt to restore the balance between demand and supply, which is characterized by a frequency of 60 Hz. The UniGen control system responds to changes in schedule deviations and takes actions to maintain the generation schedule. This is equivalent to balancing demand and supply, thereby directly and quickly preventing frequency changes before they occur. The authors are not familiar enough with NERC standards and penalties to estimate the financial impact of this.

LIST OF ACRONYMS

Term	Definition
AGC	Automatic Generation Control
California ISO	California Independent System Operator
CCCT	Combined Cycle Combustion Turbine
DER	Distributed Energy Resource
MW	Megawatt (1,000,000 watts)
MWh	Megawatt hours
NERC	National Electric Reliability Council
Pmin	Minimum load of a power plant
RPS	Renewable Portfolio Standard
RTAC	Real-Time Automation Controller
SCADA	Supervisory Control and Data Acquisition
SCCT	Simple Cycle Combustion Turbine
UGN	UniGen
UniGen	UniGen *Smart System for* Renewable Integration
VER	Variable Energy Resource

REFERENCES

Power Conversion and Control of Wind Energy Systems, by Bin Wu, Yongqiang Lang, Navid Zargari, Samir Kouro, IEEE Press Series on Power Engineering, Wiley, 2011.

Appendix A: Estimating VER Generation in 2024

California ISO expects that the explosive growth of VER generation will result in effectively meeting the 50% RPS requirement by 2024, six years early. For this reason, we use 2024 as reference. Forecasts for electricity sales in 2024 by the CEC[29] are about 330,000 GWH. The amount of VER generation for the purposes of this study is assumed to be one-half that or 165,000 GWH. Subtracting the amount of existing generation results in an estimate of how much new VER generation will be needed, that is, 89,086 GWH. This is a 230 percent increase over an eight year period, a growth rate of 11 percent per year. Most of this growth is expected to be in the from of new solar generation. For this study it was assumed new solar generation will outpace wind by a factor of 10-to-1 (Table A-1 and Table A-2).

Table A-1: Estimate of VER Generation in 2024

VER Generation	GWH
Electricity Sales 2024	330,000
50% RPS (2024)	165,000
VER GWH (2016)	38,465
Other Renewable (2016)	37,449
New VER Gen by 2024	89,086
New Solar Gen 2024	80,987
New Wind Gen 2024	8,099
Total Solar Gen 2024	95,452
Total Wind Gen 2024	32,099

Source: Onset, Inc.

Table A-2: Estimate of New VER Capacity to Meet Generation Targets

VER Capacity	MW
New Solar Capacity	40,196
New Wind Capacity	2,802
Solar Capacity 2024	47,376
Wind Capacity 2024	11,104

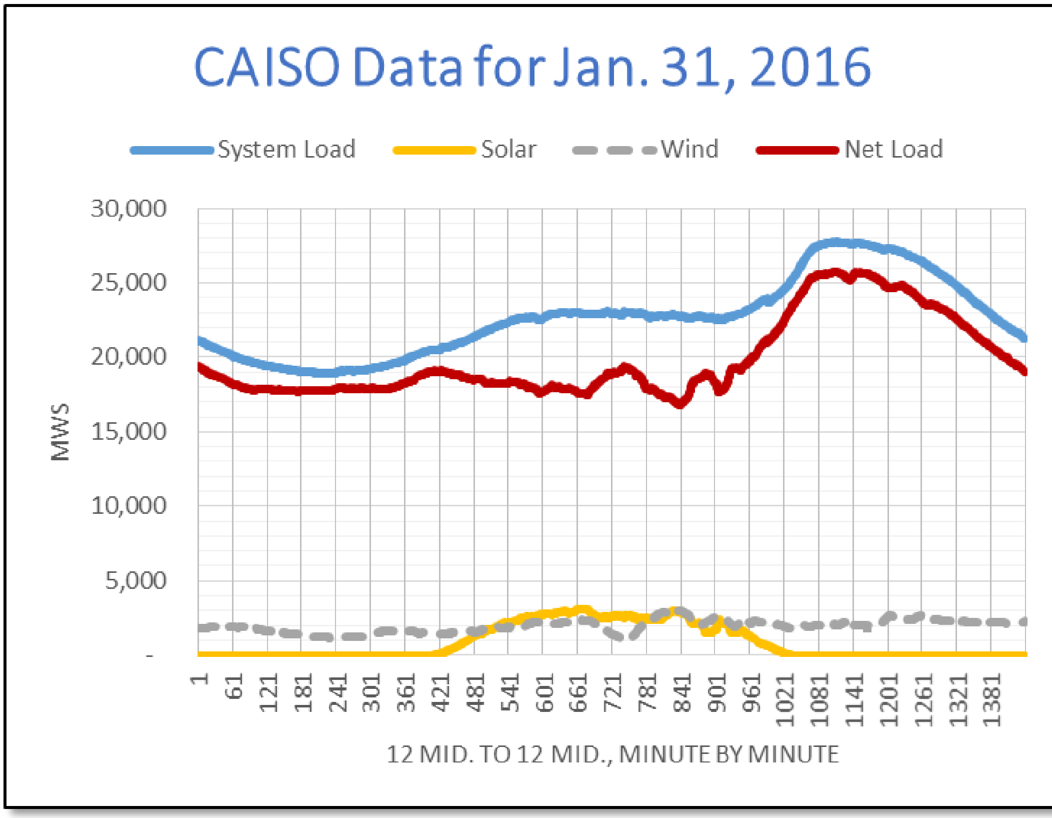
[29] California Energy Demand 2016-2026, Revised Electricity Forecast, January 2015.

Source: Onset, Inc.

Appendix B:
Data Used in the UniGen Simulation Model of Over Generation

In order to simulate the over generation conditions and analyze the mitigating effects of using UniGen, data for load, wind generation, and solar generation for the California ISO system on January 31, 2016 was taken from the OASIS webiste[30]. This data was used to construct the curves in Figure B-1. The load and generation curves for 2024 have the same shape as for 2016, but are scaled upward using estimates made in Appendix A (Figures B-2 and B-3).

Figure B-1: Actual CAISO Data Used in Analysis



Source: Onset, Inc.

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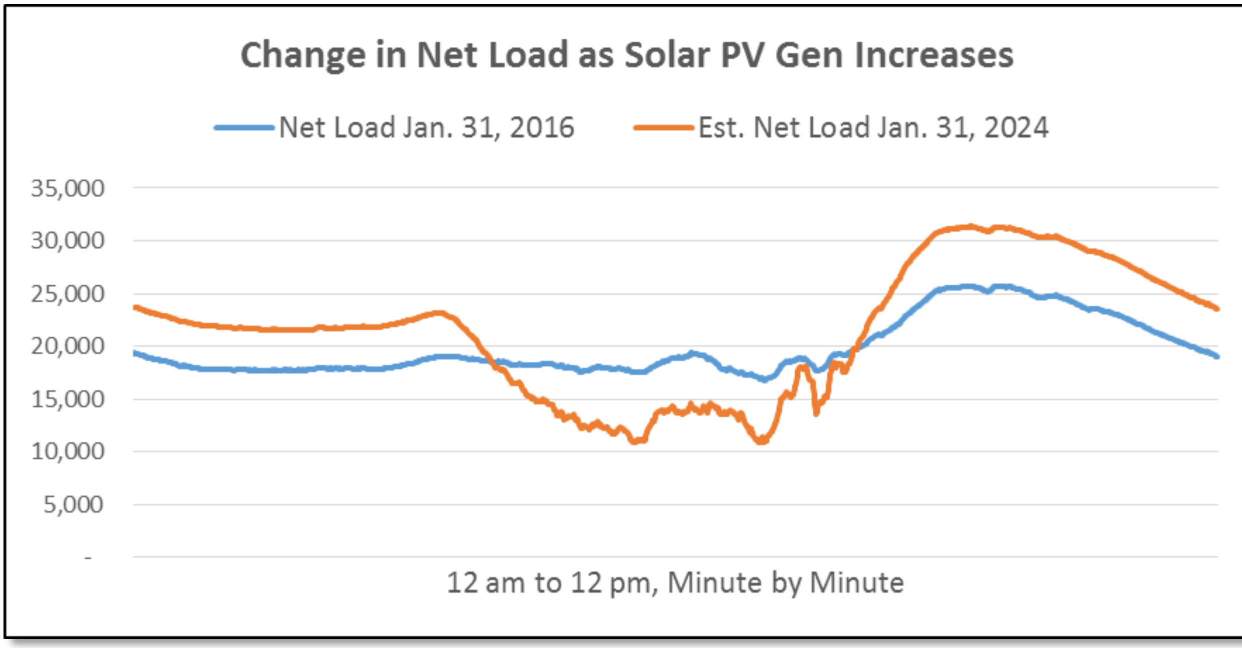
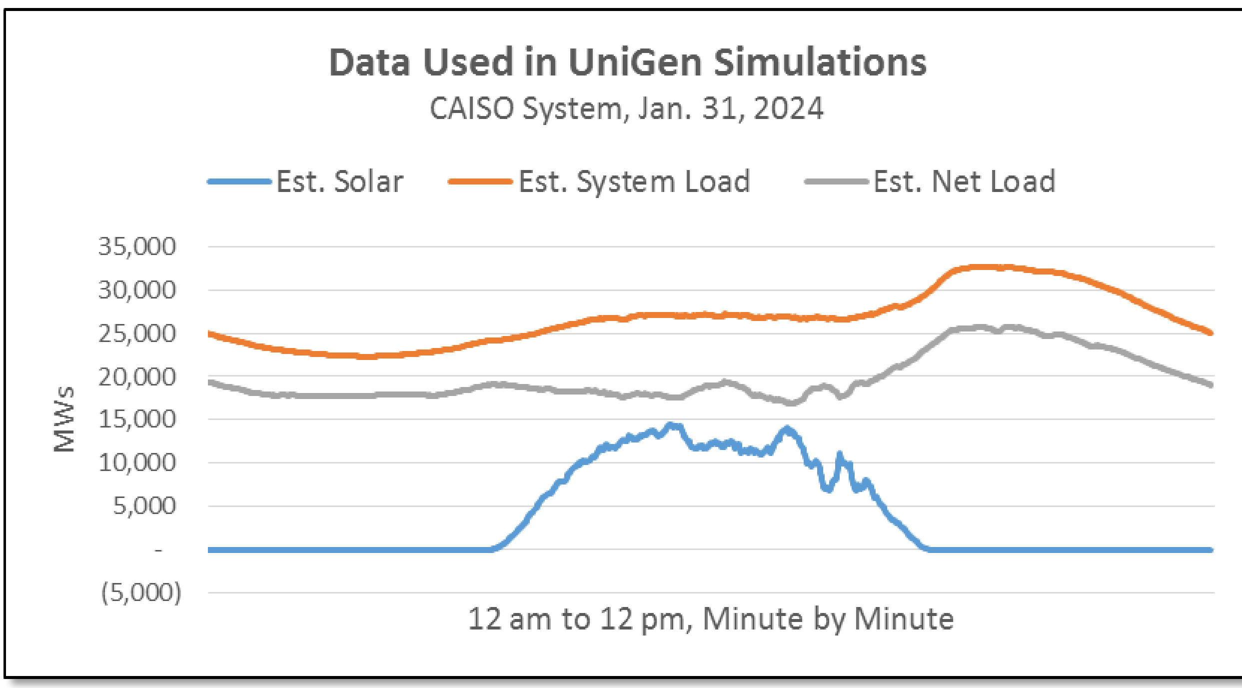
[30] Open Access Same-time Information System (OASIS) site. OASIS provides real-time data related to the CAISO transmission system and it's Market, such as system demand forecasts, transmission outage and capacity status, market prices and market result data. http://oasis.caiso.com/mrioasis/logon.do

Figure B-2: Changes in Net Load as Solar Photovoltaic Generation Increases



Source: Onset, Inc.

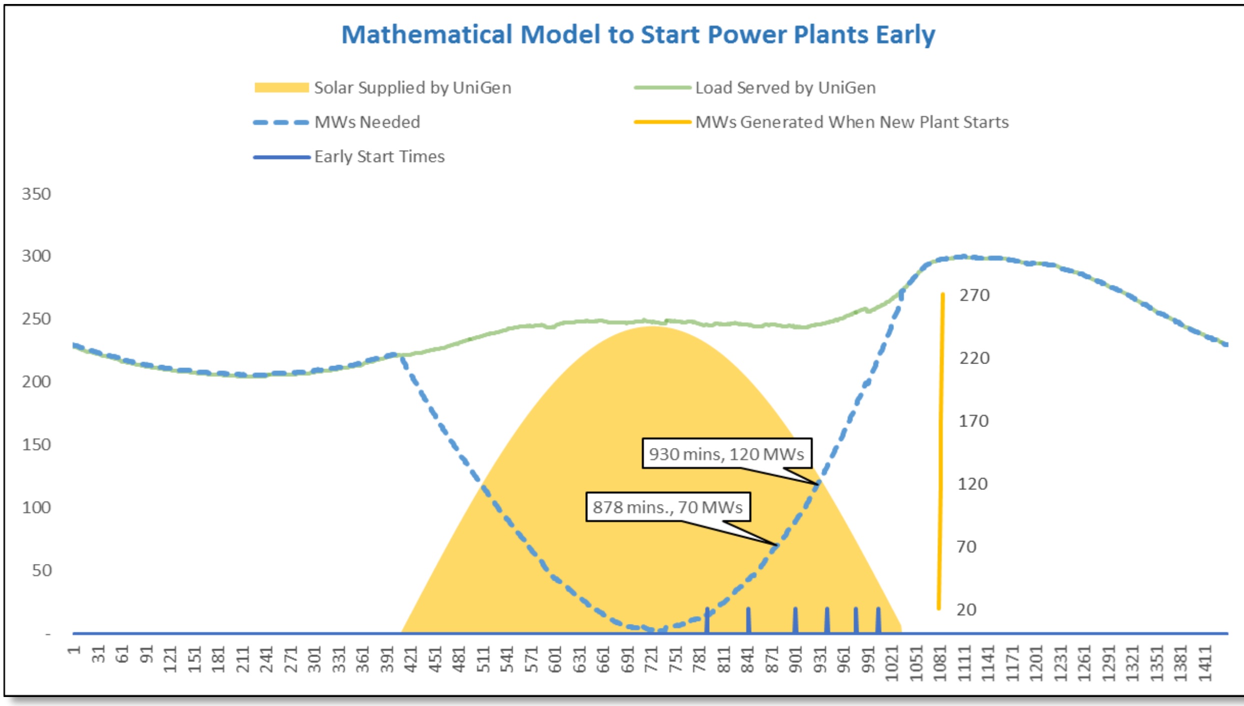
Figure B-3: Data Used in UniGen Simulations



Source: Onset, Inc.

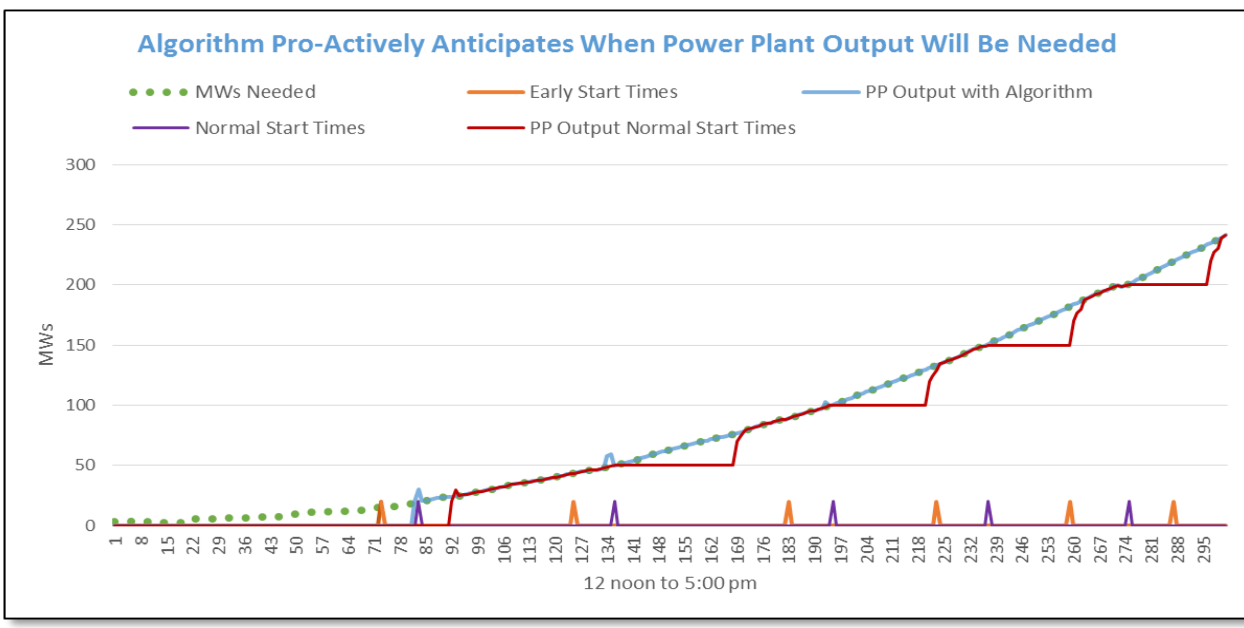
Appendix C:
Early Mover Algorithm

Figure C-1: A UniGen Algorithm to Proactively Start Power Plants



Source: Onset, Inc.

Figure C-2: Early Mover Automatically Pre-Loads Firming Generation



Source: Onset, Inc.

Appendix D: Seasonal Effects of Over Generation

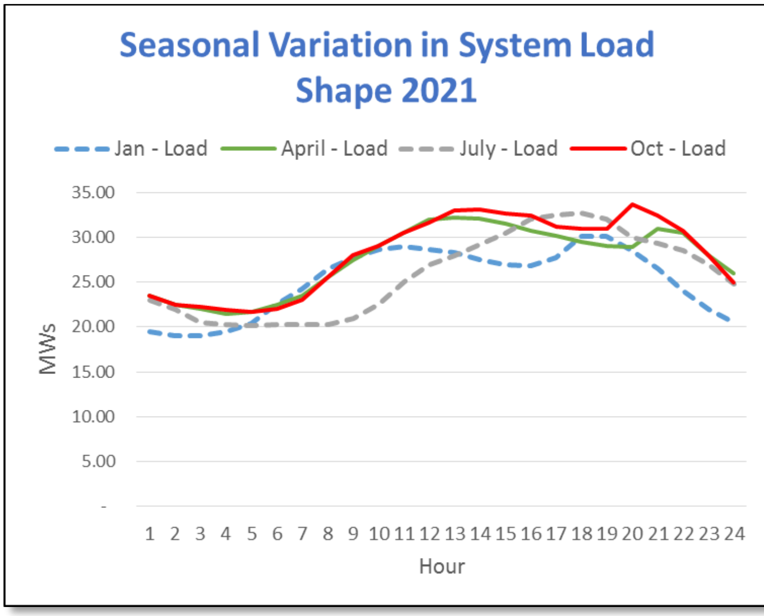
The figures that follow are the results of four different simulations of the UniGen system with each scenario having a different load and solar generation profile. These shapes were taken from a California ISO presentation "California ISO's proposed TOU periods to address grid needs with high numbers of renewables," November 17, 2015, slide 7 (Figure D-1).

Our analysis shows that the ramps following an over generation condition are greatest in January and July, but for different reasons.

In winter months, the load shape is flatter (peak to average is ~1.06) than at any other time of the year. The solar generation curve has a tight distribution with 70 percent of the energy generated between 10 am and 2 pm. The result is that solar generation takes a big chunk out of the system load but stops as the afternoon ramps are just beginning. This creates a deep well from which the system has to climb with no help from solar. Wind generation helps but recall that the assumption in these analyses, based upon CEC forecasts, is that when the 50 percent RPS is reached,

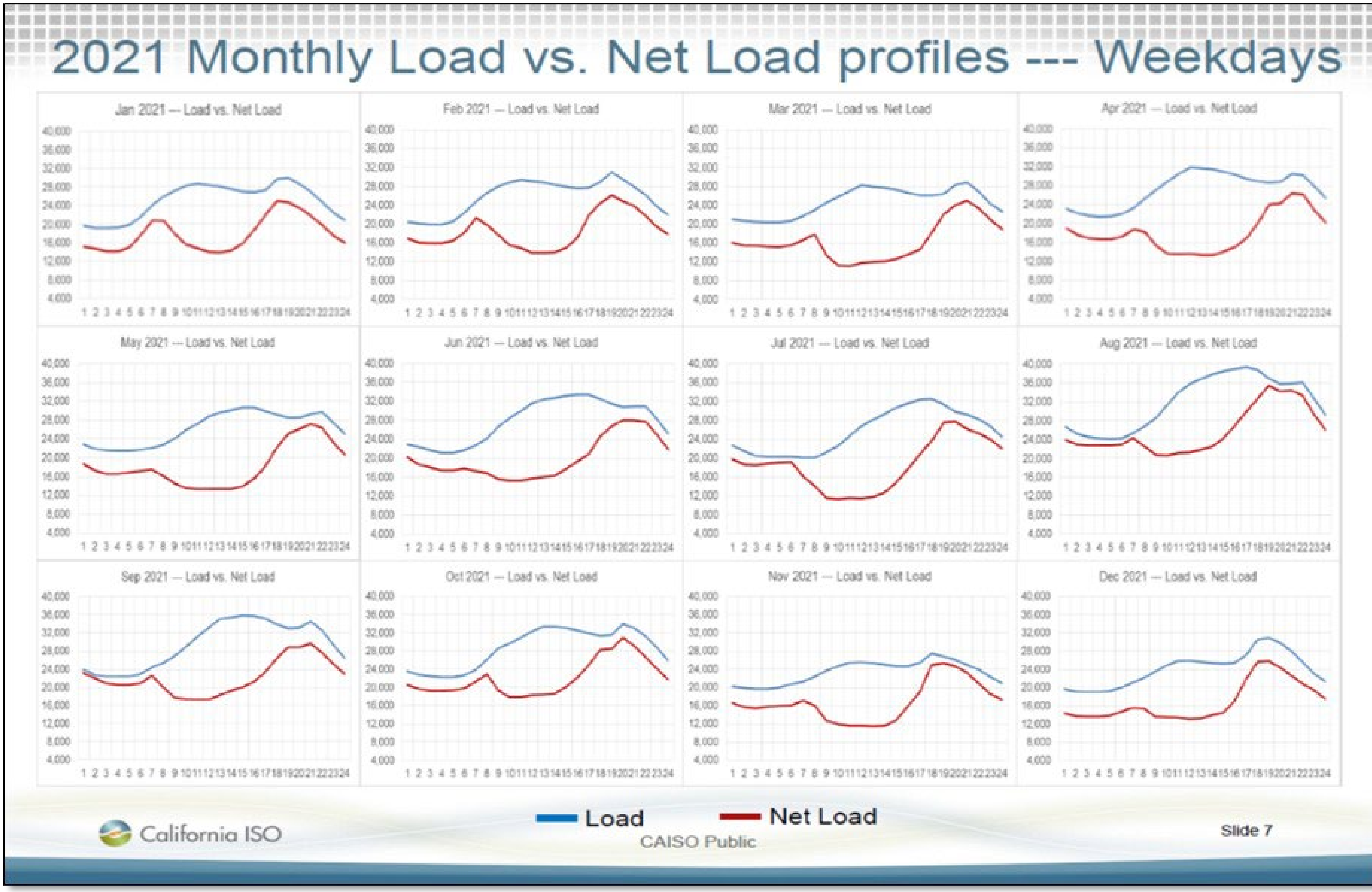
In summer months, the solar generation curve is quite different. Peak generation is, of course, much higher. However, the important feature is that the distribution of the solar generation curve has spread out, that is, the standard deviation from the mean is larger, so that 70 percent of the energy is generated between 8 am and 4 pm. Solar does help the system climb out of the well but the increase in peak load means it falls short.

Figure D-1: Seasonal Changes in Load



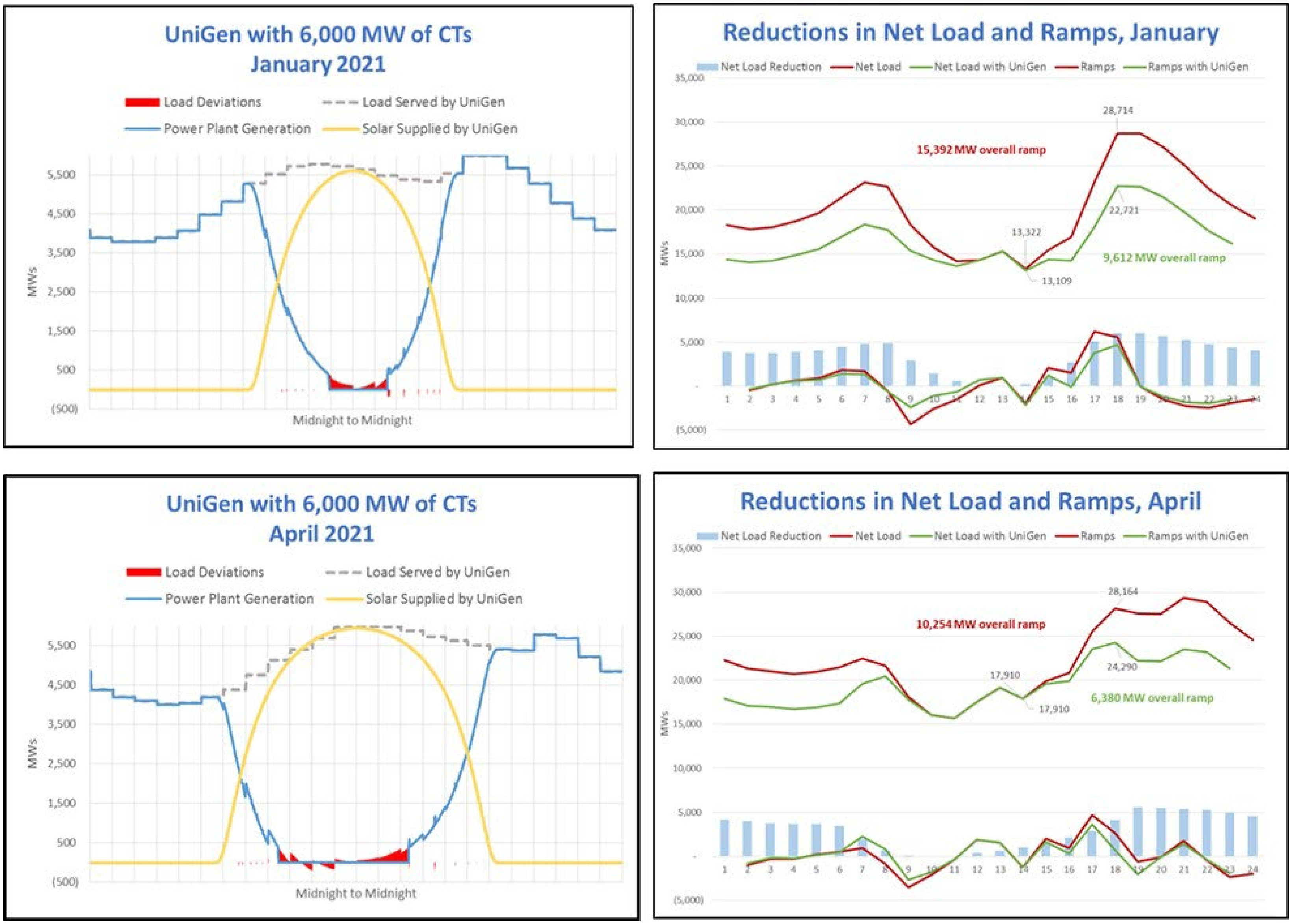
Source: Onset, Inc.

Figure D-2: Seasonal Shapes of Net Load



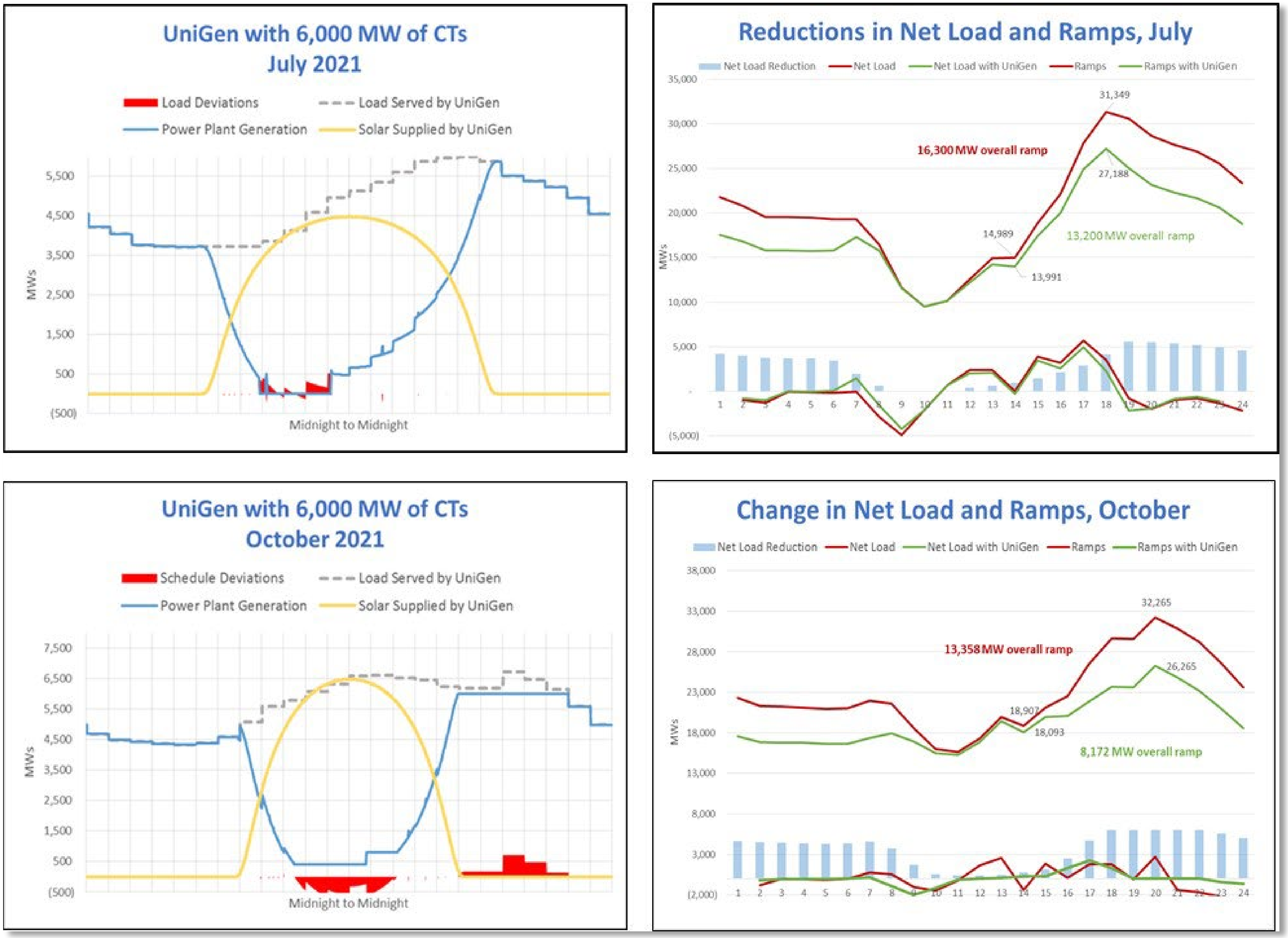
Source: CAISO

Figure D-3: UniGen Mitigates the Effects of Over Generation.



Source: Onset, Inc.

Figure D-4: UniGen Mitigates the Effects of Over Generation



Source: Onset, Inc.

Appendix E: Reducing GHG Emissions by Reducing the Number of Thermal Units Running at Part Load

The increase in regulation from 400 MW to 800 MW, as described above, was in effect for the four-month period (late winter and early spring) when generation forecasts have the highest error. Of course, there are forecast errors throughout the year and these are managed using CAISO markets and dispatch operators.

The number of units committed each day to meet the expected load is determined by California ISO's three markets Day-ahead Markets: Bid Mitigation, Integrated Forward Market (IFM), and Residual Unit Commitment (RUC). Bids are submitted and accepted if they pass the Bid Mitigation market power test. The IFM is then run to determine if there is enough generation to meet demand. If not, additional generating units are committed via the RUC process. Adjustments to available capacity are made before and during the Real Time Market.

The differences between the day-ahead forecasts of VER generation and actual VER generation represent a large uncertainty[31] (and increasingly the same is true for demand[32]). The amount of capacity procured in the RUC market is directly related to this uncertainty, leading to more capacity than would otherwise be needed "just in case." California ISO's statement of the problem was cited earlier:

> *"As the ISO sees additional wind and solar resources generation at higher RPS levels, this lack of day-ahead scheduling may lead to increased day-ahead over-commitment of thermal generation (to minimize the risk of a supply shortfall)"*

For thermal plants to respond at a moment's notice to forecast errors, they must be synchronized to the grid and ready to quickly ramp. As a result, a significant number of Thermal units are operating at partial load during most of the day, as the series of figures in the Appendix explain.

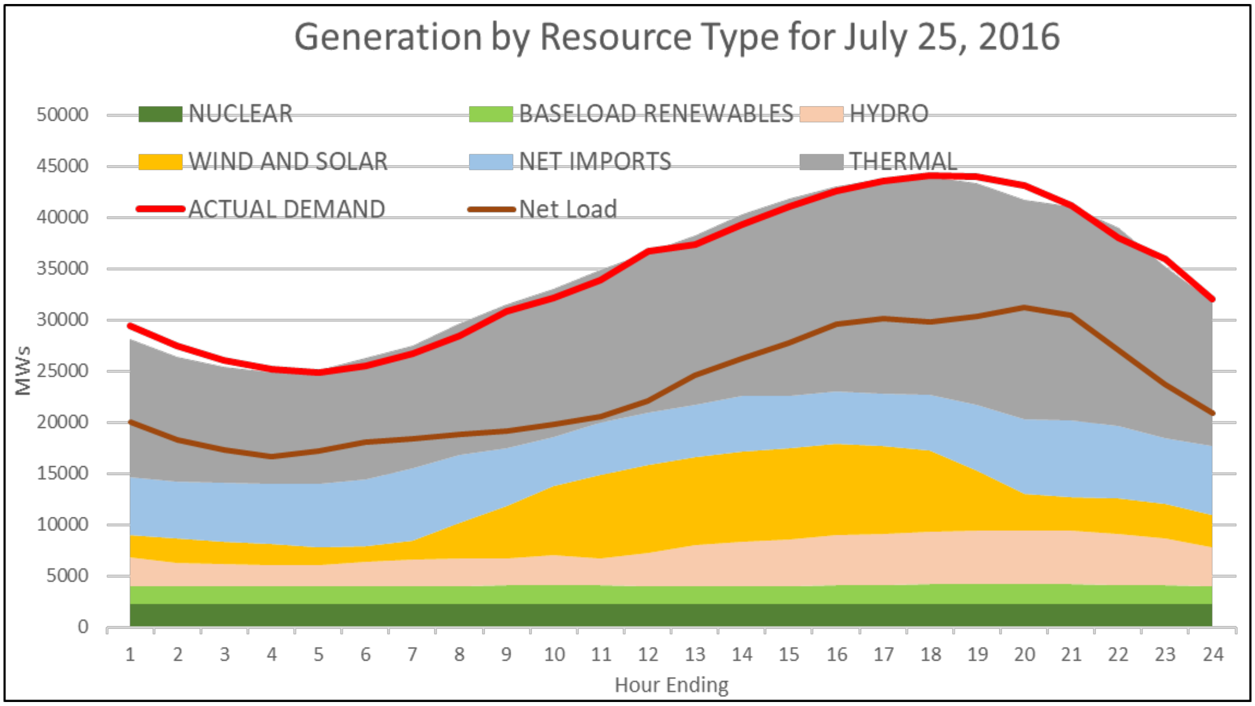
Figure E-1 was constructed using California ISO's published data to depict a snapshot of the generation resources being utilized during the course of a single day (July 25, 2016). The red line depicting actual demand is not exactly the same as the sum of all

[31] An example of this was given to us by California ISO. The Real-Time market closes 7.5 minutes before each 5-minute dispatch interval. During that time, solar PV generation can change by 1,000 MWs. Obviously, one cannot wait for the Real-Time market to dispatch units from cold or hot shutdown. The plants must be online and ready to ramp.

[32] Demand is no longer influenced primarily by temperature but is now more a function of temperature, Demand Response, Plug-In Vehicle load, and Distributed Solar.

the generation, perhaps because these numbers come from two different sources of data (OASIS and California ISO website.) They are close enough for this analysis.

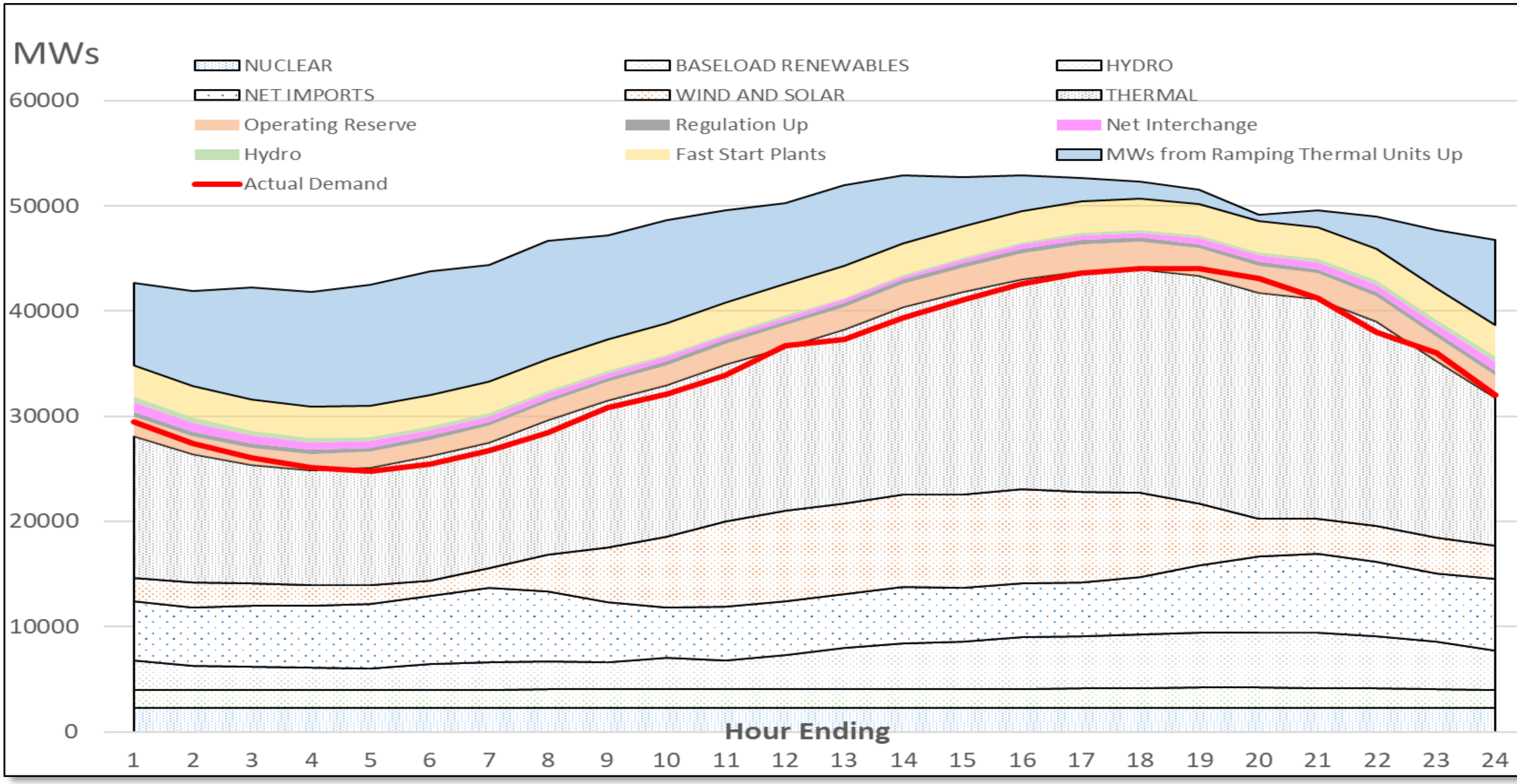
Figure E-1: Generation by Resource Type for July 25, 2016



Source: Onset, Inc

California ISO also publishes the amount of Available Energy Resources (AERs) by resource type. An AER is defined to be hydro, a fast start engine or a thermal unit that is online but has some upward ramping capability (headroom.) By definition, this last group of Thermal units are partially loaded. The data for AERs was used to construct Figure E-2, which shows how much headroom Thermal units have compared to the actual generation. At the start of the day, there is about 10,000 MW of upward capacity from online Thermal units that is completely used when demand reaches its peaks in the late afternoon.

Figure E-2: Actual Generation and Available Resources



Source: Onset, Inc

Now that it is known the upward ramping available and the actual generation from thermal units, the average load factor can be estimated for all the thermal units online (Figure E-3). What can be seen clearly is that the number of thermal units synchronized to the grid is constant throughout the day with only the loading factor changing. It would appear that the number of online units are calibrated to help meet the daily peak demand. After the peak demand is met, the loading factor declines (the plants are dispatched downward) but are not shut down. Operators keep these units online during the night because some are longer start plants but more importantly because they do not want to run the risk of the plants not returning to service.

Requiring Thermal plants to be running all the time at part load is inefficient compared to running at full power. The fuel costs and GHG emission are 50 percent to 60 percent greater. It is costly because payment is made on all the capacity, even though much of it is never used. In addition, it exacerbates the problem of over-generation because partly loaded plants have less downward ramping capability.

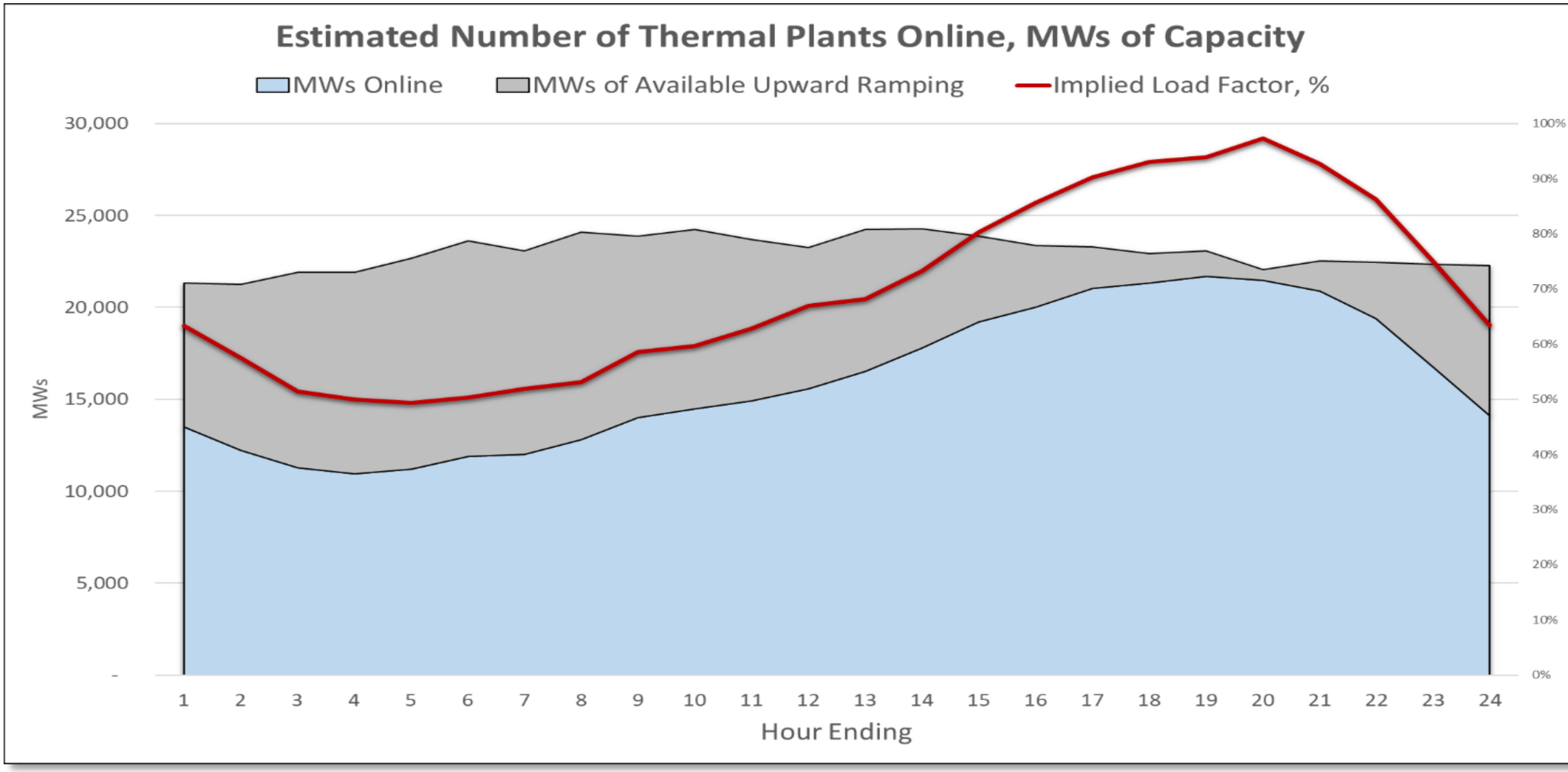
UniGen converts the VER resource, a dedicated gas plant(s), and energy storage systems into a renewable baseload plant whose joint output predictably meets a schedule. This reduces the inherent variability and uncertainty associated with wind and solar production. The result is fewer thermal plants are needed to be online as will now be discussed.

There are 3,000 MW of fast start engines in CAISO. If this capacity was used and combined with an equal amount of solar capacity using UniGen, the result would be as shown in Figure E-4. This looks like any other baseload plant that operated during the day but was shut down at night. Figure E-5 shows what the resulting generation mix looks. There is excess Thermal capacity (most probably Combined Cycle) as represented by the blue area above the red line which represents demand. There are periods when UniGen Renewable Baseload Plants that are capable of meeting the peak demand and shutting down at night replace 5,000 MW of Thermal capacity, which cannot be shut down.

Conceptually, this means that the fast start engines, referred to as flexible resources, are no longer on the sideline. These plants are now generating power alongside the solar resource, ramping up and down, which is what they are designed to do. The hybrid resource takes on flexible characteristics. UniGen makes this possible.

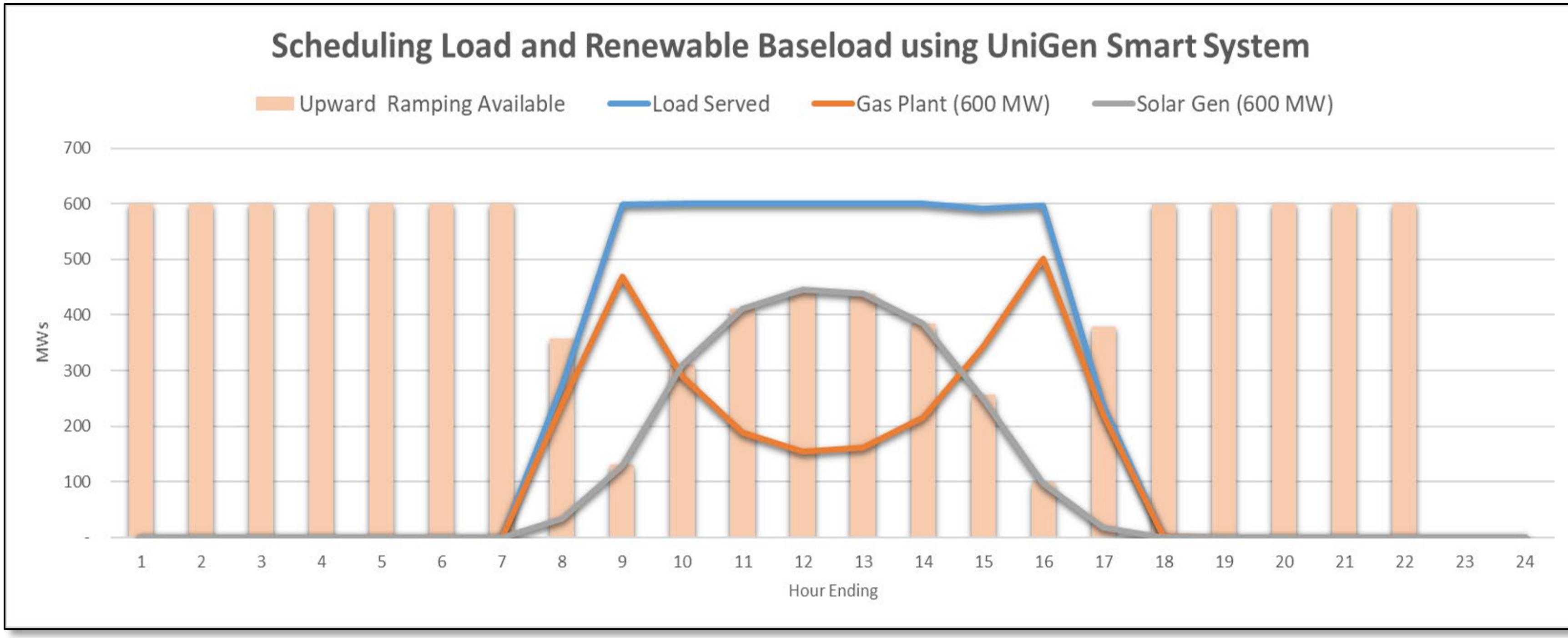
Meanwhile, the Thermal units can go back to doing what they do best which is to be a baseload resource that operates at full power with modest ramping.

Figure E-3: Est. Capacity of Gas Plants Online to Meet Ramping Needs



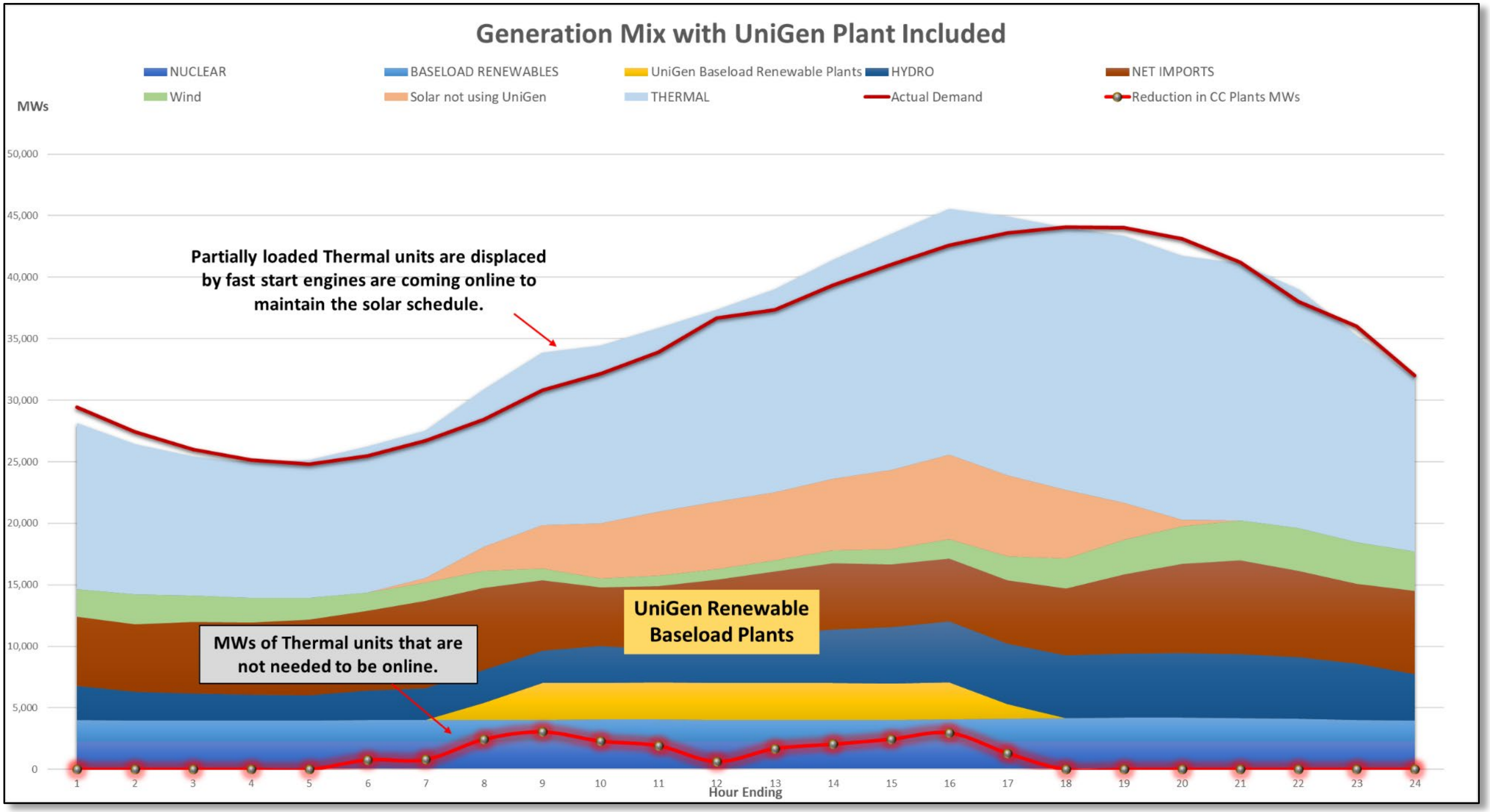
Source: Onset, Inc

Figure E-4: Creating Flexible Capacity with UniGen



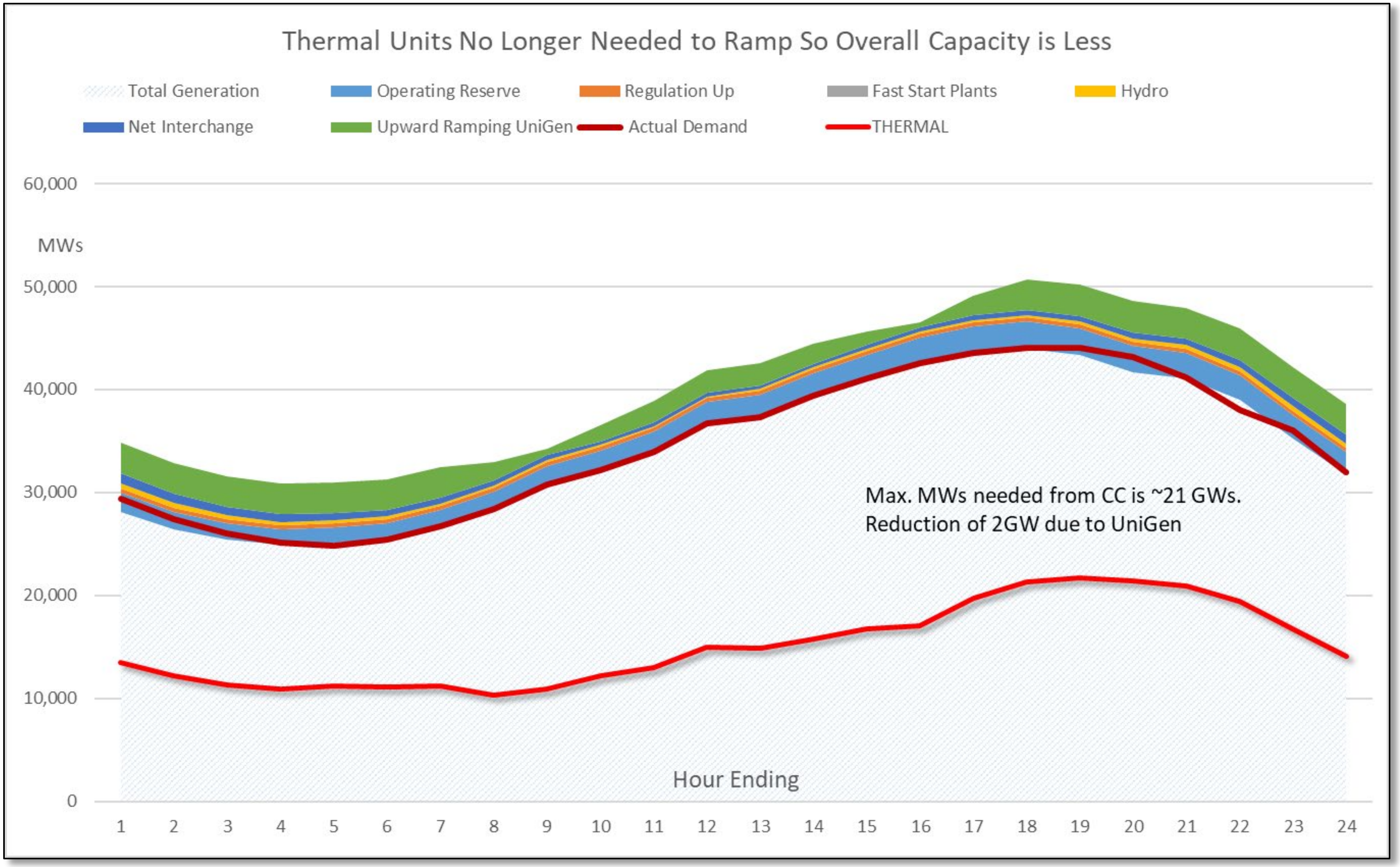
Source: Onset, Inc

Figure E-5: Fewer Thermal Units Need to Be Online to Meet Ramping Needs



Source: Onset, Inc

Figure E-6: UniGen Has the Potential to Reduce the Number of CC Plants at Min Load



Source: Onset, Inc