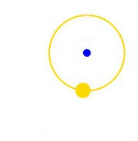
Managing Energy in a Distributed Network of Energy Resources

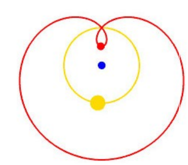
The electrical grid is becoming a network of Distributed Energy Resources (DERs) that harvest energy from wind, water, solar, combined with energy storage. These resources are low-cost, resilient, and deliver power reliably for decades. A new approach is required to operate these resources that maximizes their performance, informs the planning process, and enables dynamic configuration.

The existing grid was designed to efficiently deliver power from centralized generation to electric loads distributed over a large area. In the past decade, as the energy transition is shaping up, the current grid has been able to absorb a limited amount of distributed power generation. The increasing penetration of renewables creates challenges that have become so severe they are limiting further growth.

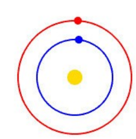
The transition from centralized generation to DERs requires a major change in perspective, much like the transition away from the geocentric model for the solar system. In the geocentric model, the Earth is in the center in blue with the Sun in yellow orbiting around it. This model works for tracking the motion of the Sun, just as the historical grid model works for central generation.



Adding the motion of a planet is complicated because it doesn't fit the model. The geocentric path of Mars, shown in red, requires an extra loop to match the observed position. Each additional planet increases complexity. The central grid model can support DERs today, but each installation is unique. As more renewables are added, the number of DERs goes up rapidly. Planning and operating the system becomes more complicated, and ultimately, impossible.



Switching to a heliocentric model puts the Sun at the center, which simplifies the orbit for Mars and for all the planets. In addition, it clarifies the underlying principles which leads to simple formulas for gravitational fields. For high penetration of renewables, the new energy model needs to enable the simple, effective and dynamic use of DERs. It also needs deliver clear information both at the local level and for larger scale planning and system design.



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By changing perspective, DERs can deliver lower cost, more reliable, and much more resilient energy than the existing grid. A *Grid-of-Grids* model enables:

1. Reliable, resilient local operation and control.
2. Local data collection and modeling to plan operation and to inform upgrades.

The future is not a one-size-fits-all solution, it is a connected network with a data-driven evolution to meet the specific requirements of every location.

What does success look like?

The foundation for this new perspective is realizing that the purpose of the system is to provide energy to everyone when and where it is needed: energy is a means to an end and not an end in itself. The success of this system can be measured by the extent in which it meets the needs of the end user, whether individuals or industry. Is heating and cooling available to keep the temperature within suitable limits? Are appliances functioning to enable storage and preparation of food? Can an industrial concern manufacture goods at a reasonable pace and with acceptable costs? It is essential that these outcomes are measured. Simply tracking the total quantity of energy harvested and consumed isn't adequate.

Like most major transitions, the one in energy is a confluence of multiple developments in different disciplines. Areas that are transformative for creating the new model are: 1) fine grained forecasting of both weather and energy consumption; 2) distributed computing; 3) secure data communication; and 4) the ability to efficiently evaluate complex computer models. Weather is a huge, first-order driver of energy consumption. There are many other predictable events that drive energy consumption that can be incorporated at both the macro level like weather, and at short intervals, such as the timing of soccer fans switching on massive numbers of teakettles. Modern IT technology makes it possible to put local sensors, control, and communication everywhere with low cost and high reliability.

The Sun is at the center of this new model. It provides solar energy directly, and powers the weather that results in wind, and drives the water cycle that fills reservoirs. The dawn each day is the most reliable and predictable source of energy throughout human history. The resulting available energy is predictable. Since the energy available and the demand required varies with the location, the season, and the weather, the new energy system must be responsive to the specifics of each environment. This is why DERs needs a *Grid-of-Grids*. Each local *Base Grid* must bring together all of the local resources to manage the local demand. In addition, this grid is responsible for managing the communication and power exchange with other grids. The collection of all of these *Base Grids* along with their interconnections forms a *Grid-of-Grids.*

Because the entire year has been modeled and planned, the operation can proceed with predicable performance. Visibility is provided on margins and problem areas can been seen in advance. Each grid can independently run alternative scenarios showing the impact of adding generation or storage. The result of improving energy consumption through alternatives such as improving thermal performance can also be modeled. With this data: 1) the user experience is optimized; 2) connected grids have data to manage their planning; and 3) informed improvements to each *Base Grid* can be made to improve performance, lower cost, or improve reliability and resilience.

The future isn't a fixed design implemented everywhere, it's a set of resources that are deployed in different configurations designed and then optimized for specific local requirements..

A *Grid-of-Grids*

The *Grid-of-Grids* as a whole fulfills the energy needs of citizens and companies. Each grid in the *Grid-of-Grids* takes responsibility for operating its *local* resources: generation, storage, and demand management, as well as communicating with directly connected grids. Some of these responsibilities may be delegated to a connected grid. Within each grid, the local demand is supported using both local generation and storage, as well as with transmission from connected resources. Both generation and demand are cyclic in nature, with daily, weekly and seasonal variations. Operating a grid is based on an "*energy model*" with information on the supply and demand, starting with information over the longest cycle, typically a year, and with all resources aggregated. The initial planning step is complemented with more refined steps for the shorter cycles and individual resources. This planning information is then used to: 1) optimize the operation of the local resources; 2) plan enhancements to the set of resources to improve the outcomes; and 3) communicate with interconnected segments to plan and schedule power exchanges.

The existing utility meter is a natural interface point to define the smallest grid. This grid, traditionally referred to as *behind the meter,* services demand and may include generation and storage. This *Base Grid* can operate semi-independently based on its own annual energy model. This energy model with its anticipated in-flowing and out-flowing power exchanges is integrated in the model for the grid(s) to which it connects. Data communication between grids is facilitated through a "smarter" utility meter. This interface communicates the planned operational model for the year with the expected in and out flows. The interface facilitates both realtime communication and power transfer in accordance with the agreed plan.

At the other side of the meter interface is another grid, typically a local power distribution segment. This segment is its own grid with planning and operational control. Its energy planning is based on the aggregated planning for all of the meter connections. The functions of the grid controlling computer are summarized in figure 1.

Model based planning

1. Create an annual load and generation plan from expected and measured performance of the DERs resources in the local grid;
2. Create an operational plan based on the annual plan and the impact on it from short term forecasts of load and generating;
3. Update the model based on actual performance;

Manage local flows of energy

1. Demand management;
2. Generation management;
3. Energy storage management;
4. Flows between energy interfaces.

Data communication:

1. With connected grids to coordinate planning;
2. Weather forecasts & other event data impacting DERs and demand;
3. With connected grids to manage planned exchanges of energy;
4. With local users for status & configuration;
5. Exception handling;

Energy exchange:

1. Agree on the transfer of an amount of energy for a specific period;
2. Allocate capacity to move energy from source to destination;
3. Deliver energy and accept energy.

Capturing data:

1. Measure relevant data
2. Aggregate data from connected grids

Figure 1: Grid controller functions.

Most of the generation and demand is predictable, and specified in the energy model. The grid controller is responsible for changes such the addition or removal of solar panels or replacement of a heat pump by one with a different power rating. After such a change, the local energy model will be updated to incorporate the new resources. The model will then be evaluated for the net effect on the need for energy from outside or the ability to supply excess energy. The result of that evaluation will then be communicated to connected grids in order to update their energy models accordingly.

This *Grid-of-Grids* maximizes the performance of DERs. Because the control is all local, it is resilient and can provide graceful degradation in the event of extreme events. By capturing data locally and constantly comparing it to the plan, the accuracy of the planning will improve over time. Aggregating these local models will provide a much more accurate overall picture of the performance. It also provides essential data to enable planning to reduce cost, improve reliability, and enhance resilience.

Enabling all resources to meet customer needs.

Energy storage, load management, and energy efficiency are important tools in designing and implementing a net-zero system of renewables. The role of local modeling in a *Grid-of-Grids* is to incorporate all resources to meet the local needs. In the model, the impacts of adding generation, increasing efficiency, and lowering demand can all be quantified to inform system upgrades. After each upgrade, the actual system performance can be compared to the plan.

There are many ways to optimize demand, but detailed data is required to compare options. For example, building thermal loads are a significant percentage of total energy consumption. Decarbonization will push most thermal management towards electrification. Since construction varies tremendously by region and type of building, local performance metrics will be very different. Temperatures can be stabilized with more electric generation, or additional insulation. Time shifting can be achieved with electric power storage, increased thermal mass, or phase change thermal storage. Capturing data and providing a feedback loop for improvement that is specific to each installation will enable accurate planning to lower costs and deliver a better customer experience.

The initial deployment of this technology will be a significant improvement over the historic centralized model because it will take into account the specific details of each *Base Grid.* Then, over time, it will become better, as data is recorded showing realworld performance of the actual equipment installed and the specifics of the site.

The Future of Electric Generation

By shifting the model from centralized generation to a collection of grids, a grid controller can be implemented that delivers optimized performance at each location. By modeling on a small scale and then tracking performance against the plan, the results are precise enough to enable real optimization of all resources.

Optimizing these elements is essential to lowering the overall cost of the system. It is also a critical part of increasing the reliability and resiliency of the system. A *Base Grid* with storage and more efficient appliances will perform better in high stress situations, and can manage overall shortages and disconnects while minimizing impact on the customer.

Additional load and DERs can be added to the system at any time and at any location and immediately placed into operation. The grid controllers keep the energy exchanges within the boundaries of the capacity of the local grid and distribution lines to directly connected grids. A complete annual model of optimized DERs based on solar and wind will have periods of generation that exceed the local demand. This model will make visible when and where this power will be available, enabling extremely low cost use of this power for loads that are not time critical and may be seasonal, such as desalinization, water movement, and hydrogen electrolysis.

The result is power that is low-cost, reliable, resilient, and carbon-free.