Demand Control Technology: The Backbone of Virtual Power Plants

Executive Summary

The emergence of Virtual Power Plants (VPPs) represents a transformative shift in how distributed energy resources (DERs) are aggregated and dispatched to support grid stability, optimize renewable integration, and unlock new revenue streams. At the heart of many high-performing VPP architectures lies demand control technology—mechanisms that enable homes and small businesses to modulate or shift consumption on command. Inergy Systems' Smart Energy Management System (SEMS) and its demand control modules provide a turnkey, end-to-end solution that ties residential loads, such as HVAC systems, water heaters, pool pumps, and electric vehicle (EV) chargers, into a unified VPP framework. This white paper explores the pivotal role that demand control plays in VPPs, how such technology integrates with broader VPP orchestration layers, and why utilities, aggregators, and policymakers should view demand control as a cornerstone of future grid architectures.

---

1. Introduction

In the past decade, the electric grid has evolved from a centralized model—where large power plants feed passive consumers—to a decentralized ecosystem in which millions of small DERs can be orchestrated in real time. By aggregating rooftop solar, behind-the-meter batteries, and controllable loads, Virtual Power Plants aggregate a diverse portfolio of resources into a dispatchable, multi-megawatt asset capable of participating in wholesale energy markets, ancillary service auctions, and local grid reliability programs.

While battery storage and solar inverters receive much of the attention in VPP discussions, the significance of demand control technology is often underappreciated. Demand control—which encompasses direct load control (DLC), automated demand response (AutoDR), and price-responsive load shifting—enables a VPP operator to draw flexibility from the "load side," not solely relying on generation assets. Inergy Systems, recognizing this potential, offers demand control modules that seamlessly integrate with SEMS. Through minute-by-minute metering, machine-learning-driven disaggregation, and secure device-level control, Inergy's technology ensures that residential and small commercial loads become predictable, reliable resources within any VPP architecture.

This white paper details the technical underpinnings and strategic advantages of embedding demand control into VPPs. We begin by defining the VPP concept and summarizing the existing DER landscape. Next, we explore the unique benefits that demand control technology contributes—both in isolation and when combined with generation assets. Subsequent sections describe how Inergy Systems' solutions facilitate rapid deployment, robust performance, and transparent settlement for VPP participants. Finally, we address regulatory considerations, operational best practices, and policy recommendations that will help utilities, aggregators, and regulators harness demand control as a foundational VPP element.

---

2. The Virtual Power Plant Concept

Virtual Power Plants aggregate geographically dispersed DERs—including solar panels, energy storage, electric vehicles, and flexible loads—into a centrally managed portfolio that can be dispatched as if it were a single, conventional power plant. Instead of investing in large centralized generators or costly peaker plants, grid operators and utilities can rely on a VPP by sending dispatch signals to each enrolled resource. These individual resources respond in coordination, collectively delivering megawatt-scale capacity or ancillary services.

Historically, VPPs have focused on generation-centric DERs: rooftop photovoltaic (PV) arrays producing midday surpluses, battery systems charging and discharging based on price signals, or backup generators participating in capacity auctions. However, a growing body of evidence indicates that controllable loads—particularly in the residential sector—offer flexible, near-instantaneous response that is often more economical than deploying batteries or large capacity resources. Loads such as HVAC systems, water heaters, pool pumps, and EV chargers represent substantial power draws whose consumption patterns can be modulated with minimal disruption to occupants. By incorporating demand control into a VPP, an operator gains a reservoir of flexibility on both the supply and demand sides, enhancing reliability, improving ancillary service performance, and optimizing energy markets participation.

---

3. Demand Control Technology Defined

Demand control technology refers to systems and protocols that adjust electrical consumption at the point of end use. In the context of a VPP, demand control modules are typically installed behind the utility meter—either integrated with smart thermostats and connected appliances or implemented via stand-alone in-home controllers. These modules monitor circuit-level consumption in real time, disaggregate usage into distinct load categories, and respond to dispatch commands or price signals by temporarily shifting or curtailing specific end uses.

Direct load control (DLC), one of the earliest forms of demand control, allows a utility or aggregator to remotely switch off or cycle specific devices—particularly large, discretionary loads such as air conditioners or pool pumps—during peak events. Automated demand response (AutoDR) builds on DLC by leveraging cloud-connected thermostats and IoT devices to adjust setpoints or shift operation schedules in a more granular manner. For instance, a qualified smart thermostat in a hot climate can pre-cool a home before a peak window, then raise its setpoint by one to two degrees during the event, reducing HVAC power draw by up to 20 percent without noticeable discomfort. Price-responsive demand programs, which toggle loads based on time-of-use (TOU) or real-time price signals, also fall under the demand control umbrella.

Inergy Systems' demand control suite encompasses these approaches, providing in-home controllers that pair with existing smart thermostats or function as standalone devices, a cloud-based orchestration engine within SEMS that issues dispatch instructions, and secure communications channels that ensure sub-minute response times when required. By embedding machine-learning algorithms that continuously refine baseline forecasts and disaggregation models, Inergy's platform delivers reliable, verifiable load adjustments that can be translated into energy market bids or reliability services.

---

4. Why Demand Control Matters to VPPs

Residential loads represent a disproportionately large fraction of peak electricity demand in many regions. In hot summer climates, for example, capacity constraints on distribution feeders often stem from simultaneous air conditioner cycling across thousands of homes. At the same time, EV charging and induction cooking have introduced new flexible loads that are highly shiftable if properly orchestrated. In contrast to behind-the-meter battery installations—whose costs remain 200 to 300 percent higher on a per-kilowatt-hour basis—demand control technology can deliver rapid flexibility at a fraction of the capital investment.

First, demand control expands the resource pool of a VPP far beyond the limited set of homes with batteries. In a typical suburban service area, fewer than 10 percent of homes may have a residential battery installation, whereas a large majority own an air conditioner, water heater, or EV charger that is amenable to load control. By tapping into those millions of kilowatts of flexible load, a VPP can expand to tens of megawatts of capacity without incurring the seven-figure costs associated with deploying utility-scale batteries.

Second, controllable loads can respond in seconds to grid signals. Many communication protocols—such as OpenADR 2.0 or IEEE 2030.5—facilitate sub-five-second latencies. This rapid response makes demand control viable for ancillary service markets (e.g., frequency regulation), where participants must ramp within 30 seconds. When aggregated, the slight delay in cycling AC compressors or water heaters still falls within market criteria, enabling VPPs to earn higher revenues than would be possible by relying on slower, manually controlled load-shifting approaches.

Third, demand control helps mitigate extreme weather events that can threaten grid reliability. During heat waves or cold snaps, sudden system stress often triggers price spikes in wholesale markets, dragging retail rates upward. By rapidly shedding or shifting end-use loads across thousands of homes, a VPP with robust demand control modules can achieve steep, aggregated load drops—on the order of 10–15 percent of local peak demand—thereby preventing price surges and avoiding emergency rolling blackouts. Inergy Systems' minute-level telemetry and disaggregation capabilities provide grid operators with the visibility and confidence to call upon residential loads precisely when they are needed most.

Fourth, demand control fosters deeper customer engagement. When homeowners see real-time data on how their controlled devices are reducing grid stress and lowering their bills, they become active participants rather than passive recipients. Inergy Systems' customer portal shows not only how much load was curtailed during a given event, but also the associated dollar savings. This transparent feedback loop drives higher enrollment and retention rates, ensuring that the VPP maintains a stable, predictable aggregation of loads.

Finally, coupling demand control with other DERs—such as rooftop solar and residential batteries—creates synergistic benefits. During midday solar peaks, demand control modules can nudge water heaters or pool pumps to soak up excess solar generation, reducing curtailment and increasing renewable utilization. In the late afternoon, when solar production falls and winds rise, controllable loads can be released to provide net-load support. This coordinated choreography, orchestrated by a VPP, maximizes both economic and operational value across the entire portfolio of DERs.

5. Inergy Systems' Demand Control–Enabled VPP Architecture

Inergy Systems has engineered a cohesive VPP architecture that leverages demand control as its linchpin. The solution consists of three interlocking layers: the in-home demand control modules, the cloud-based orchestration platform within SEMS, and the customer/utility interfaces that facilitate enrollment, monitoring, and settlement.

At the home level, Inergy's controllers connect to major load circuits—HVAC, water heater, pool pump, EV charger—through non-intrusive CT sensors or by integrating directly with compatible smart devices. These controllers measure usage at one-minute intervals, capturing the transient load signatures of each end use. Machine-learning algorithms running on the edge or in the cloud disaggregate the total consumption into specific end-use categories, providing both granular visibility and the ability to model each load's response characteristics (for example, how many minutes of compressor off-time will reduce HVAC power draw by 1 kW).

When a utility or market operator issues a demand call—whether for peak shaving, frequency regulation, or market arbitrage—Inergy's SEMS platform receives that signal via secure API or OpenADR message. SEMS then analyzes which homes can respond without impacting occupant comfort, taking into account factors such as current thermostat setpoints, outdoor temperature forecasts, state of charge in home battery systems, and the homeowner's predefined comfort thresholds. The platform dispatches tailored instructions to each home's controller: for instance, 3 kW of HVAC reduction for Home A, a 2 kW postponement of water heating for Home B, and a 5 kW deferral of EV charging for Home C. The controllers execute the instructions within a defined latency window—ranging from sub-five seconds for regulation to five to fifteen minutes for peak-shaving events.

Meanwhile, SEMS aggregates the real-time telemetry—confirmation of actual load reduction, changes in net import/export for homes with solar or batteries—and displays these metrics on a utility or VPP operator dashboard. Historical performance data feeds into baseline recalibration models, ensuring that settlement with market entities or customer bill credits are based on accurate measurements of what loads would have been absent the demand control event. By combining demand control with generation resources, SEMS manages a true hybrid asset: drawing flexibility from loads when needed and injecting stored energy when price signals favor discharge.

Finally, Inergy's customer portal keeps homeowners informed and engaged. Participants receive event notifications—via text message or app—explaining the type of demand event, its expected duration, and the projected bill credits. After each event, the portal highlights exactly how much load was shed or shifted and the corresponding monetary value. Over time, homeowners gain a clear sense of how their willingness to let the controller modulate end uses translates into financial savings and grid reliability benefits. Through this transparent, feedback-driven engagement, Inergy maintains program participation rates above 90 percent even after multiple seasons of demand events.

---

6. Case Studies and Performance Metrics

In the early pilot phase of a Southwest utility's VPP, Inergy Systems' demand control modules were installed in 4,200 homes that already housed compatible smart thermostats. The utility sought to verify that residential loads could participate effectively in both day-ahead capacity markets and real-time ancillary service auctions. Over a three-month summer period, Inergy's system orchestrated 24 peak-shaving events—each lasting two hours during the critical 3 PM to 6 PM window—plus 15 frequency-regulation events, where homes modulated HVAC loads to track 0.1 Hz up and 0.1 Hz down signals from the regional transmission operator.

During peak-shaving events, homes averaged 1.3 kW of load reduction per house, yielding a total of 5.46 MW of peak relief. The utility deferred a planned $2.5 million substation upgrade by two years, realizing $2 million in net present value savings. For frequency regulation, the VPP delivered an aggregated, bidirectional resource of 3 MW with a sub-10-second response time. Regulation revenues averaged $12 per kilowatt-year, contributing $36,000 monthly—enough to cover device lease costs and deliver $75 to $125 in bill credits per household each season.

In a separate case study in a Northeastern service territory, Inergy integrated demand control modules with existing residential battery installations. During winter heating peaks, the VPP coordinated discharge from home batteries while simultaneously dispatching demand control clusters that raised thermostat setpoints by 1 °F and cycled water heaters. This dual-action approach provided 6 MW of load-shifting capacity for three consecutive evening peaks, reducing wholesale procurement costs by $150,000 and improving net conservation voltage reduction performance at the feeder level.

A third demonstration targeted low-income multifamily housing, where units lacked individual smart thermostats. Inergy installed stand-alone demand control modules that managed corridor lighting, electric baseboard heating, and a centralized hot water loop. Despite atypical load profiles—driven by shared corridor lighting schedules and variable occupancy—the SEMS platform's adaptive baseline models accurately predicted each building's expected consumption. Over the pilot year, multifamily demand control delivered 1.2 MW of peak shaving on critical days, earning $85 per kW in capacity payments. The participating nonprofit housing authority reinvested those revenues into LED retrofits and weatherization, creating a virtuous cycle of efficiency and resilience.

---

7. Technical Considerations and Best Practices

A successful demand control–enabled VPP hinges on robust communications, accurate baselining, participant engagement, and adherence to market protocols. Inergy Systems recommends several best practices gained from real-world deployments:

First, unify device protocols wherever possible. Although Inergy's controllers can integrate with a range of smart thermostats and connected appliances via proprietary APIs, encouraging device manufacturers to adopt open standards—such as OpenADR 2.0, IEEE 2030.5, or Green Button Connect My Data—greatly simplifies large-scale integrations. In regions where heterogeneous device types abound, Inergy's platform employs a translation layer that normalizes telemetry and command structures, but the industry's long-term goal should be universal interoperability.

Second, invest in adaptive baseline algorithms. Baseline estimation remains one of demand control's thorniest challenges: accurately predicting what a home would have drawn absent a load control event requires incorporating weather forecasts, historical usage trends, real-time occupancy metadata (when available), and equipment characteristics (such as HVAC SEER ratings). Inergy's machine learning models continuously retrain on fresh data to minimize discrepancies between predicted and actual consumption. Periodic submetering in a subset of pilot homes serves as ground truth to calibrate these algorithms.

Third, design customer communications for transparency and trust. Inergy's portal delivers event notifications well in advance, specifying the type of event (peak shaving, regulation, etc.), expected duration, and minimal impact on comfort. After the event, participants see a clear breakdown: "Your home reduced 1.2 kW during yesterday's 4 PM–5 PM peak-shaving event, earning $3.60 in credits." Maintaining this transparent feedback loop is crucial; when customers understand the direct link between allowing their HVAC to cycle 15 minutes and their $20 bill credit, program retention remains high.

Fourth, ensure security and privacy by design. All communications between SEMS and in-home controllers use TLS 1.2+ encryption, and data at rest in the cloud is secured with AES-256. Role-based access control (RBAC) ensures that no unauthorized entity can issue dispatch commands. Customer consumption data is anonymized before participating in demonstration studies or third-party audits. Strict opt-in agreements delineate what data is shared, how often it is collected, and how it may be used, complying with PII and energy data privacy regulations such as CCPA and GDPR.

Fifth, align program incentives with grid and market value streams. A multifaceted VPP can earn capacity payments in day-ahead auctions, regulation revenues in real-time markets, and energy arbitrage profits. Demand control modules should allow homes to stack multiple value streams. For instance, a home might pre-heat its water heater to absorb midday energy, then modulate HVAC slightly for a frequency regulation event at 3 PM, and finally defer its EV charging until an off-peak window at 10 PM. Inergy's SEMS orchestrates these stacked actions automatically, maximizing total revenue while ensuring occupant comfort.

---

8. Regulatory and Market Considerations

Utilities and aggregators seeking to incorporate demand control into VPPs must navigate a shifting regulatory landscape. In many U.S. regions, independent system operators (ISOs) and regional transmission organizations (RTOs) set minimum bid sizes, telemetry fidelity requirements, and performance obligations that historically favored large-scale generation and battery resources. However, as demand control technologies have demonstrated sub-10-second response times and aggregated quantities reaching into the multiple-megawatt range, several market operators have eased thresholds for participation.

For example, PJM Interconnection has reduced minimum bid-size requirements for regulation from 1 MW to 100 kW for aggregated DER portfolios, allowing a cluster of several hundred homes to participate independently. Similarly, the California Independent System Operator (CAISO) now accepts demand response bids in its wholesale markets via Proxy Demand Resource (PDR) rules, provided participants meet baseline accuracy and telemetry standards—both domains where Inergy's platform excels. Equally important, state public utility commissions have begun to adopt performance-based ratemaking that rewards utilities for achieving quantifiable peak reduction targets rather than simply for selling more kilowatt-hours.

Yet, regulatory pathways differ by jurisdiction. Some states require explicit utility procurement of demand response resources through long-term solicitations, while others allow third-party aggregators to enroll customer loads directly. Navigating these nuances is critical to program viability. Inergy works closely with utilities and policymakers to craft filings that demonstrate demand control's quantifiable benefits—deferred capacity investments, avoided ancillary service costs, and customer bill savings—thereby securing regulatory approval for VPP pilot programs and full-scale deployments.

---

9. Strategic Benefits of Demand Control–Enhanced VPPs

The integration of demand control into VPPs delivers strategic advantages that extend beyond immediate peak-shaving or market participation benefits. First, demand control resources exhibit lower capital expenditure requirements compared to behind-the-meter battery deployments. Even as battery costs continue to decline, they remain three to four times more expensive on a per-kilowatt-hour basis than leveraging a controllable load.

Second, demand control modules can rapidly scale across existing infrastructural footprints. In many utility territories, a large fraction of homes already possess one or more controllable endpoints—smart thermostats, connected water heaters, or smart EV chargers. By deploying software patches or installing small in-home controllers, utilities can unlock latent flexibility without waiting months for new hardware rollouts. This agility was on full display during an unanticipated heat wave in 2024, when Inergy's platform enabled a utility to incorporate 2,500 residences into its VPP within ten days, providing 3 MW of emergent capacity to avert transformer overloads.

Third, demand control bolsters resiliency. During extreme weather events—heat waves, cold snaps, or storm-induced generation shortfalls—VPPs with demand control can rapidly reconfigure. Homes with solar and battery systems can discharge into local feeders, while controllable loads simultaneously reduce net demand. This synergy reduces the likelihood of unplanned outages. In contrast, a VPP composed solely of solar and batteries may find itself challenged when batteries deplete during prolonged weather extremes; the addition of controllable loads provides a critical backup buffer.

Fourth, demand control enhances customer engagement and acceptance of energy programs. When households see that allowing a thermostat shift of one degree on a sweltering summer afternoon results in a $100 bill credit, they feel rewarded rather than inconvenienced. Inergy's ongoing analysis shows that transparent communication of event impacts, combined with a no-penalty opt-out policy, yields retention rates above 90 percent even after two consecutive years of multiple DR events. In turn, high retention preserves the VPP's size and reliability over time, preventing aggregation drop-off that could undermine market bids.

Fifth, integrating demand control into a VPP creates a platform for future services. Once homes are "onboarded" with Inergy's controllers, that same infrastructure can support personalized home-energy insights, smart thermostat scheduling, EV charger custodial management, and even utility-funded weatherization programs. In essence, demand control becomes the "thin layer" that dovetails into a broader home-energy ecosystem—driving long-term customer value, operational efficiency, and preparing the grid for electrification's next wave.

---

10. Challenges and Mitigation Strategies

Despite the compelling benefits, several challenges remain in fully unlocking demand control's VPP potential. A major hurdle is accurate baseline estimation. For market participation and utility settlements, determining what a home would have consumed absent a demand control event is critical. Inergy addresses this by layering machine learning models that factor in weather patterns, historical usage, occupant schedules (when available), and equipment metadata. Periodic ground truthing—submetering a representative subset of participants—ensures continuous model calibration and reinforces confidence among market operators and regulators.

Another challenge lies in the heterogeneity of device ecosystems. Although Inergy's controllers offer integrations with major thermostat brands, legacy thermostats and non-standard appliances may not support open-protocol commands. To mitigate this, Inergy's stand-alone controllers can retrofit directly onto HVAC compressor contactors, water heater elements, or pool pump circuits. While this approach requires minimal installation effort —clamping around existing wiring—the industry's long-term goal should be universal interoperability. Inergy actively collaborates with thermostat manufacturers and standards bodies to accelerate the adoption of OpenADR 2.0 and IEEE 2030.5.

Customer recruitment and retention present another barrier. Some homeowners remain wary of ceding any control over their comfort systems, fearing that the utility might raise thermostat setpoints too aggressively or turn off key appliances. Clear, upfront communication—demonstrating that setpoint adjustments seldom exceed two degrees and that water heater cycles occur only when surplus energy is available—helps assuage concerns. Inergy's opt-out policy allows participants to skip any event, providing an additional safety net. Furthermore, the immediate, transparent display of bill credits in the customer portal reinforces trust and encourages ongoing participation.

Finally, regulatory frameworks vary widely by region. In areas where capacity markets remain inaccessible to aggregated DERs, VPP operators may find it challenging to monetize demand control resources. Inergy mitigates this by exploring alternative value streams—such as distribution system operator (DSO) contracts for local congestion relief, behind-the-meter flexibility products in wholesale markets, and partnerships with retail energy providers for demand response programs. By demonstrating demand control's reliable performance in smaller pilot projects, Inergy helps utilities and regulators build the case for broader DER market reforms.

---

11. Policy Recommendations

To accelerate integration of demand control technology within VPPs, stakeholders should consider the following policy measures. First, regulators should reduce minimum bid-size requirements in wholesale capacity and ancillary service markets for aggregated DER portfolios. By lowering thresholds from 1 MW to 100 kW—or even 50 kW—smaller aggregations of residential loads can participate, expanding competition and diversifying resource types.

Second, state and regional policymakers should incentivize demand control installations through targeted rebates or low-interest financing. By bundling demand control with energy-efficiency programs—such as home weatherization or LED upgrades—low-income and underserved communities can participate at no net cost, broadening equity outcomes while increasing VPP resource pools.

Third, interconnection procedures for behind-the-meter resources should explicitly address demand control assets. When a home installs a "smart D." . . (to enable demand control), the distribution utility needs a clear, expedited path to register that asset as a grid resource. Creating a streamlined "small DER" interconnection track for demand control modules reduces transaction costs and accelerates program rollout.

Fourth, data privacy regulations must strike a balance between protecting personal information and enabling grid benefits. Legislators should clarify that anonymized, aggregated load data—where homes are identified only by randomized IDs and location is aggregated to the ZIP code or census tract level—can be shared with authorized market entities for VPP settlement and grid planning purposes.

Lastly, regulators should promote open communication standards in procurement processes. When utilities seek to procure demand control or VPP services, RFPs should specify adherence to OpenADR, IEEE 2030.5, or Green Button Connect My Data protocols. By mandating open standards, regulators encourage device manufacturers to prioritize interoperability, simplifying future integrations and creating a more level playing field for technology providers.

---

12. Conclusion

As the grid continues its shift toward decentralized, renewable-heavy architectures, Virtual Power Plants will play an increasingly prominent role in ensuring reliability, optimizing market participation, and deferring legacy infrastructure costs. Demand control technology—anchored by precise, minute-level metering and automated load modulation—represents a highly cost-effective, scalable pathway to harnessing the flexibility inherent in millions of homes. Inergy Systems' Smart Energy Management System and its demand control modules exemplify how residential loads can be seamlessly integrated into a VPP framework, delivering megawatts of dispatchable capacity, enabling ancillary service participation, and empowering consumers with transparent bill savings.

By adopting demand control as a core VPP component, utilities and aggregators unlock broader DER portfolios, achieve steeper peak reductions at lower cost, and create more resilient grids in the face of extreme weather and renewable variability. Regulatory reforms—such as reduced bid-size thresholds, targeted incentives for demand control deployment, and streamlined interconnection processes—will further accelerate adoption. When policymakers, utilities, and technology providers collaborate around open standards and transparent customer engagement, demand control-enhanced VPPs will transform how electricity is generated, distributed, and consumed, ushering in a new era of grid flexibility, reliability, and customer empowerment.

Through Inergy Systems' proven technology and unwavering commitment to innovation, that future is within reach today.