Energy Optimized

Whitepaper

Today's energy landscape is changing. There is a global energy transition underway in which renewable energy sources, led by wind and solar power, will ultimately replace legacy thermal generation. Falling supply costs, coupled with technology innovations in energy storage, software, and automation, are facilitating this change.

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Introduction

In 2015, the State of Hawaii became the first state in the U.S. to legally commit to a 100 Renewable Portfolio Standard (RPS). The 100 percent RPS law requires power utilities in the state to procure 30 percent of their energy from renewables by December 31, 2020, 70 percent by December 31, 2040, and 100 percent by December 31, 2045. As of 2018, Hawaii meets 28 percent[1] of its energy demand from renewable energy and California meets 34 percent[2] of its energy demand from renewable energy.

We will continue to see a global transition towards more sustainable energy systems. Earlier in 2018, the launch of the UK100 pledge received the support of over 90 local city leaders across the United Kingdom to commit to 100 percent clean energy by 2050. The International Energy Agency (IEA) estimates that by 2040, total global generation capacity will increase by 60 percent, and renewable energy sources will make up more than 45 percent of that total. As the world moves toward a future that utilizes 100 percent renewable energy, utilities, independent power producers (IPPs) and other energy providers must act to harness its potential.

Underpinning the energy transition is the falling cost of renewable energy. In 2018, Xcel Energy, a utility company serving the upper Midwest United States, announced that in response to a solicitation they issued, they received solar + storage PPA bids of $36/MWh and wind + storage PPA bids of $21/MWh. Both prices are less than the cost of conventional thermal generation. Some of these prices benefit from incentives. The federal investment tax credits (ITC) in the United States allows investors to deduct 30 percent of the cost of installing a solar energy system from federal taxes. The production tax credit (PTC) is an inflation-adjusted per-kilowatt-hour (kWh) federal tax credit for electricity generated from wind power. Regardless, renewable prices continue to drop and unsubsidized renewables and storage will continue to expand worldwide.

1 - https://dashboard.hawaii.gov/stat/goals/5xhf-begg/fgyu-2f7k/b6pj-n292
2 - http://ieefa.org/california-tops-2020-goal-of-33-renewable-energy/

As renewable energy drops in price, it becomes the new low-cost baseload for the grid. While cheap renewables create tremendous economic and environmental benefits, they also create integration challenges for grid operators. Due to the intermittent output of solar and wind generation, grid operators must deal with power reliability challenges different from those faced in the past. These challenges are distinct in different parts of the world based on each local grid's resource mix.

While renewables create integration challenges, new technologies have emerged to solve these challenges. Today, the grid is balanced primarily with thermal and hydro power generation. These power plants provide both energy and ancillary services to keep supply and demand on the grid balanced. Increasingly, battery energy storage is used to integrate more renewable power and improve grid flexibility. In some cases, energy storage is co-located as a "hybrid" with another energy generation asset, such as a thermal generation plant, to increase the flexibility and performance of the thermal plant. The challenge for operators is that energy storage and hybrid plants have vastly different operational tradeoffs from traditional solutions. The optimal energy generation resource mix has changed, and new tools are needed to deliver optimal performance.

This white paper seeks to characterize different grid optimization challenges and describe how energy management systems (EMS) have evolved to solve the energy optimization problems found in different grids.

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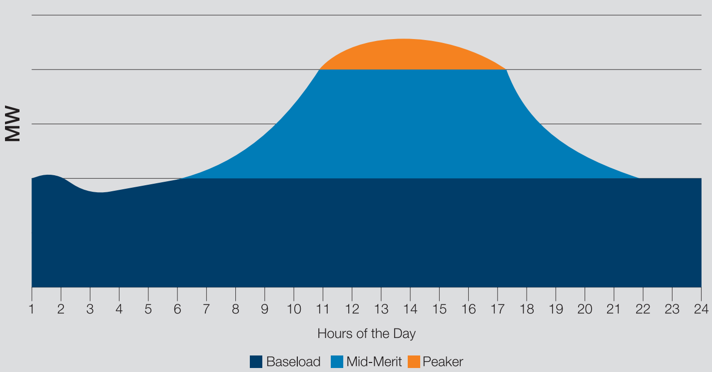
Electricity grids face diverse challenges

Electricity grids operate differently across the globe. In a small island grid, the supply of electricity may consist of a small number of thermal generators operated manually. In large developed grids, operators use sophisticated software platforms which use economic dispatch logic to determine which generators run. In open electricity markets, different energy products are sold and purchased based on offers and bids. Due to different trading strategies and physical power system limitations sometimes, generation costs are not always reflected in energy prices.

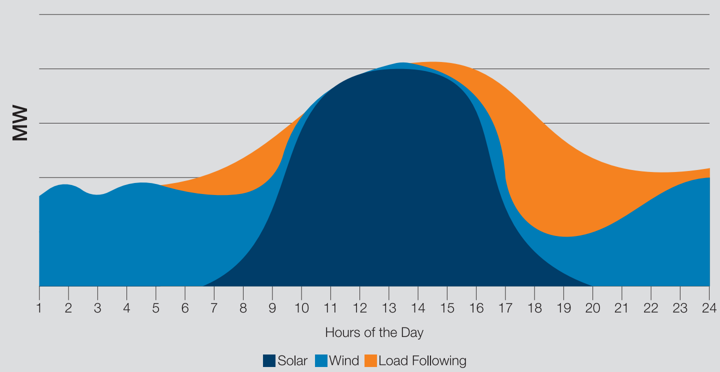
Grids also vary in their progress in the transition from traditional to renewable generation. Whereas grid operators of traditional grids must maximize the efficiency of their thermal generation fleet to minimize costs, grid operators of high renewable grids minimize costs by maximizing renewable energy output. Renewables as baseload create a new set of requirements for grid reliability.



Traditional generation grid

- Baseload (coal, nuclear, etc.)
- Mid-merit
- Peakers

Reliability challenge: grid operators must minimize cost with efficient generation while meeting peak demand with sufficient generation capacity



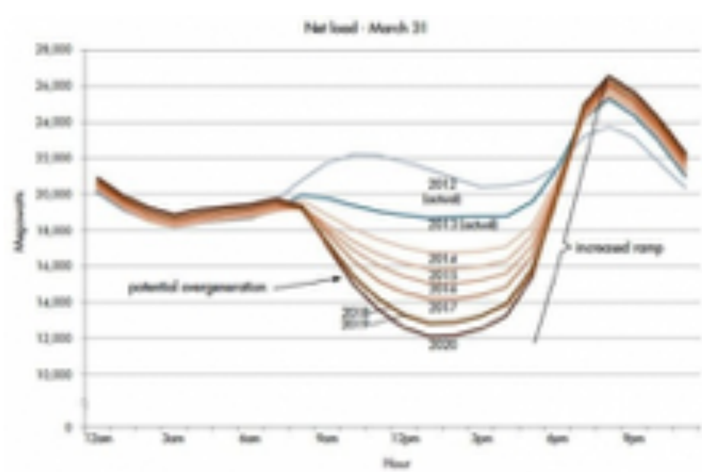
High renewables grid

- Baseload from renewables
- Load following from energy storage & flexible generation

Reliability challenge: grid operators must minimize cost by integrating renewables with load following resources

Examples of energy resource challenges facing different grids

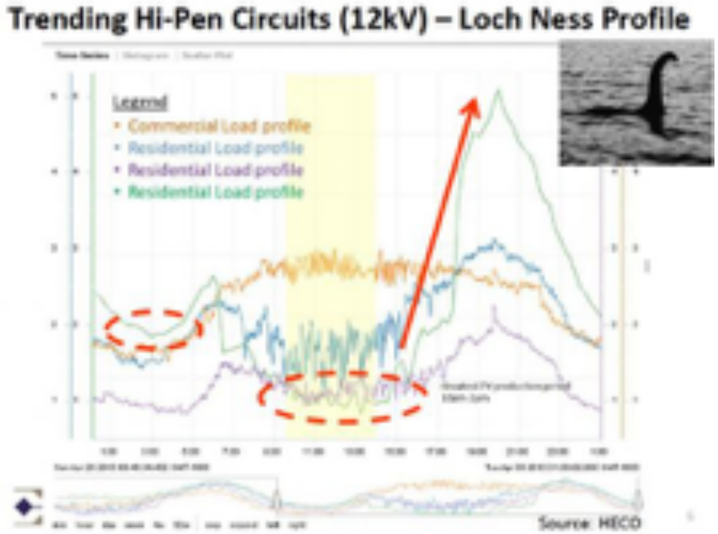
Finally, grids have different resource mixes across both traditional and renewable resources. Renewables create challenges of intermittency and predictability, and the specific challenge depends on local renewable resource profiles. Here is a look at three different grids transitioning to high renewables penetration and their respective energy resource challenges.



Source: US Department of Energy
https://www.energy.gov/eere/articles/confronting-duck-curve-how-address-over-generation-solar-energy

California - “Duck Curve”

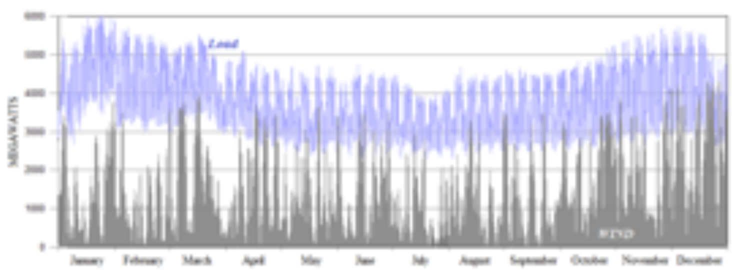
Commonly recognized as “the duck curve” due to the trendline silhouette, this graph illustrates the timing imbalance between peak demand and renewable energy production over the course of a day. In California, the net peak demand occurs after sunset, when solar power is no longer available. Energy storage in this scenario is most valuable for ramp rate control and load shifting to address the evening increase in demand.



Source: Greentech Media, from HECO
https://www.greentechmedia.com/articles/read/hawaiis-solar-grid-landscape-and-the-nessie-curve#gs.k4Z2YpM

Hawaii – "Nessie Curve"

In Hawaii, officials from HECO call the impact of high penetration PV the "Nessie Curve," based on the shape of the evening net load ramp. The evening ramp is even steeper than in California because solar reduces midday load and demand increases in the evening concurrent with solar output drops. In smaller island grids renewable energy is more difficult to integrate because there are no neighboring grids with which to exchange energy.



Source: Euan Mearns, University of Aberdeen
http://euanmearns.com/wind-power-denmark-and-the-island-of-denmark/

Denmark – "Danish Hedgehog"

In Denmark, wind power is the primary source of renewable generation. Wind power exhibits erratic output where output can stay high or low for weeks at a time. In a wind-heavy grid such as Denmark, the net load shape in Denmark does not exhibit a common daily profile as do the net load shapes in California or Hawaii.

In each of these three example markets, the energy generation mix can be optimized. In each case, optimization requires consideration for the unique characteristics of the local market energy mix.

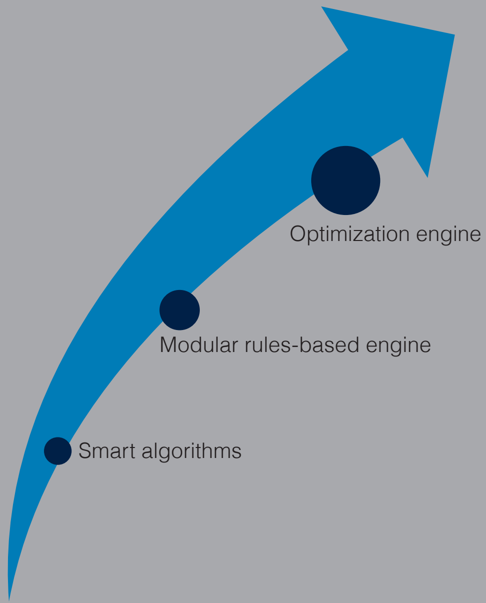
All regions of the energy world are undergoing a transition towards renewables. There is a growing need to optimize the changing mix of generation assets and ensure grid reliability. The optimal generation mix in each case will be different. The unifying theme is optimization of the energy resources available. Greensmith built the Greensmith Energy Management System (GEMS) to solve this challenge.

Energy resource optimization

GEMS is a proprietary software platform that can optimize energy generated from multiple sources, regardless of grid size, energy market construct, or energy generation mix. Our focus is on the optimization of energy storage and hybrid resources. Resources controlled by GEMS may be part of a larger grid, or GEMS may control the entire gird as in the case of an island microgrid. GEMS can maximize revenue for a single energy resource, or for objectives across a portfolio of energy resources.

Energy optimization requires a deep understanding of energy resource tradeoffs and constraints, especially those of dispatchable resources. Among dispatchable energy resources, battery energy storage presents a uniquely complex set of tradeoffs. With storage, both power capacity and energy capacity are limited, and for the leading battery technologies, energy capacity degrades over time with use. At this same time, energy storage resources offer unique benefits, including fast-ramping capabilities and accurate power output. The constraints of storage can be mitigated, and benefits enhanced when we pair energy storage with other generation resources in a hybrid configuration.

The tradeoffs of battery energy storage operation are not always well understood by existing power producers. Only in the past 5 years has battery energy storage become cost-effective enough to justify commercial investment. In the future, battery energy storage will be a critical resource to integrate renewables. Since our inception in 2008, Greensmith has developed a detailed understanding of the tradeoffs in energy resource optimization, especially energy storage optimization. With over 70 grid-scale systems deployed across nine countries for customers such as AEP, AltaGas, E.ON, NextEra, NRG and Oncor, GEMS is a proven platform in a nascent industry. With GEMS, we have built the tools to deliver optimal energy resource controls for any grid. Let us show you how we did it.



Smart algorithms

Example Project:

- ESS Size: 20 MW / 9 MWh
- Use Case: PJM Frequency Regulation
- Operation Date: 2014

Modular rules-based engine

Example Project:

- ESS Size: 10 MW / 2.5 MWh
- Solar Size: 1 MW
- Use Case: Frequency regulation, voltage regulation, manual capacity shifting, solar ITC compliance
- Operation Date: 2017

Optimization platform

Example Project:

- ESS Size: 7 MW / 3.2 MWh
- Solar Size: 1 MW
- Wind Size: 4.5 MW
- Engine Size: 5 MW split across 6 engines
- Use Case: Microgrid management, renewable energy optimization
- Operation Date: 2018

Smart algorithms

GEMS is built on a PC-based architecture, which allows us to more easily develop and modify complex applications compared to the PLC-based control architecture prevalent in the energy generation industry. Greensmith made the choice to develop a PC-based technology in 2008, which enabled us to take a market leadership position in applications that require complex controls logic. Our flexible PC-based approach also allows us to modularize the energy hardware selection. Rather than building control logic specific to a particular energy storage or generation technology, GEMS allows any technology's unique characteristics to be input variables in our smart algorithms.

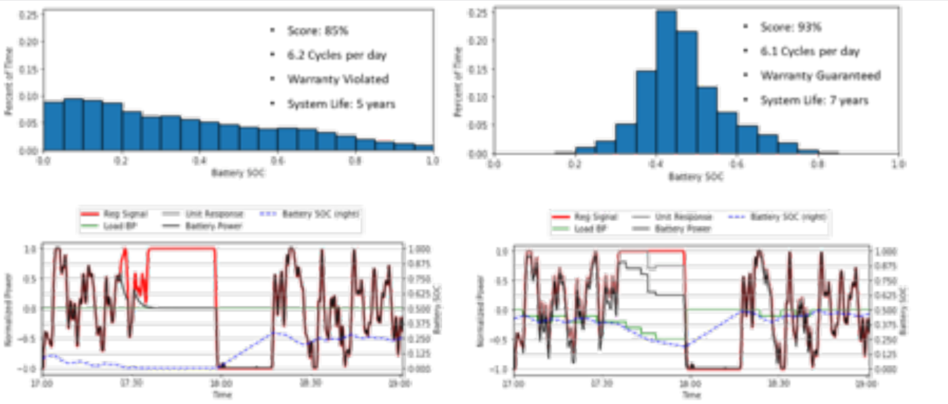
One example of an application that requires a smart algorithm is provision of frequency regulation with a battery. Different electricity markets have different approaches to maintaining grid frequency. In many large electricity markets, central grid operators send second-by-second power commands to generators via an automatic generator control (AGC) signal. The second-by-second commands instruct generators and energy storage systems to adjust their power setpoint up or down, thereby keeping the grid stable. In other electricity grids, including most vertically integrated markets, frequency is maintained autonomously by generators and energy storage systems which respond to deviations in local grid frequency based on a frequency droop curve. Despite these different grid requirements, the commonality across frequency regulation market rules is that there are always tradeoffs to be made in the provision of frequency regulation.

Greensmith has deployed eight energy storage systems that participate in the PJM Regulation-D market. PJM covers 13 states in the northeastern United States and is the largest electricity market in the United States, with 177 GW of generating capacity. For PJM Regulation-D, we have developed a smart algorithm that maximizes financial return of each energy storage system over the total project lifetime.

To do this, we must understand both the market revenue potential and the operational impact of charge and discharge cycles on batteries. While some may view frequency regulation as an example of a battery application where the battery controls system just "follow a signal", we found that there are always degrees of freedom to take advantage of to manage battery health. Figure 1 shows a side-by-side example of a "dumb" algorithm that follows the PJM signal directly and a "'smart" algorithm that considers performance metrics in PJM as well as battery health preferences. "Smart" algorithms make more revenue and protect battery health to ensure long-lasting operation. It may seem obvious that "smart" algorithms are a good idea, but we have seen examples in the field of commercial battery systems operated as per the "dumb algorithm" logic presented in Figure 1.

Figure 1 – At left: Example of an energy storage system that follows the PJM Regulation-D signal without a smart algorithm.

At right: Example of Greensmith smart algorithm in PJM which maximizes operator revenue and battery health.



Each battery chemistry type has a different tolerance for different operating parameters, such as the resting state of charge and energy throughput. Our algorithms are configured based on the underlying technology. Greensmith has an extensive library of real-world performance data from batteries in the field, and we use this in-house knowledge to maximize the battery health for all of our deployments. In doing so, we pass on the benefit of improved retained energy capacity and extended battery lifetime to our customers. Deep understanding of battery technology performance is crucial in the design of smart algorithms.

The smart algorithm approach works well in markets where the energy storage system is doing one or two applications, but Greensmith quickly found that more complex use cases demanded more complex software controls decision making.

Modular rules-based engine

Early commercial energy storage deployments often targeted a single application. In many markets, regulatory requirements have limited energy storage from taking advantage of stacked revenue streams. In other cases, only a single revenue stream is valuable enough to pursue. In these cases, the approach of smart algorithm development is sufficient.

In more recent years, energy storage operators have begun to deploy storage systems tasked with providing multiple applications to the grid. This trend has been led by vertically integrated electric utilities, meaning utilities which own all levels of the supply chain: generation, transmission, and distribution. These utilities are now deploying energy storage at commercial scale. Vertically integrated utilities typically face fewer regulatory barriers to monetize the multiple values of storage from a single storage asset.

It is technically possible to design a single smart algorithm to perform a stacked use case. However, such an algorithm quickly becomes too complex and lacks transparency. When software lacks transparency, our software engineers and customers face barriers in determining how to best modify or update the algorithm. Such modifications are critical when changes in grid requirements occur. Changes in grid conditions and requirements are inevitable over the expected lifetime of a power generation asset.

The solution to increasing complexity in energy storage algorithms is a modular rules-based engine. Greensmith developed a modular rules-based engine within GEMS, which has enabled us to tackle increasingly complex energy storage projects.

The rules engine allows us to combine various applications based on rules defined in consultation with our customers. The modular rules engine architecture enables the following benefits:

Transparency

Greensmith develops the rules hierarchy in consultation with the customer, so controls logic is transparent and delivers the intended use.

Future-Flexibility

When modifications to the system occur, or market conditions changed, the control logic can be modified with transparency and with limited impact on the overall system.

Modularity

Smart algorithms from our application library are quickly and easily configured for a new project.

In any control system, it is easy to create conflicting rules. Greensmith works carefully to test all possible edge cases from the rules-based engine in a digital twin, which is a real-time system emulation of the system. We create a digital twin for each energy storage system before it is deployed where we can troubleshoot in a virtual environment.

Our customers are tackling increasingly challenging grid problems which require complex controls. As energy storage and energy optimization become more complex, a modular rules-based engine becomes critical. The rules-based engine allows Greensmith to tackle complex challenges with a transparent, modular, and flexible software approach.

Rules-based engine example: storage + solar

As an example, Greensmith worked on an energy storage system designed for ancillary services with a vertically integrated utility with a high solar penetration. The utility wanted the energy storage system primarily to provide frequency response. They also wanted the ability to manually dispatch the energy storage system for grid support in cases such as planned outages. In addition, the utility wanted the battery to perform secondary use cases when grid frequency was stable, including voltage support and smart charging based on battery and local solar conditions.

Within GEMS, Greensmith developed a rules engine to enable each of these operations. The rules engine creates a set of control hierarchies, which can be defined by "if . . . then . . ." statements. A simplified version of this rules-based hierarchy is shown in Figure 2.

In Figure 2, applications are shown in blue. For each application, Greensmith works to develop a smart algorithm to maximize performance of the battery subject to grid requirements and battery constraints. As in a standalone application, there are always degrees of freedom that we can use in any application to maximize the health of an energy storage system.

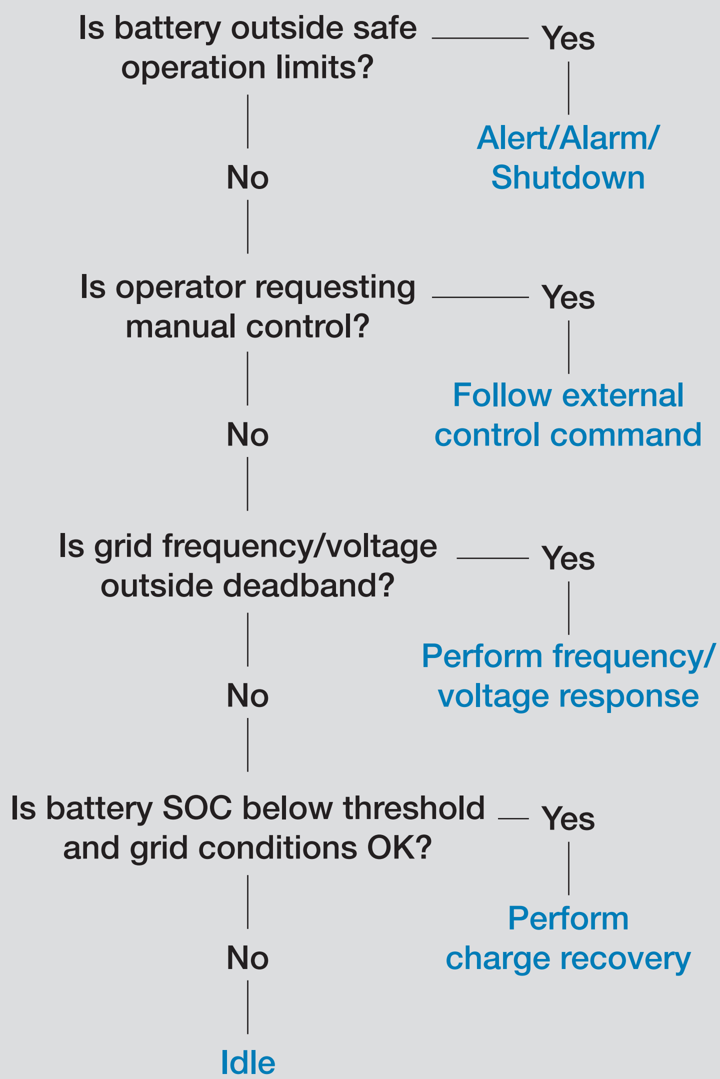


Figure 2 – Example of controls hierarchy in rules-based engine

GEMS optimization platform

Operators are asking energy storage resources to solve increasingly challenging problems. Smart algorithms and a rules-based engine can solve many grid challenges, but not all. Some grid objectives require a more rigorous mathematical approach. To address these types of challenges, Greensmith built an electricity-centric optimization platform within GEMS.

Optimization consists of maximizing or minimizing an objective function subject to constraints. Within mathematics, optimization is a mature field. In our daily lives, we use tools and services that are based on applied optimization. When we use a mapping service for driving directions, the software optimizes for minimum travel time. When we use an online airfare search tool, the software optimizes for low cost and trip duration. When the weather forecast changes, electricity grid operators in developed markets run an optimization to determine which power plants will be turned off or on to meet the changing load to minimize costs.

The requirements for energy optimization are increasing and changing. New grid assets, such as intermittent renewables, energy storage, and controllable loads, create new challenges and opportunities for grid optimization. With GEMS, Greensmith created an optimization tool that includes detailed knowledge of energy storage system technology constraints and tradeoffs. In many cases, the objective of a grid optimization is clear. Examples include: maximize IPP revenue, minimize consumer cost, or minimize greenhouse gas emissions. The difficult part is to correctly formulate the optimization problem with a detailed understanding of the constraints of all energy resources involved in the operation. Greensmith has a best-in-class understanding of the operation and constraints of energy storage, renewables, and thermal generation technologies. With that knowledge, we built GEMS, which is uniquely suited to handle optimization of energy technology using time-series grid data.

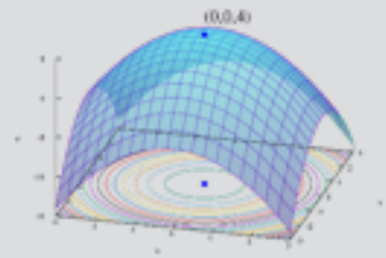


Figure 3 - Graphic representation of optimization, "Max Paraboloid"
Source: Wikimedia Commons

Figure 4 - Example of route optimization
Source: Google Maps

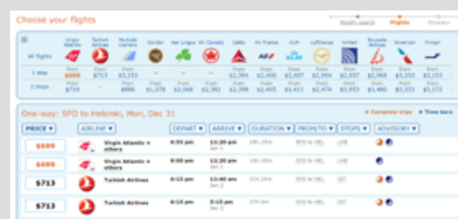
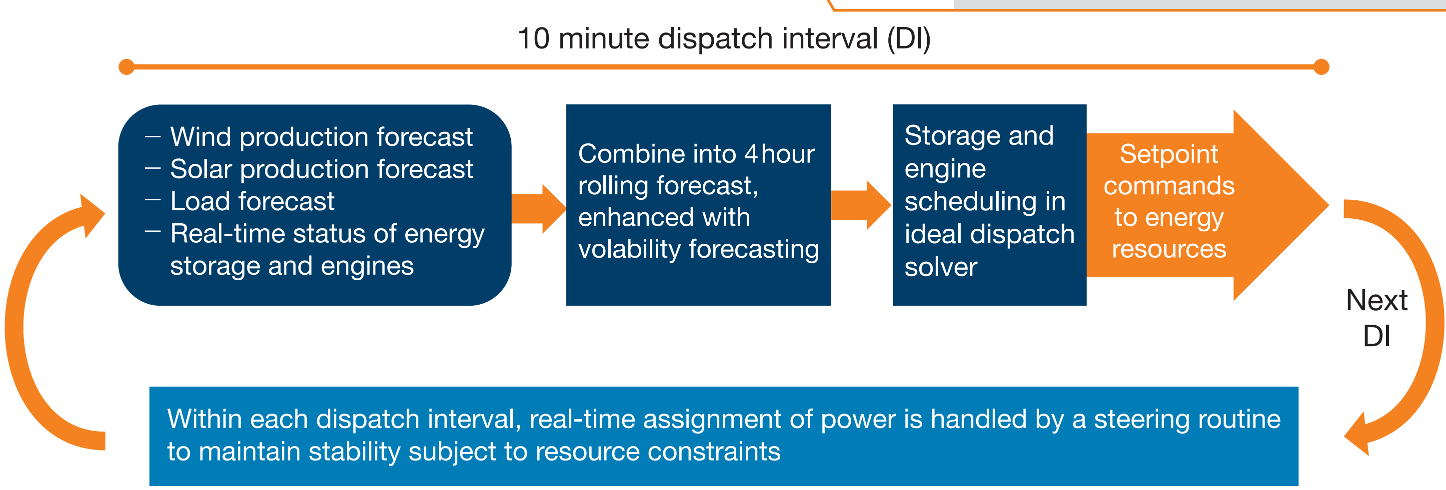


Figure 5 - Example of airfare optimization
Source: ITA Software

Figure 6 - Optimization process for island microgrid



Optimization example: island microgrid

Greensmith is delivering GEMS as a control system to an island microgrid on the island of Graciosa in the Azores. The island has a peak demand of 2.2 MW. The challenge is that the island is a small grid and the renewables output fluctuates quickly, making grid stability a challenge. In this island microgrid, GEMS must accomplish two things simultaneously: 1) maintain grid stability, and 2) integrate as much renewable energy onto the grid as possible by optimizing the usage of renewables, energy storage, and the existing thermal power plant.

The GEMS platform accomplishes these two objectives by operating two concurrent control operations (see Figure 6). Every 10 minutes, GEMS takes in renewables forecasts and energy resource statuses. GEMS then schedules the energy resources for the next 4 hours to minimize diesel fuel usage. This scheduling optimization also manages grid reliability constraints such as reserves in the event a resource fails or the renewable output drops. Both the 10-minute dispatch interval and the 4-hour scheduling horizon are configurable. At the same time, real-time assignment of power to the energy resources is handled by a steering routine with a control loop that occurs in milliseconds. This steering routine operates separately from the scheduler to protect the generation equipment and ensure that the current and future load can be met.

With GEMS, Greensmith can tackle a diverse set of energy resource optimization problems. GEMS is made more powerful by our existing library of smart algorithms, and our modular rules engine. With these tools, we can address the most complex energy resource controls challenges in the industry. Here are some optimization problems run by the GEMS:

- Maximize the energy and ancillary service market revenue of a standalone ESS in a restructured electricity market
- Minimize operating cost of an industrial customer using onsite generation
- Maximize the portfolio net revenue of an integrated energy company with renewable generation and retail loads obligations
- Minimize CapEx of installed renewables and storage to deliver a 100 percent-renewables firm PPA

Prior to the deployment of GEMS, the island was run 100 percent on diesel engines. With GEMS, the island is targeted to run with 65 percent renewable energy from wind and solar.

GEMS is a groundbreaking tool for the optimization of energy resources. In addition to the island microgrid, GEMS is already deployed at one of the most sophisticated microgrids in the United States, a site operated by Oncor in Texas. At the Oncor microgrid, GEMS is the master controller for batteries, solar, controllable load, and several generators. In addition, GEMS optimizes energy generation dispatch in multiple island grids as well as grid-tied systems. GEMS is used for pre-project feasibility as well as for real-time operation of a project. The potential to optimize energy is vast, and we have only begun to apply GEMS to grid challenges.

Energy optimized

Greensmith's mission is to deliver integrated energy solutions that build a resilient, intelligent and flexible energy infrastructure – unlocking the way to an optimized renewable future. We use GEMS to integrate multiple-generation assets (thermal, renewables, and storage) to fully harness renewable energy as reliable baseload, the new everyday energy.

With recent cost declines of renewables and energy storage, the optimal operation of many electricity grids has changed. Without deep understanding of these energy resources, grid operation will be suboptimal and unnecessarily costly to consumers, investors, and the environment. GEMS is best suited to solve these new optimization problems. The pre-project feasibility tools of GEMS allow for the design of the optimized system with the right equipment to address business use cases. Once projects are in operation, GEMS controls energy resources for optimal performance.

There are multiple benefits to the optimization of energy generation via sophisticated software. First, an optimized energy mix reduces cost. Renewables are now the most cost-effective form of electricity in many parts of the world. These inexpensive renewables must then be integrated with the optimal mix of flexible resources, which requires smart controls. Second, software-based controls can operate autonomously and automatically, while allowing for manual intervention if needed. Energy optimization requires decision-making based on complex forecasts and risk analysis, which is beyond the scope of a manual grid operator. Software frees personnel to focus less repetitive tasks, such as contingency planning and longer-run forecasting. Third, sophisticated software improves performance over time. At our deployments, GEMS gathers and analyzes tens of thousands of data points each second in default mode. Some of this data enables improvement over time with machine-learning techniques, such as site-specific forecast values. Other data sets, such as equipment performance, can contribute to a better understanding of equipment tolerances and capabilities to ensure top performance.

Greensmith is continually working to ensure that our energy management system takes full account of the range of use cases desired and grid conditions faced by customers – even as electric grids evolve and are changed by deregulation, distributed energy resources, renewable portfolio standards, smart grid technologies, and more. As an energy systems integrator, Greensmith uses data modeling and analytics tools, as well as machine learning and artificial intelligence to understand the energy generation needs of our customers worldwide. We advise our customers on how to take full advantage of the leading technologies, including flexible generation, renewables, and storage.

GEMS is the future of energy storage as a competitive market resource and the enabler of a high-renewables future.

warstila.com/energy