GRIDCO SYSTEMS™

INTELLIGENT POWER MANAGEMENT

and the Future of the Distribution Grid

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WHITE PAPER

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EXECUTIVE SUMMARY

Today's utilities are operating in a changing environment that poses a wide variety of challenges, but also opportunities for innovation. Grid infrastructure designed for predictable, unidirectional power flows must now accommodate bi-directional power flows resulting from distributed and variable generation resources. Centralized base-load generation and especially transmission capacity are growing tighter in the midst of political and financial impediments to deployment. Increasing volatility in global weather patterns is placing further pressure on grid reliability, creating the need for more proactive fault management and faster outage recovery. Consumer generation and demand patterns are becoming increasingly unpredictable, requiring more fine-grained monitoring and adaptation of grid assets. Finally, increasing diversification of customer needs is creating stress on regulatory frameworks that have traditionally been oriented towards 'one-service fits all' power delivery. In the face of these challenges, utilities must continue to deliver on their fundamental mission of supplying reliable and affordable electric power, while also introducing system flexibility in order to be adaptive to a more dynamic and diverse demand/supply environment. Emerging at this intersection of requirements is a historic opportunity for regulators, utilities and suppliers to innovate. It is this innovation across traditional boundaries that will be the catalyst for a new utility ecosystem.

IT IS THIS INNOVATION ACROSS TRADITIONAL BOUNDARIES THAT WILL BE THE CATALYST FOR A NEW UTILITY ECOSYSTEM.

Given the current trends in regulatory and legislative policies supporting enhanced system reliability and the adoption of distributed renewable generation sources, now is an opportune time to take a systemic approach to evaluating infrastructure investments that not only cost-effectively address the problems of today, but future-proof the distribution system for tomorrow. Such investments must exhibit quantifiable and subsidy-free benefit-to-cost ratios, render quantifiable system reliability improvements, meet stringent cyber-security requirements, and give rise to a grid that is increasingly **distributed, dynamic, and decoupled** in nature. Fortunately, there is help on the way. The last decade of private-sector investment in grid-oriented IT technologies has given rise to a set of sensing and communications building blocks at the disposal of grid planners. Moreover, a new class of **power regulation infrastructure** is now coming to market that provides the long-awaited missing ingredient of an agile and intelligent grid – the ability to autonomously and rapidly react to changing grid conditions via the distributed and dynamic control of power flow.

A CHANGING GRID LANDSCAPE

In the United States, consumers and businesses have become accustomed to a generally high level of electricity reliability. For this reason, maintaining this level of service, while planning to meet future grid expectations, including accommodating new distributed energy resources (DERs) and other grid trends, is a difficult task. Challenges continue to mount for utilities in key areas that can profoundly impact the growth and success of their business, including reliability, capital cost containment, and operational cost containment.

INCREASING PENETRATION OF DISTRIBUTED ENERGY RESOURCES

As a direct result of the favorable renewable energy policies and incentives, the deployment of low-emission renewable wind and solar generation has proliferated over the past decade and continues to gain momentum, particularly distributed solar photovoltaics, or PV. However, the inherently variable nature of solar resources, in conjunction with their highly distributed deployments, creates power flow characteristics that the grid was not designed to accommodate.

POTENTIAL IMPACTS OF DER INCLUDE:

- Voltage Issues
- Fault Current Issues
- Islanding Issues
- Ground Fault Overvoltage Issues
- Phase-Ground Fault Overvoltages
- Reverse Power Flow
- Power Factor Management
- Load Tap-Changer (LTC) Wear-and-Tear
- Fault Protection Coordination

Today, grid operators limit circuit capacity penetration or relegate the problem to the PV industry through costly and unpredictable system upgrades. It is not uncommon for PV developers to avoid potential system impacts by paying to reconductor lines, upgrade transformers, capacitor banks, reclosers, relays, communications infrastructure and other circuit equipment.

"Smart PV Inverters" For utility-owned PV systems, advanced inverter features are increasingly being offered. However, as a comprehensive approach to managing the distribution grid, neither the technical requirements for controllability of many non-utility assets, nor the economics around grid support functionality are ready for mainstream application. Where we are today is that the utility infrastructure required to control, manage, and operate non-utility assets, such as solar inverters, is not standardized or simply not existent. Power electronics have a role in the future power grid, but a utility-owned, utility-managed approach is required today to achieve high penetrations of renewables in the future. This approach will unlock untapped potential in our energy future, placing the utilities in a leading role as proponents of innovation.

DER Coordination This situation is not specific to PV; all distributed energy resources have distinct performance profiles that are impacting existing load profiles, changing the nature of distribution grid planning. Currently, visibility into issues at the edge of the network is limited, and devices are unable to respond to a range of commands and controls at coordinated response times due to latency and bandwidth constraints. Research is needed that delves into the management and coordination of a variety of distributed energy resources (including PV, demand response, electric vehicles and storage) that leverages existing infrastructure for a variety of applications. For instance, where data exists through advanced metering infrastructure (AMI) deployments, there is an abundance of opportunity to gain knowledge from that data and build upon that the ability to then respond physically to the information in a real-time scenario.

INCREASING CAPACITY CONSTRAINTS

Increasingly utilities are experiencing physical voltage and thermal capacity limitations, political obstacles in permitting transmission upgrades, and capital barriers in financing the deployment of assets with long amortization periods. Grid operators need to consider transmission and distribution grids as one holistic system, with the ability to become increasingly aware of the impact each system has on the other in the context of the availability and changing nature of the generation mix. Utilities are challenged to execute demand response for peak load management when networks are unable to reach distributed resources.

INCREASING GRID RELIABILITY CHALLENGES

Natural Disaster Preparedness and Aging Infrastructure In the wake of climatological superstorms, legislators are calling for a renewed hardening of the grid and reinvestment in our nation's infrastructure to improve grid resiliency, outage management and restoration. Disruptions to the electric grid resulting from severe weather can occur due to faulted (typically downed) transmission and distribution lines, equipment failures due to flooding or overloading, or loss of generation assets, although the latter occurs less frequently. An investment in our nation's generation, transmission, and distribution systems can improve reliability, reduce congestion, and build the foundation for economic growth.

Increasing Threats to Cyber Security Real-time operations in distribution systems will require advanced power control devices and increased monitoring and sensing. However, as additional data points and new distributed technologies enter the system

A BRIEF HISTORY OF THE DESIGN CHALLENGE

The electric grid was designed to deliver power to meet predictable loading patterns in a reliable, cost effective and unidirectional fashion, from a relatively small number of centralized generation sources to a large number of geographically diverse end customers. Reliable operation of the grid is dependent on a continual balance between supply and demand. As such, electric utilities have become experts in predictive load following, short-term actuation of peaking power sources, and the maintenance and operations of a transmission grid dedicated to the efficient and reliable delivery of power to distribution substations.

In this environment, utilities have tended to view generation and transmission assets as the crown jewels of the grid, and indeed in aggregate, expend much capital and operational resources on the management of these assets. The result of this continued investment is a very reliable transmission and generation asset base, albeit one with recently emerging capacity limitations. In contrast, the distribution grid has experienced comparatively little fundamental change over the last century. LTCs, line regulators, capacitor banks and transformers have become more efficient, but the basic technologies and operating principles of a distribution feeder have remained the same. In particular, the fundamental role of a distribution system is to deliver voltage to customers within a predefined industry-standard band.

at a more rapid pace there are more points of vulnerability from cyber-attacks. Many utilities need robust system solutions in the physical layer and in the information layer to support increased situational awareness. These stacks, or service delivery layers, currently lack coordination and are introducing additional vulnerabilities to cyber security threats. Cyber security techniques exist to thwart these threats, but need to be applied to the grid infrastructure in a practical way.

THE FUTURE OF THE DISTRIBUTION GRID

EVOLVING INTO A FLEXIBLE, AGILE AND RESILIENT GRID

In response to the aforementioned challenges, many utilities have recently deployed sensing, communications, and back-office software technologies (e.g. AMI, distribution automation) to improve the operation of their distribution system. While these technologies have generally improved situational awareness and provided limited improvement in grid automation and optimization, the full benefit of these information and communications technologies cannot be realized without new **actuation** technologies.

In order for the current grid to evolve into the agile, flexible and resilient power distribution system needed to accommodate spatially distributed, time-varying and asymmetric load flows, utilities must revisit the fundamental grid design and operational assumptions that have served them so well for the past century – centralized, linear and static. The grid of the future should not depend on point solutions that are designed for one specific application or dependent on customer owned and operated equipment for normal grid operation. The grid of the future must itself become distributed, dynamic and decoupled.

THE NEED FOR CLOSING THE GAP

Based on current investment trends, the national electricity infrastructure gap is estimated to be $107B by 2020, or just over $11B per year. By 2020, shortfalls in grid investments are expected to account for almost 90% of the investment gap with nearly $95B in additional dollars needed to modernize the grid.

Closing the electricity investment gap would lead to fewer brownouts and blackouts and save US businesses $126 billion, prevent the loss of 529,000 jobs and $656 billion in personal income losses for American families.

AMERICAN SOCIETY OF CIVIL ENGINEERS

DISTRIBUTED CONTROL: *FLEXIBILITY TO SOLVE THE OBSERVABILITY & CONTROLLABILITY PROBLEM*

Distribution engineers have historically relied on the primary feeder voltage profile as a proxy for voltage delivered at the point of common coupling. Indeed, when load profiles conform to historical norms, this proves to be a reasonable assumption, and the goal of ensuring customer voltage delivery within the ANSI/IEC and CBEMA limits can generally be achieved by using relatively few MV-oriented devices such as substation LTCs, line regulators and capacitor banks. However, in light of the increasing penetration of DERs and changing loads, this centralized Volt-VAr management approach using bulk compensation devices faces two key limitations: 1) an inability to 'see' the actual voltage being delivered to customers and 2) an inability to react quickly enough to rapid variations in power flow.

With the focus of Volt-VAr control on the primary feeder voltage, utilities have generally not monitored power quality beyond the MV feeder and have therefore not widely deployed sensors at or below the distribution transformer. Furthermore, since power at the medium voltage (MV) level represents the aggregate of multiple low voltage (LV) secondaries, the averaging effect 'dilutes' the observed effects of localized generation and loads on the secondary. As a result, the centralized approach to managing primary feeder voltage does not *observe* or consider local voltage excursions occurring on downstream LV secondaries. Despite the fact that customers experience fluctuations, a lack of dynamic observability renders MV-oriented bulk compensators unaware of problems at the edge of the grid and challenged to address them.

CENTRALIZED VOLT-VAR MANAGEMENT APPROACH USING BULK COMPENSATION DEVICES FACES TWO KEY LIMITATIONS: OBSERVABILITY AND CONTROLLABILITY

Volt-VAr management is traditionally designed to compensate for voltage drop along a feeder in order to ensure that all customers are served with voltage within a standard range. Even without PV, this was already a challenge for centralized bulk compensators, particularly on long feeders with end-of-line customers that were far from the substation, or on feeders where the low voltage limiting points migrated throughout the day. Now, with increased penetrations of PV, the centralized bulk compensators must also compensate for voltage *rise*, constraining the degrees of freedom upon which they can operate. Making matters worse, since PV can be highly distributed along feeders, adjusting a centralized bulk compensator downwards to compensate for high-side voltage excursion may negatively affect a customer that already has low voltage and may not have DG.

Beyond ANSI-compliance, utilities are now also struggling to meet Conservation Voltage Reduction (CVR) requirements. Localized voltage rise is now counter-acting the centralized CVR architecture that utilities have designed using bulk compensators. What was once assumed to be 118 V being delivered to customers is now much higher for those customers who have deployed PV. The neighboring effects of PV are also contributing to decreasing CVR compliance as localized voltage rise affects all secondary customers. Bulk compensators can't address this problem because the voltage rise is local to the LV secondary networks.

Traditional tools used to manage voltage regulation are increasingly stressed in their ability to deliver power within the ANSI-mandated range. The centralized Volt-VAr approach using substation and MV-line devices is growing increasingly ineffective at observing and controlling LV secondary voltage and must be supplemented with a distributed approach that involves deploying control points closer to the LV secondaries that can manage voltage and other power parameters more granularly and autonomously in accordance with the unique needs of local DERs. This approach is already being taken in many parts of Europe and Australia where increasing penetrations of distributed energy resources are impacting LV lines.

DYNAMIC RESPONSE: *ENABLING AN AGILE GRID*

As outlined previously, the distribution grid already contains actuation technologies for Volt-VAr control – substation LTCs, line regulators and capacitor banks. However, all these technologies exhibit relatively slow response times (10-100 cycles) and lifetime limitations resulting from their electro-mechanical nature. Moreover, these devices typically operate in an open-loop manner, and are actuated on a seasonally dependent daily cycle, typically switching only 2-3 times per day.

Many utilities are experiencing over-actuation of line devices resulting in increased wear-and-tear, shortened lifetimes, and unanticipated increases in capital and operation costs. In some cases, utilities have reported device failures in 2-3 years, five times sooner than originally intended. The timescales on which these existing devices operate are insufficient to handle the voltage fluctuations caused by intermittent renewable generation. The impact of variable renewable generation is seen at a variety of timescales, but voltage management, power quality, and systemic efficiency are growing concerns amongst many utilities.

UTILITIES NOW NEED DYNAMIC AND CONTINUOUS POWER ACTUATION TECHNOLOGIES AT THE DISTRIBUTION LEVEL.

Utilities now need dynamic and continuous power actuation technologies at the distribution level, similar to FACTS devices that have been deployed at the transmission level. As more and more renewable generation is connected to MV and LV distribution, the variability of voltage, power quality and load is difficult to manage with existing mechanical devices. Hardware systems that can respond on a sub-cycle basis are required to increase the flexibility and agility of the distribution system.

Dynamic devices can address variability at local levels, and can also address systemic problems, specifically sags and swells that cause nuisance tripping of equipment and system-wide problems such as Fault Induced Delayed Voltage Recovery (FIDVR).

DECOUPLED ARCHITECTURE:
ENABLING A STABLE, SCALABLE AND RESILIENT GRID

The vast majority of today's grid infrastructure consists of devices exhibiting linear input/output characteristics, rendering a highly interconnected, but also highly interdependent system. A power outage in one area can cascade across vast areas of the grid, impacting interconnected loads thousands of miles away. Protection systems have been rapidly developing to inhibit these cascades from occurring. However, when it comes to the interdependence of voltage and frequency regulation, the grid is still highly coupled.

In complex systems, modular design simplifies the engineering problems and lends itself to scalable, fault tolerant architectures. The grid should be increasingly modular. It should evolve its linear nature into one consisting of interconnected 'regulation zones' that function autonomously from one another. This necessitates the introduction of nonlinear power devices whose input-output characteristics are functionally decoupled. Such devices would provide the 'isolation' required so that downstream Volt-VAr control, power quality, power flows, and faults can be managed independently and in coordination from the larger grid.

IN COMPLEX SYSTEMS, MODULAR DESIGN SIMPLIFIES THE ENGINEERING PROBLEMS AND LENDS ITSELF TO SCALABLE, FAULT TOLERANT ARCHITECTURES.

In today's distribution grid architecture, a natural location to introduce decoupling is the distribution transformer that steps down MV to LV and provides service to residential, commercial and industrial customers. This would effectively insulate LV from MV and create regulation zones out of LV secondaries, allowing utilities to manage locally.

A decoupled distribution grid would provide a primary advantage of segmenting a distribution feeder from a Volt-VAr perspective and immediately benefit many of today's distribution applications such as CVR and renewable integration. By decoupling and effectively isolating limiting LV customers from the feeder, utilities can greatly enhance CVR programs (up to twice the savings). Similarly, decoupling renewable generators would greatly reduce interconnection studies, costs, and feeder limits. Decoupling would essentially allow utilities to simultaneously meet ANSI/IEC voltage delivery and CVR targets while simplifying the control and coordination of mechanical MV devices.

Over time, regulation zones can be expanded to include the lateral and even portions of the main MV feeder. One can imagine a similarly flexible, agile and resilient distribution system where power flows can be dynamically rerouted to ensure adjacent zones remain unaffected, and where zones can be administratively taken offline and re-engaged with the grid during scheduled and predicable maintenance windows, greatly improving the stability of the overall grid.

INTELLIGENT POWER MANAGEMENT FOR TOMORROW'S GRID

Modernizing the distribution grid involves more than just replacing old assets with new versions of the same equipment. In order to effectively address current, emerging and future business challenges and regulatory goals, utilities need new tools to transform existing distribution systems into flexible, agile and resilient power delivery platforms that can reliably and efficiently accommodate bidirectional and variable power flow. We propose that a utility-owned, utility-controlled solution, based upon innovations in power electronics and distributed controls, can enable intelligent power management while also addressing utility cost, reliability, efficiency and operational requirements. At Gridco Systems, we are on a mission to develop such solutions.

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