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WHITE PAPER

MANAGEMENT AND CONTROL OF A DISTRIBUTED MICROGRID

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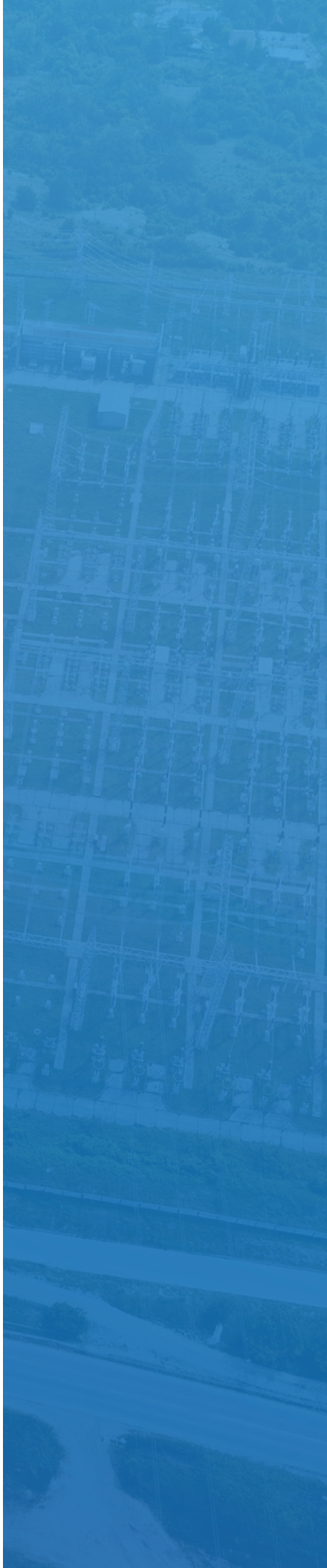


EXECUTIVE SUMMARY

The purpose of this document is to describe a technology developed by Veritone and Microsoft for the implementation of a management and control system for a distributed microgrid. The technology is geared towards the implementation of a distributed renewable micro-grid that includes some intelligent loads and is highly extensible and scalable. This ensures rapid deployment from initial distributed energy resources initiatives to Smart Cities spanning contents. The technology is realized by the integration of two proven component technologies: Microsoft's secure cloud-based architecture implementing economic dispatch and unit commitment using a hierarchical framework; and Veritone's rules-based distributed optimization edge control system.

In general, economic dispatch in a power grid assigns generation power (and energy) to generating units in the grid, and connectivity and other controls to the loads in the grid. Microsoft Azure System generates unit commitment on an hourly basis and economic dispatch energy commands to Veritone's Distributed Edge Controllers every five minutes. The information will include the allocation of generation sources to loads at the sector level, with committed extra reserve capacity, for the next five minute period with maximum and base values. The information will also include the risk associated with the allocation so the system is resilient to the criticality of the components. Microsoft has a centralized program that maximizes satisfaction to determine this allocation.

Veritone will implement the Edge Controllers for those components that are controllable. Each Edge Controller controls the combination of DER generation, smart loads, and conventional power generation for a sector. The Edge Controller generates a plan that satisfies the requirement, performs load synchronization, and controls the micro-grid.

Veritone's system also consists of the Hamiltonian learning module, the tomograph approach, the parameter adaptation engine, and rules. Over time the Edge Controller will be learning the incremental model of the devices, so the dynamics are learned. The network is synchronized over each unit in the sector, so the loads for the sector are satisfied. The mean field approach, is used to achieve this synchronization

Microsoft unit commitment and economic dispatch may also collect SCADA data directly (for example composite substation load for the federal level load balancing. The optimizations are coordinated so that the economic dispatch is fully respected in the Hamiltonian.

Our goal is to use these proven technologies that provide generation/load balance while satisfying the essential requirements to achieve, maintain and recover generation/load synchronization in distributed microgrids and dramatically improve the efficiency of DER/renewables which significantly reduces energy cost and carbon footprint.

OVERVIEW OF DISTRIBUTED CONTROL FOR MICRO-GRIDS

This document describes a technology developed by Veritone and Microsoft for the implementation of a management and control system for a distributed micro-grid. The technology is geared towards the implementation of a distributed renewable micro-grid that includes some intelligent loads. The technology is realized into two components: cloud-based architecture implementing economic dispatch and unit commitment using a hierarchical framework; and a rule-based distributed optimization edge control system. The two fundamental components interact and exchange information in a real-time framework to transfer commitment and dispatch commands to the distributed edge controllers, and to receive from the edge controllers the updated parameters in a specified framework. The edge controller functionality includes the regulation of the state of the controlled elements of the micro-grid (renewable generators and smart loads), tracking the dispatch and commitment commands, learning the parameters of the elements, and synchronizing the elements of the micro-grid (load/generation). The economic dispatch that sets the goal for the energy balancing is then implemented by a combination of direct dispatch from economic dispatch and the distributed edge controllers.

HIERARCHICAL ECONOMIC DISPATCH AND UNIT COMMITMENT

In general, economic dispatch in a power grid assigns generation power (and energy) to generating units in the grid, and connectivity and other controls to the loads in the grid. In our implementation, the unit commitment solves on a 24 hour basis – hourly. This is necessary to ensure storage charging and Demand Response numbers/depth of requests align to best deliver energy during price or load peaks. The economic dispatch runs on a 5 minute basis right now to balance against renewables variabilities. This may need to be faster. This is a tuning between Veritone, and what the Microsoft Service cycle time should be set at. Ideally, we should be running economic dispatch on a 30 second basis. The economic dispatch is achieved over a pre-specified interval (e.g., five minutes), by solving a stochastic hierarchical quasi- linear optimization model. For small networks, each bus in the network is represented in the optimization algorithm directly. For larger networks, of networks with multiple time scales, buses (nodes of the network) are aggregated to form a virtual bus, called a sector, preserving connectivity of the network in the aggregated network with equivalent aggregated generation capacity and aggregated loads. As needed, several layers of aggregation may be added to provide adequate commitment commands in a timely fashion. The aggregated model is a quasi-linear stochastic optimization algorithm in which the criterion optimizes a desired objective, such as, maximize DER utilization in the micro-grid, minimize uncertainty, maximize robustness, minimize average VAR generation, etc. The criterion is subject to a set of constraints that couple generation energy over the planning interval (e.g., five minutes), average power of the elements, or virtual elements. The coefficients of the constraints are given by parameters that come from aggregated sensor readings from the distributed edge controllers. These parameters are updated more frequently than the intervalof economic dispatch (e.g., one minute versus five minutes). The joint approach is

FIGURE 1.
Illustration of a typical microgrid.

a load following synchronization and load generation synchronization at the edge that the economic dispatch commands.

For the purpose of illustration, we show the structure of the economic dispatch optimization model. The generating command for the ith aggregated generator (e.g., DERs), is gi , for i = 1, … , n and the capacity function is $K(g1, \dots, gn)$. The load to be consumed by the smart loads is denoted $l1, \dots, lm$ and the load function is $L(l1, \dots, lm)$. The network connectivity at the aggregated sector level is captured in the a parameters, and the constraint matrix At is generated from the edge controller sensors. A criterion is $C(K, L, a)$ and ω represents the uncertainty. The model is

$$Minimize\ C(K, L, \alpha)$$
$$Subject\ to\ \ [At\ ][K, L]T + \omega \geq\ 0.$$

The parameters in At are generated from the edge controller sensors, and a are the connectivity parameters.

Once the economic dispatch is resolved, requirements for resiliency are activated to solve a binary linear program at the same level of aggregation to determine additional generators that must be committed with zero energy generation.

OPERATIONAL FUNCTIONALITY

TMicrosoft Azure System generates unit commitment on an hourly basis and economic dispatch energy commands to Veritone's Distributed Edge Controllers every five minutes. For some loads that require a large amount of generation capability of fast change in generation, the system can prepare the dispatch for a 3 hour advance interval. The information will include the allocation of generation sources to loads at the sector level, with committed extra reserve capacity, for the next 5 minute period, in kilowatt hours (kWh) with maximum and base values. The information will also include the risk associated with the allocation; the amount of energy that must be supplied so that the system is resilient to the criticality of the components. For example, the information may say that, for the next 5 minute period, Unit 1 will generate 20% of the load in sector 1, Unit 2 will generate 80%, and Unit 3 will be committed to generate an additional 10% if needed. It is possible for a bus in the network to have both a load and a generator. Microsoft has a centralized program that maximizes satisfaction to determine this allocation.

Veritone will implement the Edge Controllers at the edge for those components that are controllable. Each Edge Controller controls the combination of DER generation, smart loads, and conventional power generation that satisfies the 5 minute rate request (by Microsoft) every 2 seconds for the sector. The Edge Controller generates a plan that satisfies the requirement, performs load synchronization, and controls the micro-grid by giving higher priority to geographically close locations. The time horizon for the control system is 5 minutes. The control will be generated every two seconds. Alarms will also be generated every two seconds.

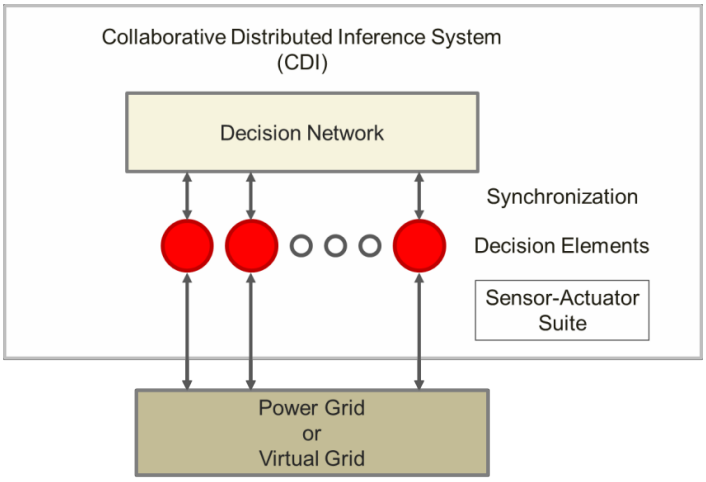
Veritone will send aggregated sensory data and any alarms to Microsoft every minute. The level of aggregation depends on the hierarchy of the economic dispatcher. Veritone will collect sensory data (from SCADA or directly) every second. The sensory data is used in the Edge Controller to update the Hamiltonian. Over time the Edge Controller will be learning the incremental model of the devices, so the dynamics are learned.

The unit commitment and economic dispatch may also collect SCADA data directly (for example composite substation load for the federal level load balancing. The optimizations are coordinated so that the economic dispatch is fully respected in the Hamiltonian.

Veritone's system consists of the Hamiltonian learning module, the tomograph approach, the parameter adaptation engine, and rules. Veritone's tomography algorithm may also generate circuit constraints that are incorporated in the economic dispatch. The rules are converted so that they become part of the Hamiltonian. The network is synchronized over each unit in the sector, so the loads for the sector are satisfied. The mean field approach, discussed below, is used to achieve this synchronization.

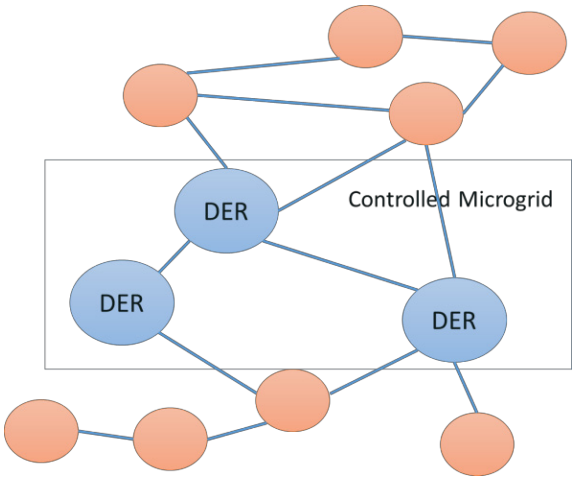
DISTRIBUTED EDGE CONTROL FOR MICRO- GRIDS

Veritone's control and synchronization system allows distributed decision elements at the edge to interact with the rule-based Cooperative Distributed Inference (CDI) synchronization engine. The decision elements and edge controllers also interact with the power grid, or virtual grid, and use real-time sensory information to observe the behavior and minimize the difference between the current state and the desired system performance.



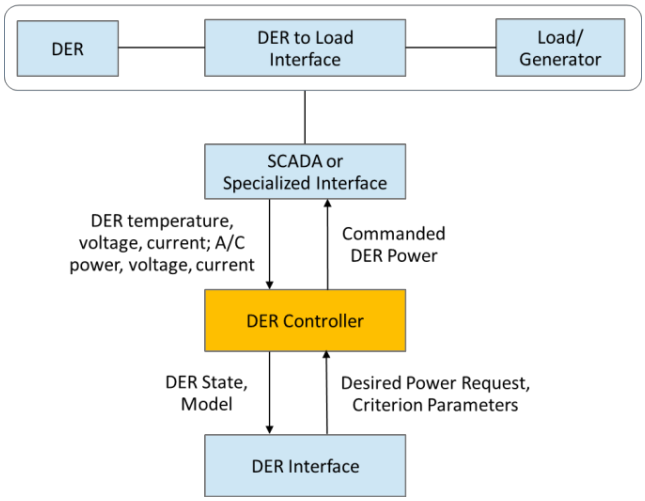
MICROGRID NETWORK WITH DER CONTROLLERS AT THE EDGE

The hybrid control system synchronizes each controlled distributed energy resource (DER) with each other and with the power grid and other uncontrolled devices to achieve performance metrics such as meet local demand, reduce cost, maintain reliability and resiliency, and satisfy environmental issues. The agents in the cloud are designed to scale automatically as DERs are added, and use a mean field for synchronization



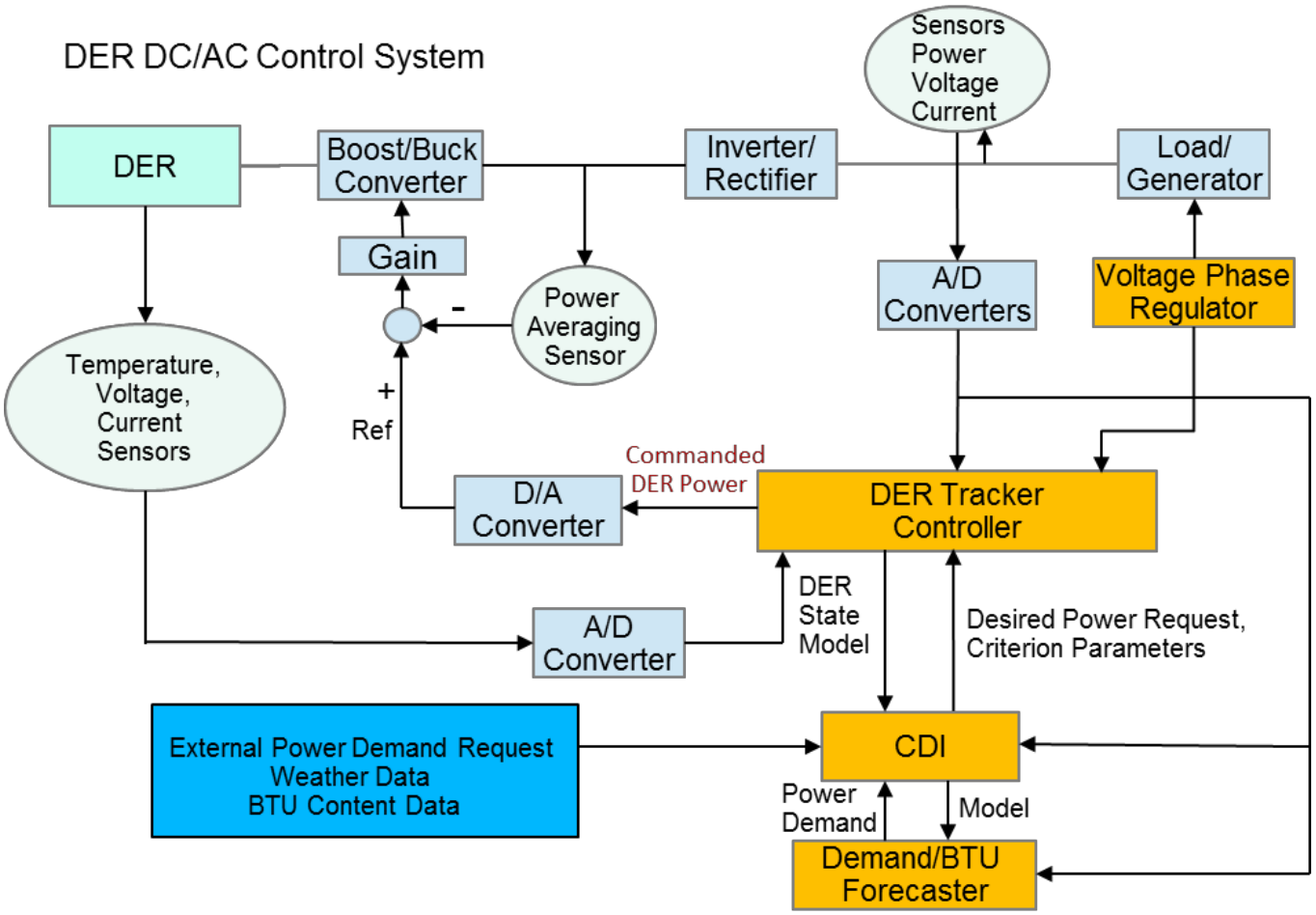
ARCHITECTURE OF MULTIPLE DER CONTROLLERS

The distributed architecture implementation allows synchronization of multiple edge DERs, loads and the power grid. The edge DERs are designed to work even if the internet connection is temporarily lost. The DER controller receives state information such as the DER temperature, voltage, power, and current, and sends a signal with commanded DER power.



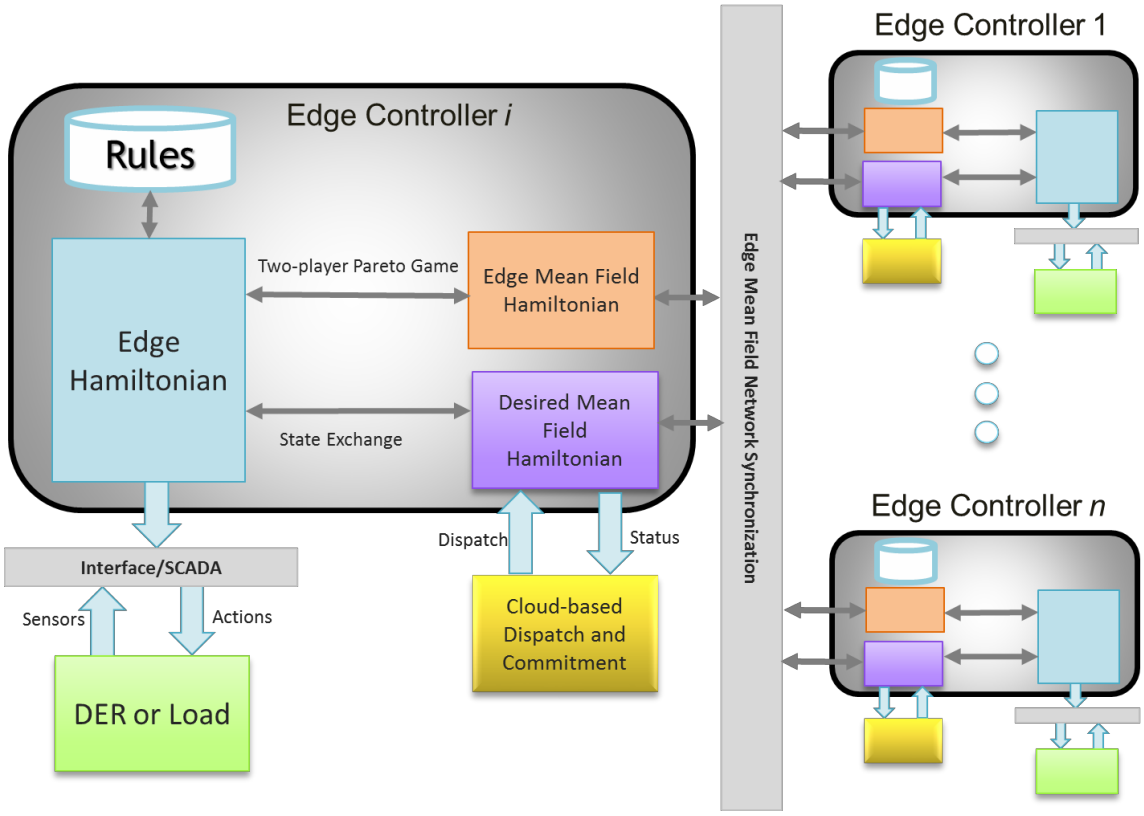
GENERAL DER CONTROL SYSTEM

The edge controller is a feedback system that tracks a desired behavior signal vector generated by rules of performance and safety encoded in the corresponding CDI element. The central mechanism is to convert the rules into Hamiltonians for effecting synchronization, adaptation and anomaly detection.



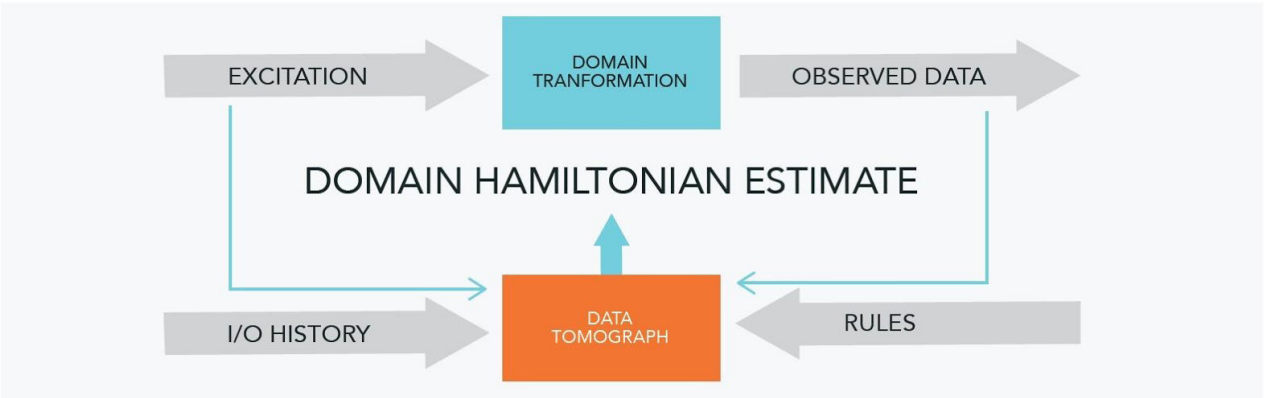
CDI AGENT SYNCHRONIZER AT THE EDGE

The cloud implementation provides resonant synchronization of DERs, loads, and the power grid. The synchronizer constructs and maintains a mean field to facilitate synchronization. The mean field interacts with individual agents, providing distributed and scalable control. The domain of synchronization is given by the state of the micro-grid. The elements of that state are demand, volatility, quality of service (QoS), voltage regulation, VARs, frequency, phase, cost and security.



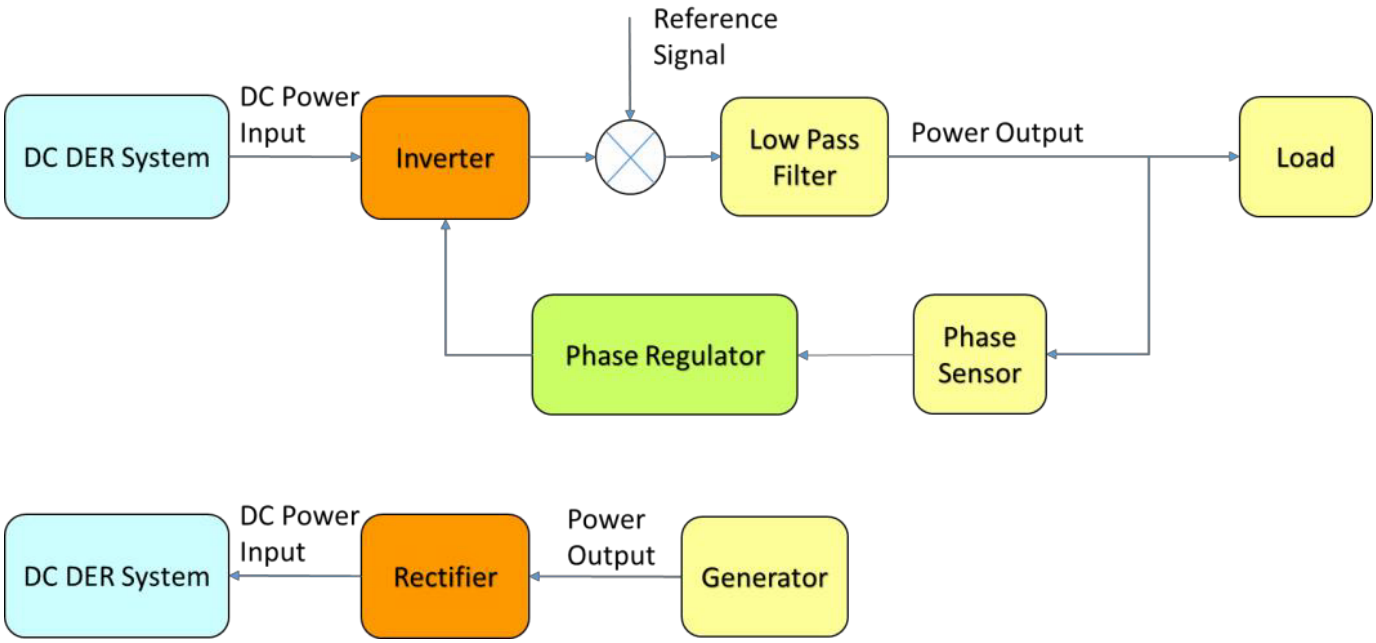
DATA TOMOGRAPH

Veritone's data tomograph is a real-time system for constructing updates to the Hamiltonian of the microgrid model and learns the structure of the system (structural adaptation) by updating the model with observed data combined with historical data and rules.



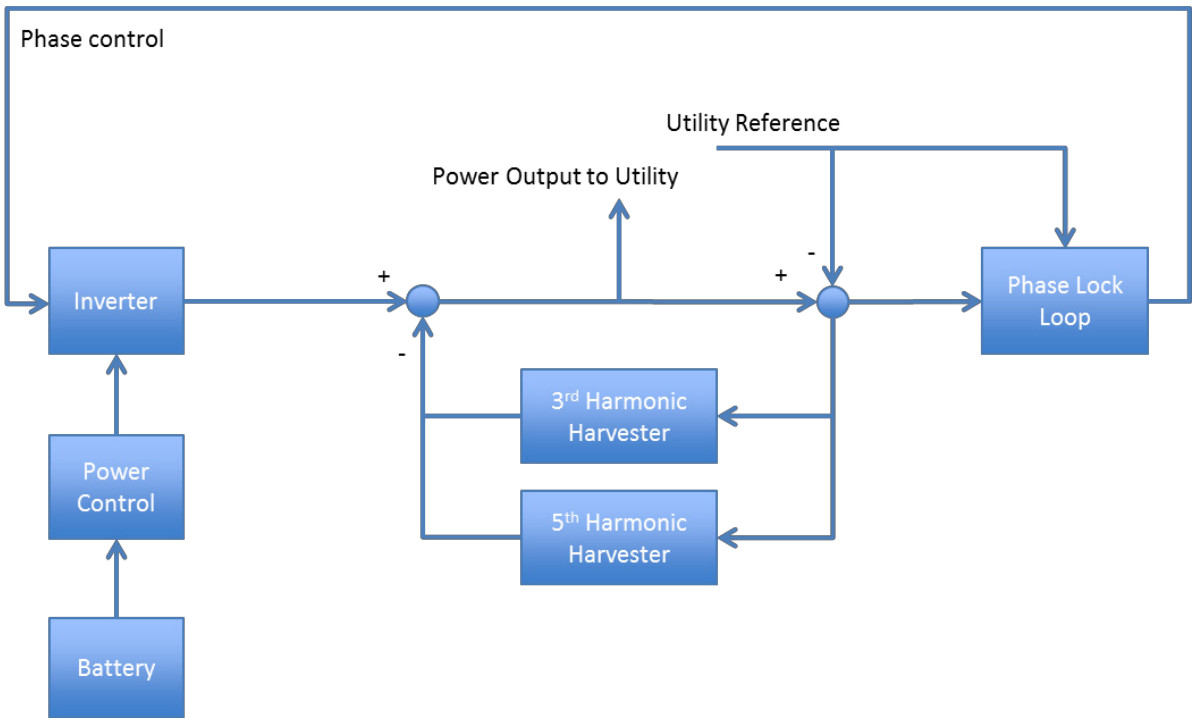
FREQUENCY AND PHASE SYNCHRONIZATION

The frequency synchronization algorithm, which can also be implemented in hardware, maintains required frequency and phase with respect to the target signal of the AC output by maintaining resonance of power on the DC side of the inverter.



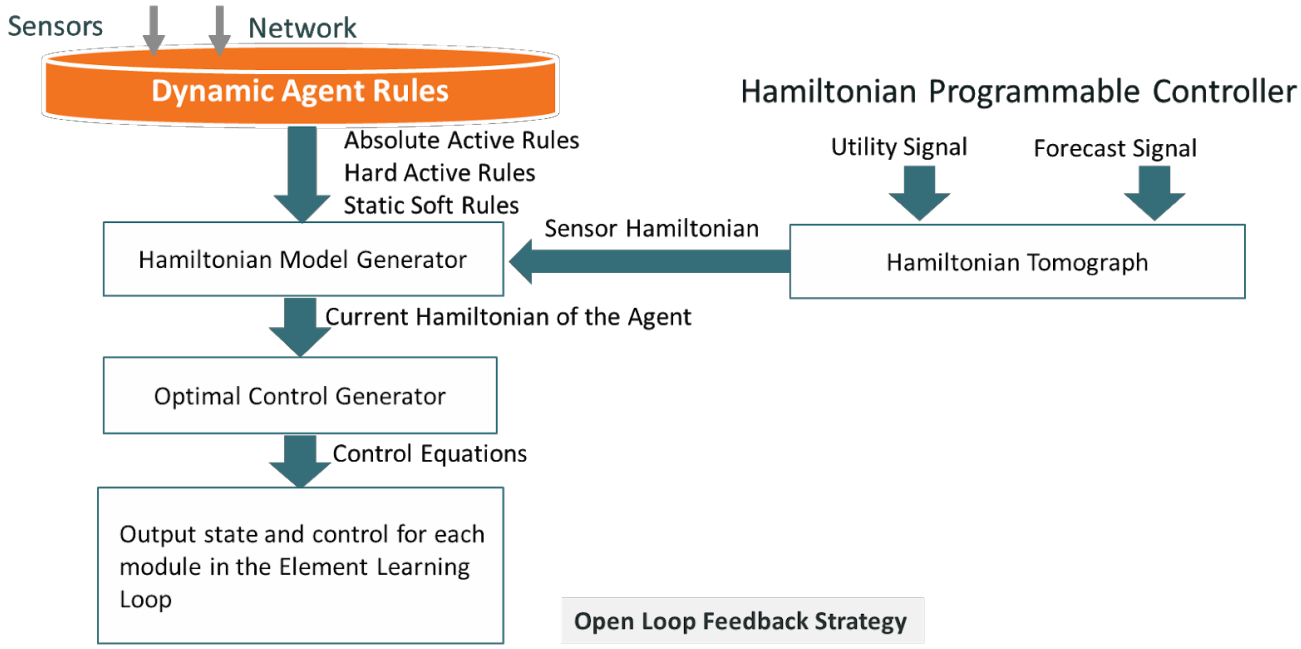
SYSTEM SYNCHRONIZER WITH HARMONIC REDUCTION

Veritone's synchronization system can be implemented in hardware or a hybrid of software and hardware. The system also manages the reduction of the effect of harmonics in the operation of the DER.



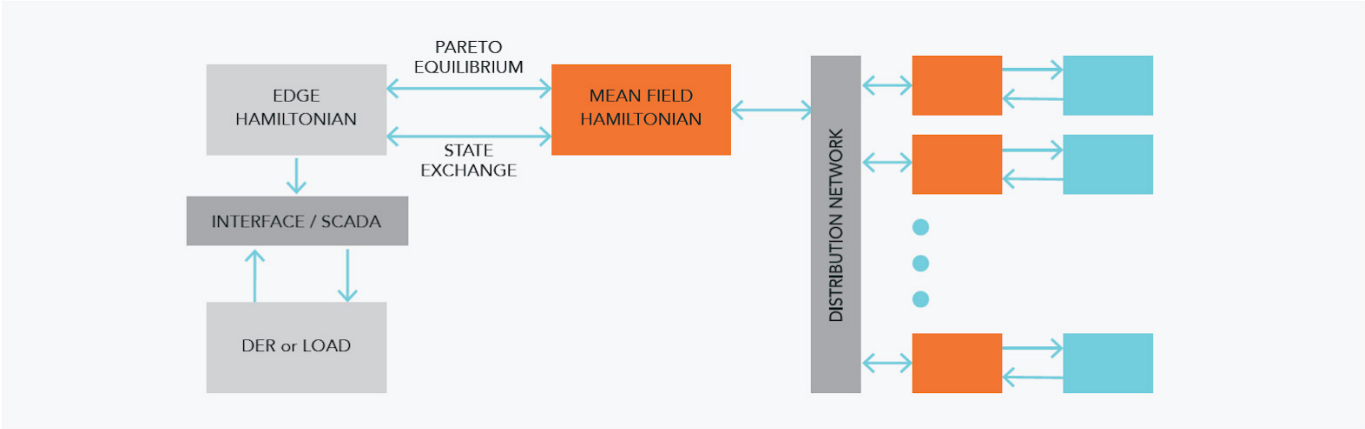
RULE- BASED CONTROL WITH LEARNING

Each DER under control maintains its own rules and interacts with the mean field agent through its Hamiltonian. The Hamiltonian model enables effective local control of the DER or load, and allows for synchronization. The quality of the controller improves over time (increase stability, robustness, etc.) because of the higher fidelity achieved by the learning capability of the data Hamiltonian tomograph.



CDI INFERENCE ELEMENT NETWORK

The CDI Inference element interacts with the distribution network so that the mean field Hamiltonian is updated by the DER or load agent at the edge through the Pareto game, and then is able to control each agent in a distributed schema.



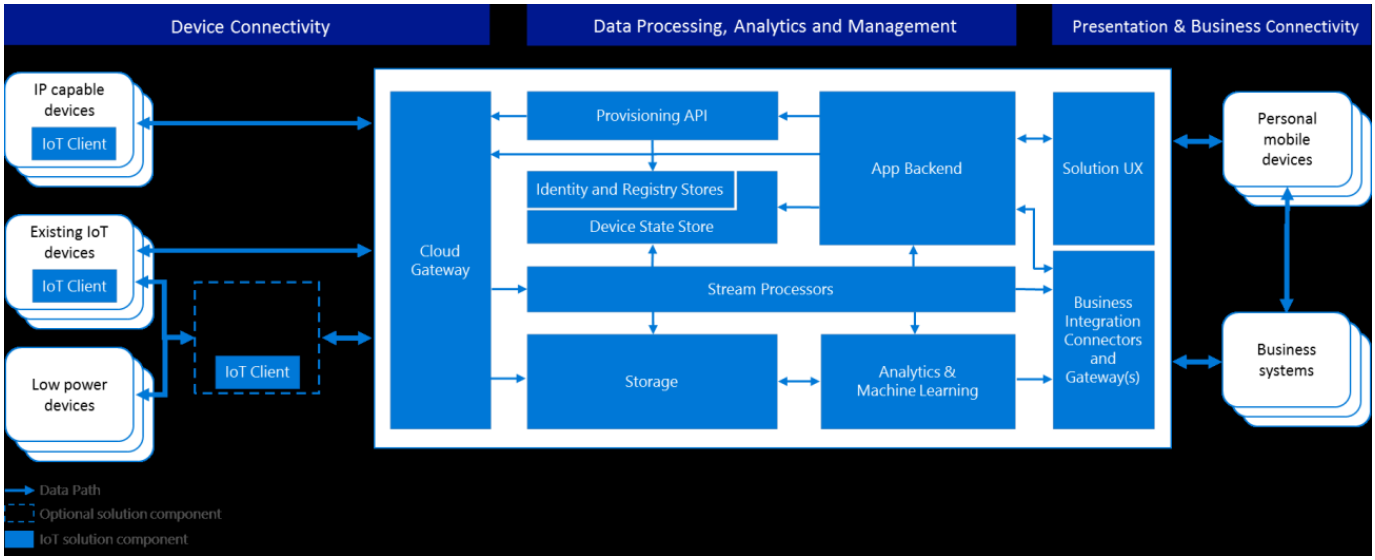
ARCHITECTURE WILL LEVERAGE AZURE INTERNET OF THINGS (IOT)

The DER Controller architecture will leverage Azure Internet of Things (IOT). Azure IoT provides a platform for building secure and scalable, device-centric solutions for connecting devices, conducting analysis, and integrating with back-end systems. This architecture enables the flow of information between intermittent or continuously connected devices and line-of-business assets and cloud-based back-end systems for the purpose of analysis, control, and business process integration.

Figure 1 shows the high-level conceptual architecture. The architecture is composed of core platform services and application-level components to facilitate the processing needs across three major areas of a typical IoT solution:

- Device connectivity
- Data processing, analytics, and management
- Presentation and business connectivity

FIGURE 1.
IoT solution architecture



The proposed architecture can support millions of connected devices. Devices can be connected directly or indirectly via a gateway, and both may implement edge intelligence with different levels of processing capabilities. Device messages are sent in a durable way to accommodate intermittently connected devices. A cloud gateway provides endpoints for device connectivity and facilitates bidirectional communication with the back-end system. The back-end comprises multiple components to provide device registration and discovery, data collection, transformation, and analytics, as well as business logic and visualizations. As datasets are ingressed into Azure, there are various storage options that can be engaged. These options are traditional database technology, table or blob, or even more complex destinations like NoSQL options are possible. As the datasets are processed in Azure, there are a number of capabilities that can be utilized. Examples of these tools are Machine Learning, Hadoop, and Stream Analytics. Stream Analytics can be used to process ingested events in real-time, comparing multiple streams or comparing streams with historical values and models. It detects anomalies, transforms incoming data, triggers an alert when a specific error or condition appears in the stream, and displays this real-time data in the dashboard. The ingested datasets can be also submitted to the Azure Machine Learning models to perform analysis such as predictive maintenance analysis to predict values such as remaining useful life. The results of the Analytics and Machine Learning tools can be presented and visualized to other systems whether they are business systems or personal mobile devices.

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ABOUT VERITONE

Veritone (NASDAQ: VERI) is a leading provider of artificial intelligence (AI) technology and solutions. The company's proprietary operating system, aiWARE™ powers a diverse set of AI applications and intelligent process automation solutions that are transforming both commercial and government organizations. aiWARE orchestrates an expanding ecosystem of machine learning models to transform audio, video, and other data sources into actionable intelligence. The company's AI developer tools enable its customers and partners to easily develop and deploy custom applications that leverage the power of AI to dramatically improve operational efficiency and unlock untapped opportunities. Veritone is headquartered in Costa Mesa, California, and has offices in Denver, London, New York, San Diego, and Seattle.

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