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WHITE PAPER

Benefits and applications of virtual power plants

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Contents

The rise of virtual power plants

Virtual power plants (VPPs) are gaining in both attention and adoption from utilities and regulators. First described in 1997, VPPs are essentially aggregations of distributed energy resources (DERs) flexibly orchestrated by software to bring desired benefits to the grid.

VPPs are seen as an attractive and cost-effective solution for a number of challenges facing utilities, notably how to meet increasing customer demand for both electricity and decarbonization while reducing expenditures on costly grid infrastructure upgrades. For example, the U.S. Department of Energy (DOE) estimates that deploying 80 to 160 GW of VPP capacity between 2024 and 2030 could save U.S. utilities up to $10 billion in grid expenditures.[1]

At their core, VPPs are aggregations of DERs operated by AI-driven software platforms for the benefit of the grid. VPPs need to handle vast amounts of data on grid conditions and operations as well as customer data. The breadth of data that VPPs must operate on from sources outside of a utility's control opens up a number of cybersecurity risks that need to be addressed.

The attraction of VPPs is the value they bring to utilities and their customers. Payments or credits provided through VPP programs can reduce customers' electrical bills and help subsidize the costs of acquiring DERs. VPPs can also be an attractive revenue stream to help incentivise the roll out of energy projects.

As a flexible resource, VPPs can bring many and varied benefits to the grid. By increasing the utilization of current grid assets, VPPs can reduce the need for capital intensive grid upgrades—and the difficult rate increases that accompany them. VPPs can provide needed resources for grid resiliency, something that is top of mind as climate change exacerbates weather-related threats. VPPs also provide the flexibility needed for the increased penetration of renewables and can act as a tool for arbitrage of wholesale electricity rates.

VPPs can reduce the need for capital intensive grid upgrades—and the difficult rate increases that accompany them

VPPs for a sustainable energy future

In 2024, utilities worldwide face a number of severe and unprecedented challenges. One is an ever increasing demand from customers and regulators to increase the amount of clean energy.

In the U.S., as of June 2024, 13 states have passed laws mandating 100% clean energy production.[2] In the European Union, there is a requirement for 42.5% of electrical generation to come from renewable power.[3]

Moveover, the major sources of renewable energy, wind and solar are by their nature a variable resource. One of the challenges with renewable energy is balancing the amount of energy available on the grid with the demand for that energy. One well-known illustration of this issue is the “duck curve” (Figure 1).

At certain times, there can be more renewable energy available on a grid than demand. To keep the grid balanced, utilities can reduce the amount of power produced by their renewable power sources or sell it to others at negative pricing - essentially paying other companies to take their electricity.

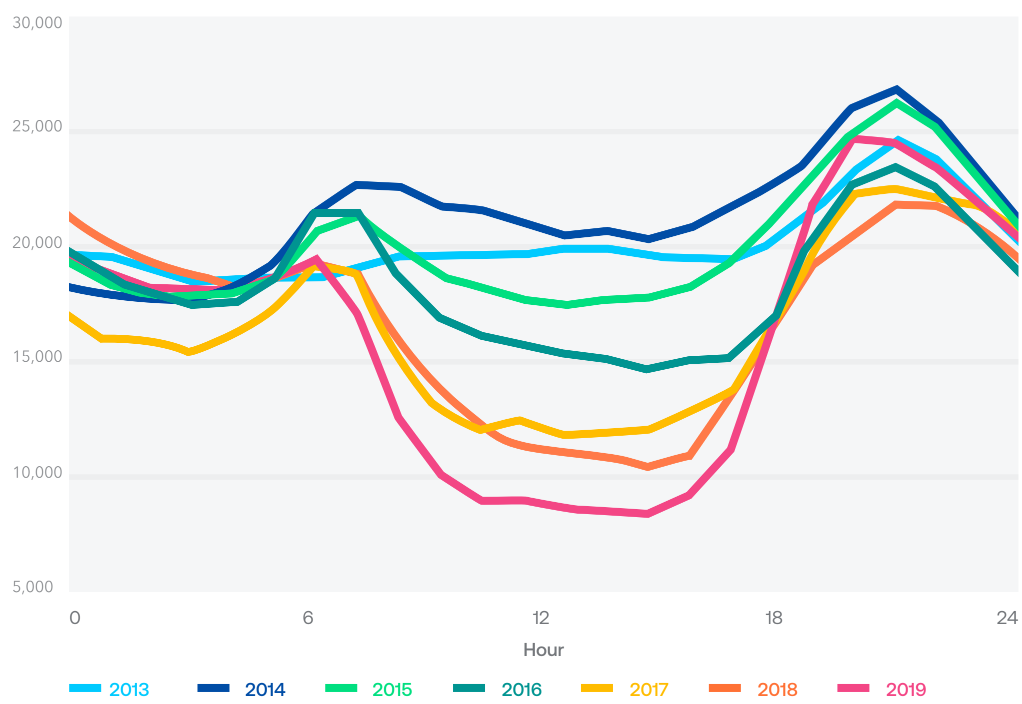


Figure 1:
A duck curve showing available renewable energy and demand in California from 2013 to 2019 over a day. The “belly” of the duck shows how much more renewable energy is available to the grid compared to demand for electricity.
IEA. License: CC BY 4.0

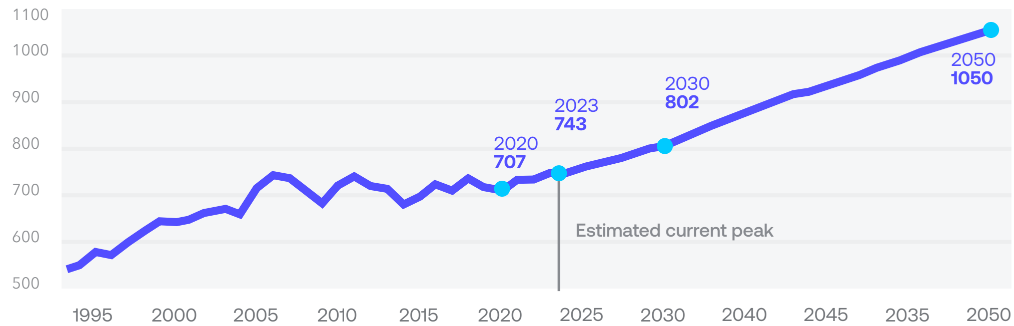


Figure 2:
U.S. peak electricity demand from 1995 to 2050, both historical and forecasted (unit = GW).
Source: U.S. DOE

Another challenge facing utilities is a forecasted increase in electricity demand. Energy demand worldwide is expected to increase by around 4% in 2024 and 2025, the highest growth rate seen since 2007.[4] In the U.S., it's estimated that peak demand will grow to 802 GW in 2030 and 1,050 GW in 2050 (Figure 2).[5] In the European Union, while demand actually decreased between 2021 and 2023 to 2400 TWh, it is forecasted to grow as high as 3128 TWh by 2030 (Figure 3).[6]

Demand growth is coming not only from population and economic growth, but from new demands from the growth of electric vehicles and data centers. For example, in the U.S., in 2023 the energy demand from EVs was estimated to be about 24,000 GWh and grow to 468,000 GWh by 2040.[7]

In 2023, worldwide new renewable energy capacity grew by 50% and solar and onshore wind in the U.S. is forecasted to more than double by 2028.[8] Utilities must grapple with these large increases in renewable energy while many are facing updating grids to handle both the increase of distributed renewable energy and meet the new demands for electricity.

Building new infrastructure is a slow and expensive process. One estimate is that spending on grid upgrades over the next 30 years should reach $14 trillion.[9] VPPs can both increase the utilization of currently deployed infrastructure as well as leverage the capabilities of DERs, often operated by customers, to reduce the need for new infrastructure spending.

As mainly software implementations, VPPs can be up and running relatively quickly and at a much lower cost.

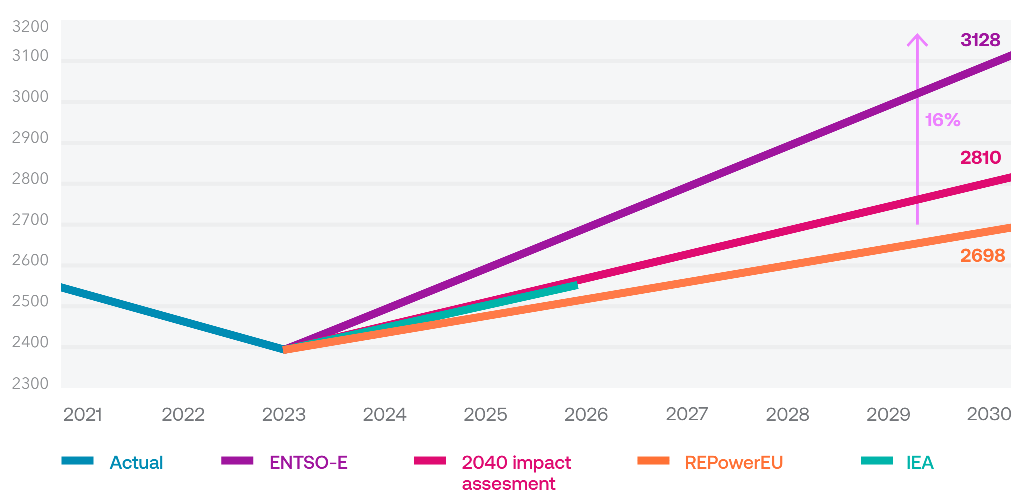


Figure 3:
Actual electricity demand in the European Union as well as three different forecasting scenarios for actual growth (Unit = TWh, REPowerEU = European Commision report, IEA = International Energy Association, ENTSO-E = European Network of Transmission System Operators).
Source: Breugel

Brief history of VPPs

According to the DOE, VPPs are defined as aggregations of DERs.[10] VPPs are run by an AI-driven software platform that connects to and orchestrates the usage of DERs and behavioral modification programs such as demand response (DR) and managed EV charging

The idea for VPPs first surfaced in a 1997 paper when it was called a "virtual utility"[11] with working VPP pilots starting in the 2000s. As the amount of renewable energy increased worldwide, industry interest in and adoption of VPPs has grown due to their potential as a relatively low-cost solution to ameliorate many of the grid issues resulting from the intermittent nature of renewable energy.

Another factor driving interest in VPPs is their ability to increase the amount of battery storage available to the grid. Li-ion battery costs have been dropping precipitously with prices of lithium-iron phosphate batteries dropping from $95 per kWh in 2023 to $53 per kWH in July 2024 according to BloombergNEF, making them more attractive for customers to adopt.[12]

In 2024, the environment for VPPs advanced to the point where Rethink Technology Research proclaimed "Virtual Power Plants (VPPs) will become the core of the future power grid." For example, Rethink estimates that by 2040, 34% of U.S. wind, solar, and battery energy storage capacity will be integrated into VPPs (Figure 4).[13]

VPP integration rate across wind, solar, and stationary batteries

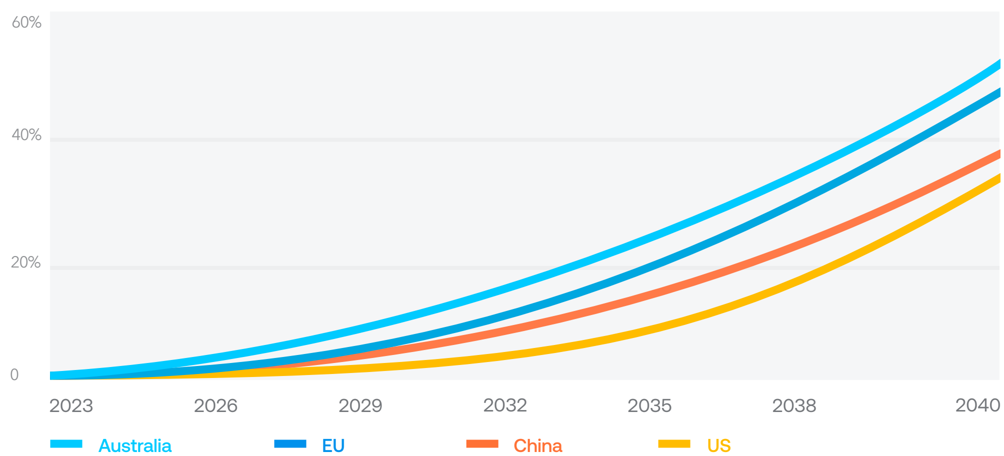


Figure 4:
Source: Rethink Technology Research

During peak demand, SDG&E can tap into distributed resources and avoid using costly peaker plants

VPPs can be roughly divided into two categories, utility-run VPPs and aggregator-run VPPs:

- **Utility-run VPPs**
  As the name suggests, this type of VPP is run by a utility. They will work with disparate types of customer assets to benefit grid operations. One example is San Diego Gas & Electric (SDG&E). Its VPP program integrates residential solar panels, batteries, and smart thermostats across the San Diego service area. During peak demand, SDG&E can tap into these distributed resources, reducing strain on the grid and avoiding the need to activate costly peaker plants.[14]
- **Aggregator-run VPPs**
  Aggregator-run VPPs typically will contract their services to a utility or directly dispatch their assets in wholesale markets. Aggregator-run VPPs may be limited to products from a certain manufacturer or run by a third-party using their own VPP platform. An example of an aggregator-run VPP comes from Tesla. Tesla operates its own VPP platform which connects to its Powerwall battery products. One result of Tesla's VPP operations comes from California where on July 11, 2024, Tesla worked with the Pacific Gas & Electric, Southern California Edison and San Diego Gas and Electric utilities to deliver 100 MW of power to meet peak energy demand.[15]

Anatomy of a virtual power plant

VPPs orchestrate energy resources based on market conditions and the demands on the grid.

Essentially, VPPs work through the adoption and usage of software platforms by utilities to orchestrate a potentially wide variety of flexible assets to benefit the grid (Figure 5),[16] examples of which are shown in Table 1.

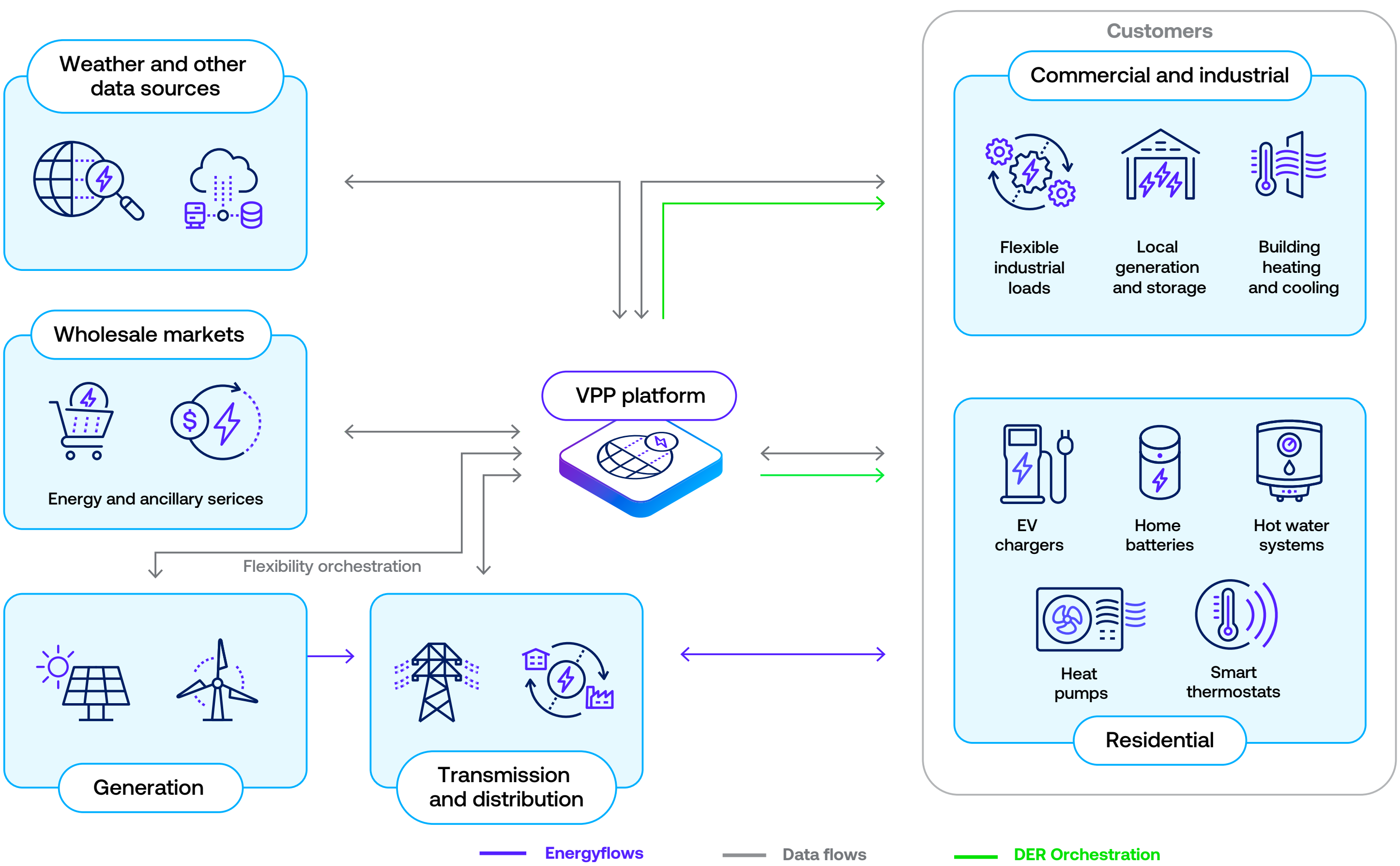


Figure 5:
The VPP platform takes in data from a number of different sources, including energy markets and utility and customer assets. Based on the data analysis, the VPP orchestrates enrolled flexible customer assets to realize desired grid benefits, including flows of energy from customers to the grid if needed.

Asset Type	Description	Notable examples
Stationary batteries	Batteries operated by either customers or utilities for purposes such as backup power.	196 GWh of residential battery capacity is forecasted to be available worldwide in 2030. (BNEF)
EV chargers	Equipment used to charge EV batteries. EV chargers could be controlled by a VPP to manage charging times to benefit a grid. Also, with a bi-directional charger and a properly equipped vehicle, VPPs can manage EV batteries to send energy back to the grid (V2G).	The U.S. will add an estimated 20 GW of EV charger capacity in 2025, rising to 90 GW in 2030. It is also estimated that in 2025, added EV battery capacity will be 305 GWh expanding to 540 GWh in 2030. (U.S. DOE)
Smart solar inverters	Devices that convert the DC output of solar panels to AC. Connected solar inverters can be controlled by VPPs.	In Q2/2024, it was estimated that the total installed residential solar capacity in the U.S. was 37,641 MWdc (mega watts defined conditions - Solar Energy Industries Association/Wood Mackenzie)
Heat pumps	Electric-powered systems that can both cool and heat a building. Heat pumps can be connected to VPPs through either a direct connection to the heat pump or through a smart thermostat.	108 GW of heat pumps were sold worldwide in 2023. (IEA)
Water heaters	Electric water heaters can be connected to a VPP though a direct connection or through a smart controller.	The global electric hot water heater market in 2022 was estimated to be $22.1B and estimated to grow at a CAGR of 4.4% through through 2032. (Global Market Insights)
Smart thermostats	Smart thermostats are connected to the internet and can be controlled by cloud-based systems such as VPPs.	19.6 million smart thermostats were installed in the US at the end of 2021 and are expected to grow to 38.3 million in 2026. (S&P Global Market Intelligence)
Demand response (DR)	DR is a system where consumer or commercial & industrial (C&I) customers are generally compensated to reduce electricity demand and help support the grid when requested.	In the U.S., in 2019 DR participation from C&I customers accounted for 27,000 MW of capacity. (U.S. Environmental Protection Agency (EPA))

Table 1:
Examples of assets that could be connected to VPPs

A VPP platform run by a utility needs to perform a number of functions. VPPs need to gather a wide variety of data inputs such as power loads on the grid, available generation capacity, DER availability and usage patterns, weather data, wholesale electricity pricing and grid congestion status. Based on these and programming inputs from the VPP operator, the VPP identifies when grid conditions require interventions and issues orders to assets to change their behavior as needed.

For example, a VPP AI determines that it will need to secure capacity to meet an expected peak demand and avoid having to run a peaker plant.[17] The AI identifies the capacity it can expect from the assets under its control, such as energy it can send to the grid from batteries and reducing loads. It then sets up schedules to implement these events.

The VPP must connect to the DERs it can orchestrate. This can generally be done in several ways. A VPP platform can directly connect to the DER device or it can communicate with cloud systems run by DER device manufacturers to orchestrate devices. The VPP platform can also communicate with controllers such as smart thermostats that control the DERs.

A VPP won't exist without the enrollment of customer DERs into the VPP. A VPP platform and program should encourage customer enrollment and continued engagement to avoid customers leaving. For example, a VPP platform could offer an app that lets customers monitor their DERs' engagement with the VPP and track the savings accumulated through their participation.

An important aspect of a VPP platform that might be overlooked is the need to protect DER devices and their data from misuse by cybercriminals and comply with applicable data privacy regulations. Cybersecurity in VPPs can be a challenge for utilities since the DERs they work with are often not under their control and could operate in environments riddled with numerous vulnerabilities. VPPs also handle a wide variety of sensitive customer data, the leakage of which could result in regulatory actions with drastic consequences for the utility. For example, the US utility Pacific Gas and Electric was fined $2.7 million when sensitive data was leaked online.[18] For more information on these issues and an approach to solving them, see the brief "Eliminating data hurdles for VPPs."

What value can a VPP provide?

Of course, when implementing a VPP, a utility needs to fully understand the VPP's value propositions. VPPs can provide a number of benefits which can be roughly divided into benefits for an utility's customers and benefits for the utility.

End customer benefits

The most immediate benefit of a VPP for customers is the flow of payments and/or credits that can help subsidize the cost of DERs or reduce their energy bills. One example comes from Origin Energy in Australia. Through their Origin Loop VPP program, consumers can receive $400 Australian ($262 US) when they have a battery installed that will work with the VPP and receive $1 Australian ($0.66 US) for every kWh of energy discharged from their battery.[19]

Another customer benefit from VPP participation is community energy projects. Community energy projects are projects such as solar power and battery installations that share their energy with community members and are an attractive option for people living in multi-tenant buildings and other situations where they may not be able to directly access clean energy solutions. Participating in VPPs can provide a revenue stream that could help subsidize the cost of energy for community energy customers.

Another example of how VPPs can help to finance community power projects is virtual power purchase agreements (VPPAs). These are financial instruments where a finance company invests in renewable power projects, such as a community power project, with payments for grid benefits being one of the expected revenue streams. The investment firm Greenbacker Capital has indicated interest in such VPPA arrangements with a VPP being one of the elements.[20]

Utility use of VPPs can also benefit all customers by helping to reduce pressure to raise rates by avoiding upgrades to utility infrastructure. Many customers also desire an increased supply of clean energy. VPP provided services can help stabilize the grid, allowing it to handle more renewable energy.

Utility benefits

Ranging from reducing demand when the grid is undergoing constraints to orchestrating demand when excess clean energy is available, VPPs can provide a wide variety of value to an utility. Many of these values benefit a utility's grid operations while others benefit an utility's generation and energy trading and retail operations. Note that in many markets, these operations can be the responsibility of separate entities, particularly in deregulated markets.

The benefits of VPPs for utilities can be summarized as follows:

- VPPs can lower the costs of ensuring enough electricity is available to meet peak demands. The cost of purchasing and running VPP platforms plus incentivising markets for them is much less than the cost of building traditional generation facilities.
- VPPs can lower the cost of energy for customers. By manipulating customer assets to consume electricity when abundant renewable energy is available at low or negative costs or when the wholesale prices of electricity are low, VPPs can help deliver energy to customers at lower price points.
- VPPs can help utilities avoid system upgrade costs. As part of a packet of measures making up what is often referred to as "non-wires alternatives," VPPs can aggregate assets in such a way that utilities can avoid some spending on new distribution and other infrastructure.

Grid operator benefits

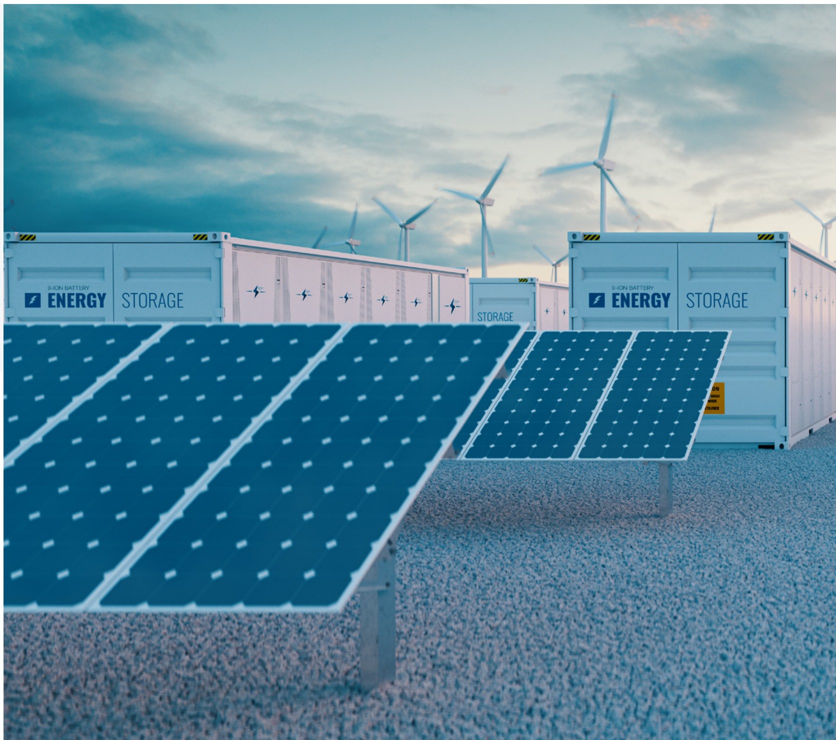
Reliability & resilience

Grids are under historical strains from rapidly increasing demand for electricity, expanding demand for interconnections for renewable energy and new buildings as well as more prevalent and extensive natural disasters. When demand threatens to overtake supply, VPPs can initiate DR programs by orchestrating DERs and other assets to reduce demand on the grid.

One example comes from California. In May 2021, the state launched the Emergency Load Reduction Program (ELRP) followed by the Demand Side Grid Support (DSGS) DR programs. The programs allowed consumer, C&I and third-party aggregator services to provide DR services during periods of grid stress, typically in summer when air conditioning demand peaks. During the summers of 2021 and 2022 the two programs have been called upon a total of 14 times and continued to increase capacity (see Table 2).[21]

Year	Capacity additions
2021	200 MW (ELRP)
2022	DSGS starts, adds 315 MW
2023	Over 790 MW added to the ELRP, 142.5 MW added to the DSGS

Table 2:
Yearly capacity additions for California's DSGS and ELRP DR programs



Grid decarbonization

VPPs can support grid decarbonization in a number of ways. One example is to avoid the use of natural gas-powered peaker plants, which can emit two to three times the carbon of typical gas powered generation plants.[22] VPPs can reduce demand at peak times through DR or by discharging batteries that have been charged at times when carbon-free energy was available either from the grid or local sources such as solar panels. VPPs can also incentivize the installation of distributed clean energy generation paired with local energy storage, such as solar panels and batteries, increasing the availability of clean energy that can be called upon by the grid if needed.

Portland General Electric (PGE) is a utility based in Oregon. Under Oregon state law, PGE must achieve 100% carbon-free electricity by 2040. In preparation, PGE is increasing the use of smart grid technologies including VPPs to enable two-way flows of energy and adopting the use of a number of assets (see Table 4), including DR. One result was during times of peak demand in August 2023, PGE shifted around 2% of its load (over 90 MW) to DR-orchestrated assets (see Table 3).[23]

Reduce transmission and distribution infrastructure expenses

To meet burgeoning customer demand and interconnection requests, utilities are expecting to invest an increasing amount in their transmission and distribution networks with one estimate of $92 billion of spending in the US between 2024 and 2026.[24]

VPPs can help avoid some of this spending. By creating flexible demand and encouraging local generation and consumption of energy, VPPs can greatly reduce the need and costs of upgrades. In California, it is estimated that increasing flexible demand could reduce investments in distribution grids by approximately 70%.[25]

The U.S. utility National Grid has developed a VPP program in several US northeastern states which reached a total capacity of 227 MW in 2023. The company is considering how this VPP can be included in a non-wires alternative solution to avoid grid congestion.[26]

Versatility & flexibility

VPPs can provide flexible demand as well as ancillary services to utilities, both of which are essential to keeping the grid stable.[27] One example is a VPP run by the VPP provider Swell for the Hawaiian Electric Company. Providing both flexibility demand and ancillary services, the VPP is under contract to deliver 80 MW in 2024.[28]

Asset Type
Smart thermostats
Managed EV charging
C&I customer oriented DR program
Multi-tenant building connected hot water heaters
Customer rebates for peak time program participation

Table 3:
Examples of assets being adopted for PGE's VPP program

Energy generation operators benefits

Resource adequacy

Utilities must have the resources available to meet customer demand 24 hours a day 7 days a week 365 days a year. In practice, this means that utilities must meet maximum demand peaks with one method being operating peaker plants. Not only do these plants release high amounts of emissions, they typically only run about 5% of the time, making their electricity very expensive.[29]

By aggregating and orchestrating DERs such as solar panels and batteries, VPPs can not only avoid the use of peaker plants, utilities can use VPPs to avoid having to build peaker plants in the first place. A pilot project run by PG&E and Sunrun, a VPP provider, demonstrated this potential. Between August and October 2023, the project consistently delivered 27 MW for two hours peaking to 32 MW.[30]

Retail operations benefits

Wholesale arbitrage

Depending on market regulations for their service area, utilities may have significant opportunities to engage in wholesale arbitrage of electricity i.e. buying electricity when it is inexpensive, such as at off-peak hours, and selling it when it is expensive, such as at peak hours. Similarly, utilities are at times forced to sell electricity at negative rates on wholesale markets due to an oversupply. This can happen when the amount of renewable energy available on a grid is greater than demand.

Utilities can engage in wholesale arbitrage by storing and selling electricity through the orchestration of batteries enrolled in a VPP. The potential for utilities to profit from wholesale arbitrage can be seen in results for grid scale battery energy storage systems in the Australian and Texas markets, both of which are unregulated (see Table 4).

Market	Period	Revenue	Year to year change
Australian Energy Market Operator (AEMO)	Q2/24	$25.4 M AUS ($16.39 M US)	+97%
Electric Reliability Council of Texas (ERCOT)	May, 2024	Average of $158,000 per MW (annualized)	+295%

Table 4:
Examples of wholesale arbitrage revenues for grid scale battery energy storage systems in two unregulated markets

Conclusion

As aggregations of DERs and other assets orchestrated by AI-driven software platforms, VPPs hold great potential to form the core of future grids, especially those dominated by a renewable energy supply.

The multiple services that VPPs can provide also represent a number of valuable benefits to both utilities and their customers. Since VPPs are primarily software installations, the relatively lower cost and faster timelines make them an attractive option compared to the hardware-based infrastructure solutions typically used by utilities in the past.

Virtual power plants optimize the grid, boost renewables, and reduce costs by coordinating distributed energy resources.

Sources

1 *Pathways to Commercial Liftoff: Virtual Power Plants,* U.S. Department of Energy, September 2023

2 Thirteen states have committed to 100% clean electricity, Environment America, June 20, 2024

3 MEPs back plans to boost use of renewable energy, *News European Parliament,* December 9, 2023

4 Excludes the unusual demand increases seen after the 2009 financial and COVID-19 crises passed. Global electricity demand set to rise strongly this year and next, reflecting its expanding role in energy systems around the world, International Energy Agency, July 19, 2024

5 *Pathways to Commercial Liftoff: Virtual Power Plants,* U.S. Department of Energy, September 2023

6 *The changing dynamics of European electricity markets and the supply-demand mismatch risk*, Breugel, July 5, 2024

7 EV charging growth: How can power and utilities prepare?, PwC, 2023

8 *Executive Summary - Renewables 2023,* International Energy Agency, 2024

9 World needs $14 trillion in grid spending by 2050 to support renewables – report, *S&P Global,* February 23, 2021

10 *Pathways to Commercial Liftoff: Virtual Power Plants,* U.S. Department of Energy, September 2023

11 *The Virtual Utility: Accounting, Technology & Competitive Aspects of the Emerging Industry,* Shimon Awerbuch, Alistair Preston, April 30, 1997

12 $95 per kWh was the global average price in 2023 while $53 per kWh was the price in the Chinese market. From China's Batteries Are Now Cheap Enough to Power Huge Shifts, *Bloomberg*, July 9, 2024

13 *Virtual Power Plant (VPP) Forecast to 2040*, Rethink Technology Research, April 2024

14 SDG&E Launches Virtual Power Plant to Support Grid in Heatwaves, decarbonfuse, August 28, 2023

15 Tesla, Tesla's California virtual power plant delivers 100 MW to help the grid, *Electrek*, July 12, 2024

16 This description of a VPP is for a utility-run VPP

17 A peaker plant is a generation facility that is kept on standby for times when it is needed to provide additional capacity to meet peak demand. Peak demand is when demand for electricity rises to high points during the day.

18 PG&E Fined $2.7M by Feds for Third Party's Data Breach, *Power Engineering*, August 28, 2018

19 Unlock your battery's potential with Origin Loop VPP, Website, July 30, 2024

20 VPPs are an emerging investment asset class, *Solar Builder*, November 30, 2022

21 *Virtual Power Plant Flipbook,* RMI, 2024

22 Peaker Plants—The Dirty Band-Aid Solution to High Energy Demand, *GlacierGrid*, February 26, 2024

23 *Virtual Power Plant Flipbook,* RMI, 2024

24 Actual and Projected Transmission Investment, Edison Electric Institute, January 2024

25 *Virtual Power Plant Flipbook,* RMI, 2024

26 *Virtual Power Plant Flipbook,* RMI, 2024

27 Ancillary services are services that utilities use to keep the grid stable, often by paying third parties for them. One example of an ancillary service are services that help maintain a stable range of electrical frequency on the grid.

28 *Virtual Power Plant Flipbook,* RMI, 2024

29 Peaker Plants—The Dirty Band-Aid Solution to High Energy Demand, *GlacierGrid*, February 26, 2024

30 *Virtual Power Plant Flipbook,* RMI, 2024

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