Sawyer Kennell
ENVM 5007: Energy Systems and Technologies
December 5th, 2025

Virtual Power Plants and Their Role in Energy Infrastructure

Introduction

Virtual Power Plants (VPPs) have seen a peak in public discourse in the past few years. Their inception into energy grids domestically and internationally is creating opportunities for grid flexibility and resilience, public and private partnerships, federal and state level support, and exciting technologies that we can deploy immediately. As the U.S. energy grid changes to compensate for increases in demand and a fluctuating political landscape, it is becoming increasingly important to consider any and all strategies that provide reasonable low-cost solutions to meet changing energy ecosystems.

Background

The energy demand in the U.S. was relatively flat prior to 2022, with two decades of growth of under 1% per year (Wilson, n.d.). Updated forecasts now show a 3% increase per year, which would require six times the planning and construction of new generation and transmission capacity (Wilson, n.d.). With this projected growth, we are seeing a corresponding increase in Distributed Energy Resources (DERs) capacity to as much as ~160 GW in 2028 based on Wood Mackenzie's most recent report (2025). There is, however, a solution that is competing for federal funds and capital investment that seeks to take advantage of these supply and demand metrics: VPPs.

Often referred to as Distributed Energy Resource Managers (DERMs), VPPs are software systems that receive data from a collection of technologies on the grid: solar panels, batteries, smart home devices, EVs, and others that produce, store, or regulate energy, and both monitor and orchestrate those technologies to meet local energy demand. These software solutions are at the forefront of commercialization, with companies like Uplight, Autogrid, Evergreen, Next

NEMOCS, Enode, Siemens, and National Laboratories producing research and products with promising results (U.S. Department of Energy, 2025). In order for these groups to be successful they must integrate with local utilities, power producers, grid managers, and other players to transition from previous grid management systems. Utilities play a variety of roles for VPPs including resource offtaking, program operation, customer enrollment, and customer payment channels, with various configurations based on who the utility is interacting with; wholesale markets, OEM platform partners, third party operators, and so on (RMI, 2024).

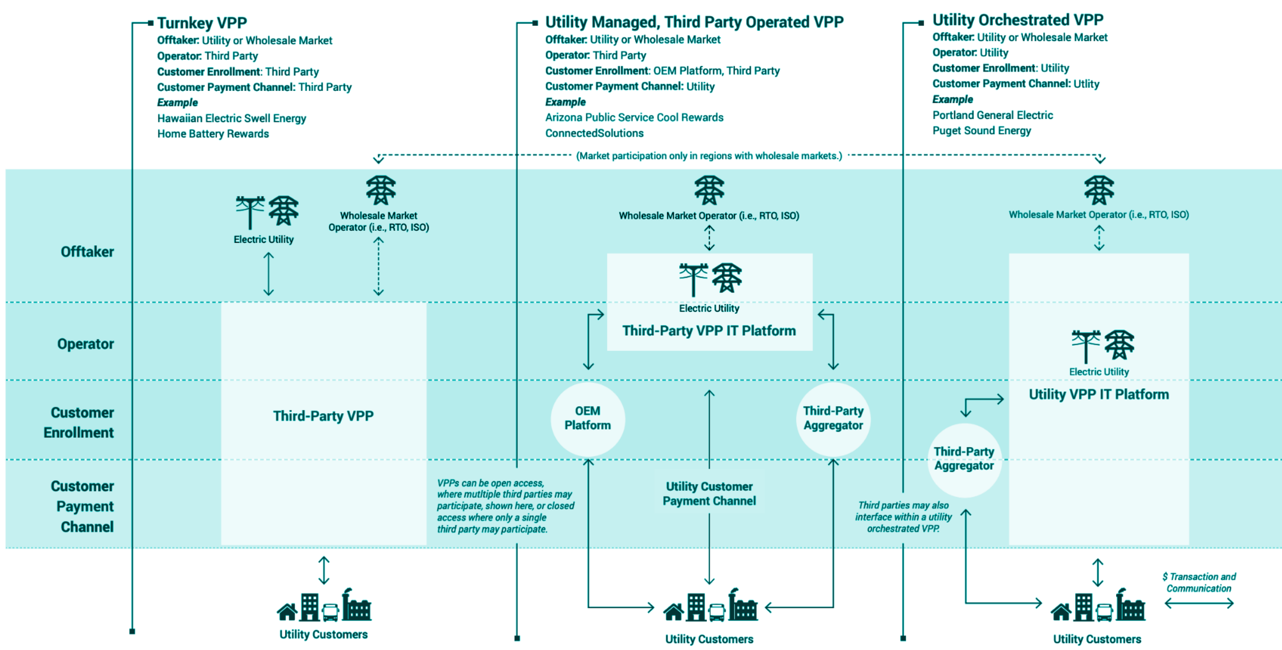

Figure 1: Example VPP utility participation models (RMI, 2023)

In addition to utility structure, there are also engagement models with customers that consider device ownership, incentivization, participation rules, and DER dispatch as core components to ratepayer impact and program success.

Technology

The software for VPPs and DERMs are typically proprietary, having been developed from a third party software company, internally from a utility, or through pilot programs on behalf of national laboratory research. As such, we will explore the system design of an open source software from the Pacific Northwest Laboratory, a tool called GridAPPs-D that is sponsored by the Department of Energy to enable industry to develop and test software applications for distributed system planning (Reiman, n.d.). GridApp is a standardized architecture and implementation approach that coordinates data exchange interfaces between devices so that, when the information flowing between systems is received, it is done so through a common interface. Every technology on the grid has specific communication protocols and conventions unique to it. These special ways of communicating need a well defined data model, logical data abstractions, and exchange mechanisms to ensure the data is effective in its use case.

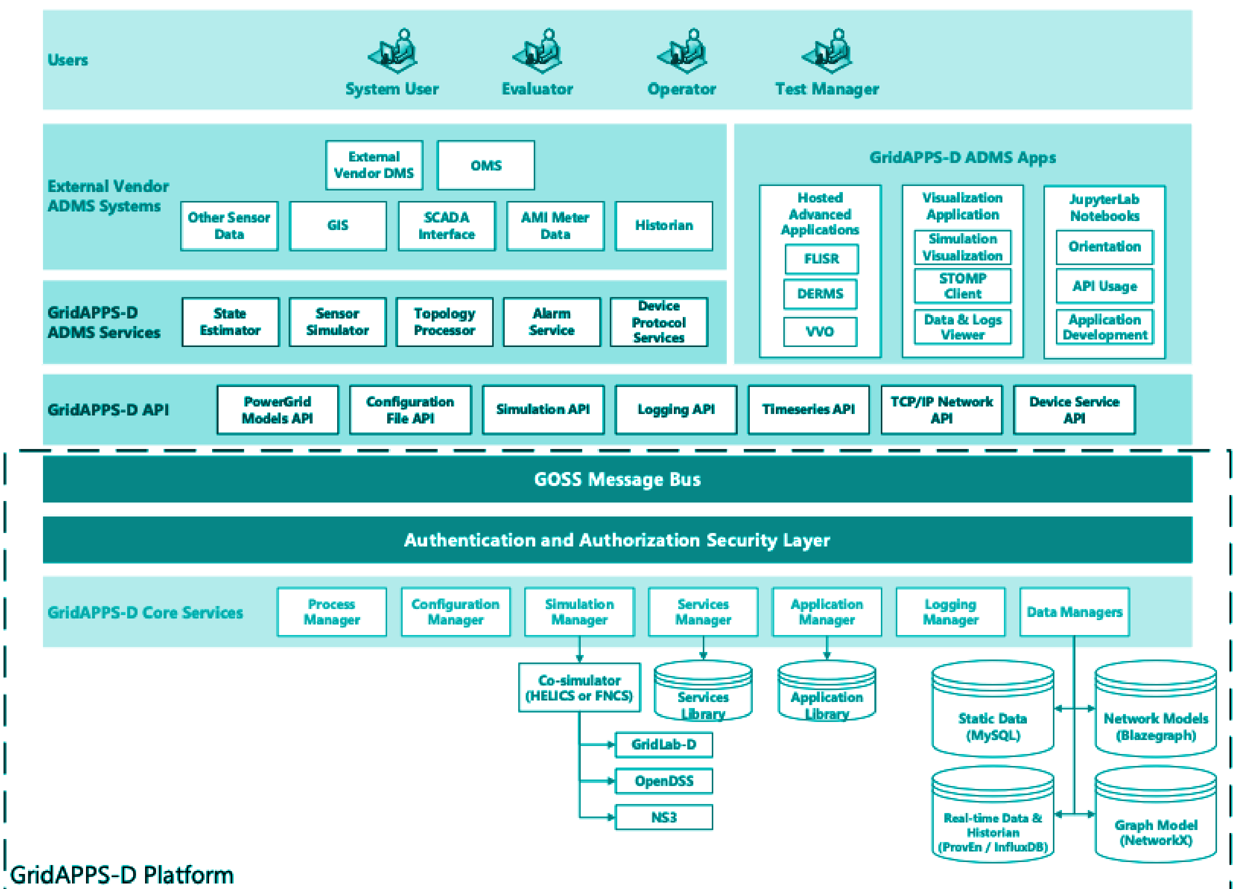

Figure 2. GridAPPS-D Platform Components and Apps System Architecture

For example, in typical distribution systems there are hundreds of different devices, but each has a number of channels (data types and messages) that correspond to those devices: telemetry streams, control commands, simulation outputs, model queries, logging, and app-to-app communication. This is where the Grid Operating System Services (GOSS) message bus comes in, serving as a publish/subscribe message bus for the above channels. GridAPPs then runs the DERMs app (provided in a prototype-like program) against a virtual grid, where a power simulation is provided with voltages, currents, physical states of the grid, and commands that are simulated and stored. The structure of this system design can be abstracted to other DER management software systems, the complexity of which can vary based on the involvement of different players in the market.

Case Studies

The projected growth of VPPs has also ushered in a number of successful and ongoing pilot programs across the nation. Puget Sound Energy partnered with a third party software developer called Uplight that began developing a VPP in 2021 (RMI, 2024). As of April 2024, over 40,000 customers have been enrolled within different inventive and program structures, where 30 MW events can be easily maintained for durations over three hours, assisting with peak demand load and service arbitrage (RMI, 2024). Rocky Mountain Power has created the *WattSmart Battery Program,* where as of 2023 has seen 61 frequency response events lasting five minutes or more were called, and 20 MW of load is available for real time dispatch, with an additional 10 MW of capacity through batteries projected to come online in 2024 (RMI, 2024). Finally, Xcel Energy launched the *Charging Perks* pilot in June 2021 to make it easier for EV customers to charge vehicles at times when renewable energy production is high and customer demand is low (RMI, 2024). In each program, customers were able to see direct reductions in their utility bills and carbon footprints, while utilities and regions benefited from improved resiliency and cost-efficiency.

Future Projections

The pilot programs in different parts of the state are showcasing promising results. These results, however, are not always driving the adoption of systems in need of support. In October of this year, Gavin Newsom vetoed several bills in support of load management and interconnection involving VPPs. Newsom argued that the bills would complicate state regulator's existing efforts to use those technologies to meet clean energy and grid reliability goals. In response, Newsom signed into law several bills to combat cost increases at the state's three major utilities: Pacific Gas & Electric, Southern California Edison, and San Diego Gas & Electric, for California residents. It's unclear why Newsom vetoed the bill, as leaders of local DER and energy affordability groups supported it, with broad legislative support that brought it to his desk. It underlies the ongoing struggle that our system presents, even with broad support for the technology and its goals. Affordability is a key concern amongst interest groups, so citing conflicting narratives around the topic can often destabilize confidence in ongoing support.

We are well past the pilot stage for these technologies. We are also at a point where typical generation technologies like large scale natural gas plants, solar arrays, and wind farms are on a five year acceptance timeline within the interconnection queue (Rand et al., n.d.).

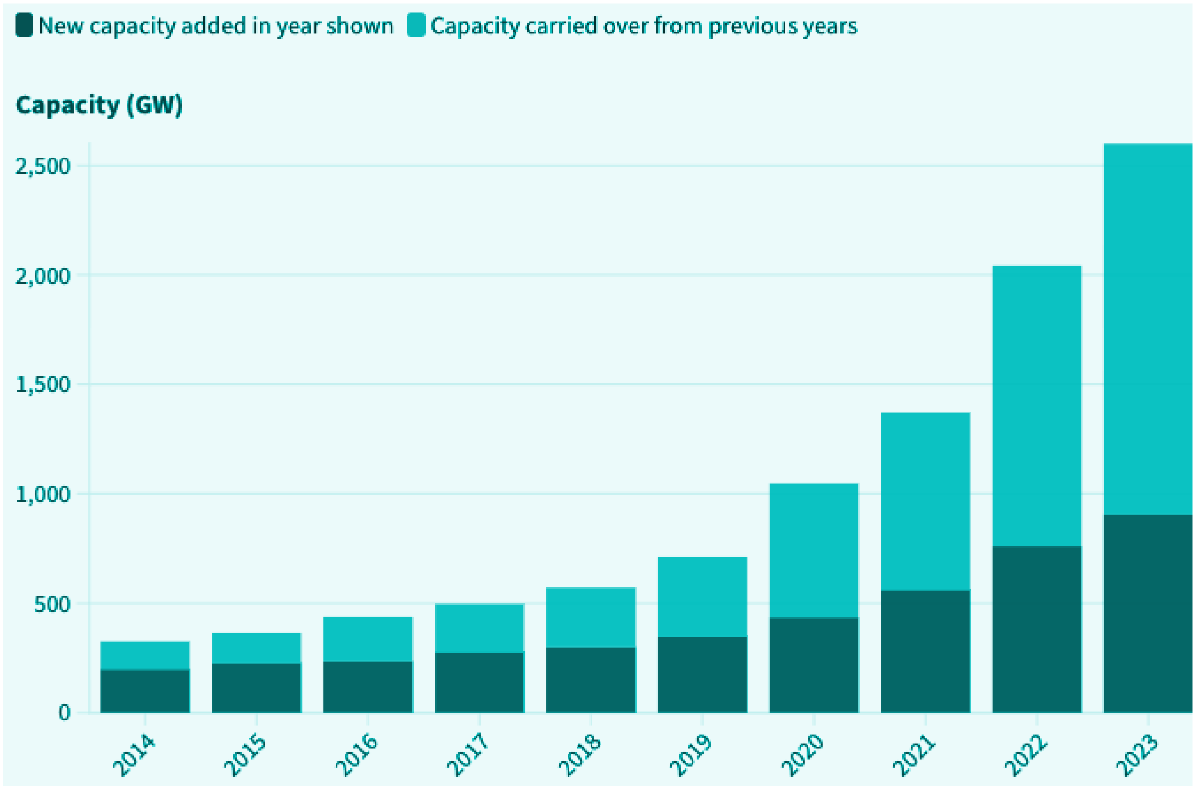

Figure 3. Power plant capacity in the Interconnection Queue from Lawrence Berkley Laboratory

The 2,600 GW of awaiting capacity in Figure 3 is a clear sign that traditional generation has barriers different from those of VPPs. This proves to be a huge entrypoint into the space, with the numbers reflecting this clear opportunity. A modest 13.7% growth of VPP capacity, a 33% increase for VPP deployments from 1,459 to 1,940, monetized programs growing at a similar rate, residential customers increasing representation from 8.8% to 10.2%, and these numbers only containing ~20% of total DER capacity going forward (Wood Mackenzie, 2025). The role for VPPs going forward is clear: they are both necessary and valuable, well above and beyond current projections. Program success, residential support, and increased technologic innovation will culminate to widespread adoption in the next five years. The future for VPPs is not just bright, it has the potential to change our energy infrastructure for years to come.

Bibliography

"100% Clean Electricity by 2035 Study | Energy Systems Analysis | NREL." Accessed December 5, 2025. https://www.nrel.gov/analysis/100-percent-clean-electricity-by-2035-study.

Bernstein, Andrey. *Final Report for ARPA-E NODES "Real-Time Optimization and Control of Next-Generation Distribution Infrastructure" Project*. NREL/TP--5D00-78531, 1762447, MainId:32448. 2021. https://doi.org/10.2172/1762447.

Canary Media. "Chart: The US Clean Energy Backlog Is Getting Bigger and Bigger." April 19, 2024.https://www.canarymedia.com/articles/transmission/chart-the-us-clean-energy-backlog-is-getting-bigger-and-bigger.

Canary Media. "Why Did Newsom Veto California's Virtual-Power-Plant Bills?" October 8, 2025. https://www.canarymedia.com/articles/virtual-power-plants/why-did-newsom-veto-californias-virtual-power-plant-bills.

Energy.Gov. "DOE Releases New Report on Pathways to Commercial Liftoff for Virtual Power Plants." Accessed December 5, 2025. https://www.energy.gov/lpo/articles/doe-releases-new-report-pathways-commercial-liftoff-virtual-power-plants.

Mackenzie, Wood. "Virtual Power Plant Capacity Expands 13.7% Year-over-Year to Reach 37.5 GW, According to Wood Mackenzie." September 17, 2025. https://www.woodmac.com/press-releases/virtual-power-plant-capacity-expands-13.7-year-over-year-to-reach-37.5-gw?utm_source=chatgpt.com.

Melton, Ronald B., Kevin P. Schneider, Eric Lightner, et al. "Leveraging Standards to Create an Open Platform for the Development of Advanced Distribution Applications." *IEEE Access* 6 (2018): 37361–70. https://doi.org/10.1109/ACCESS.2018.2851186.

"NODES | ARPA-E." Accessed December 5, 2025. https://arpa-e.energy.gov/programs-and-initiatives/view-all-programs/nodes.

Rand, Joseph, Nick Manderlink, Will Gorman, et al. *Characteristics of Power Plants Seeking Transmission Interconnection As of the End of 2023*. n.d.

Reiman, Andrew P. *Building GridAPPS-D into a Platform for Advanced Distribution Operations R&D*. n.d.

Rocky Mountain Institute. *Virtual Power Plant Flipbook: How Utilities and Their Customers Are Already Benefiting from VPPs and Insights for Future Implementation.* RMI / VP3, June 2024.

"Small Colorado Utility Sets National Renewable Electricity Example Using NREL Algorithms |

News | NREL." Accessed December 5, 2025. https://www.nrel.gov/news/feature/2019/small-colorado-utility-sets-national-renewable-electricity-example-using-nrel-algorithms.

"US to Add 217 GW of Distributed Energy Resource Capacity through 2028, Wood Mackenzie Projects | Utility Dive." Accessed December 5, 2025. https://www.utilitydive.com/news/wood-mackenzie-sees-217-gw-new-distributed-energy-resources-2028/720581/.

Wilson, John D. *Strategic Industries Surging: Driving US Power Demand*. N.d.

"VPP Deployments Jump 33%, but Capacity Growth More Modest, Wood Mackenzie Says." *Pv Magazine USA*, September 24, 2025. https://pv-magazine-usa.com/2025/09/24/vpp-deployments-jump-33-but-capacity-growth-more-modest-wood-mackenzie-says/.

Yao, Yiyun, Ketian Ye, Junbo Zhao, Fei Ding, and Julieta Giraldez. "DERMS Online: A New Voltage Sensitivity-Enabled Feedback Optimization Framework." *2022 IEEE Power & Energy Society Innovative Smart Grid Technologies Conference (ISGT)*, April 2022, 1–5. https://doi.org/10.1109/ISGT50606.2022.9817506.