The Smart Grid Node in a Distributed Intelligence Grid Architecture
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SECTION 1: Introduction

Smart grid development and deployment activities are accelerating globally.

- The United Kingdom has announced that all of its gas and electric meters (around 53 million) will be smart meters by 2019.¹
- In the United States, over US $8 billion has been invested (public-private) through the Smart Grid Investment Grant alone.²
- In China, the smart grid market is expected to rise from US$22.3 billion in 2011 to US $61.4 billion by 2015, an annual growth rate of 29.1 percent over five years.³

Early smart grid adopters have identified challenges and gained significant insights into best practices that can benefit those utilities looking to deploy systems today. These insights include:

- Achieving alignment of business, regulatory, and functional requirements, across various departments and operating units, is a major challenge. A broader set of utility personnel should participate in the evaluation process as internal design and operating standards are developed for all new technologies to be installed on the grid. This alignment, however, can create a consensus, that can inform a company-wide roadmap for deployment of common technologies to achieve grid modernization goals.
- In order to fully leverage new investments, a comprehensive and forward-looking technology strategy must be developed prior to embarking on deployment. This will enable the flexibility in existing operating resources to incorporate future applications and end-point types as they emerge.

These insights go against the traditional norm for grid modernization of deploying disparate systems independent of one another and, in most cases, managed independently of one another. The data generated within disparate systems are typically collected, transmitted to, and analyzed at a centralized location using an array of communications technologies, each independent of the next. Learning from best practice suggests a better approach to grid modernization, an approach that emphasizes system-wide common architectures, capable of pushing data collection, analysis, and application out to the edge of the utility network while leveraging multiple communications technologies. This approach can maximize value by:

- Reducing the cost of implementation, communications and operations
- Delivering network visibility and control
- Providing for new applications and technology through a flexible foundation
- Incorporating and extending the value of legacy assets

This white paper explores the value of a smart grid infrastructure based on an architecture that decentralizes and distributes processing power and intelligence throughout the distribution grid, and provides for multiple communication paths to various endpoint devices, creating a truly smart grid. This paper will explore the value of distributed smart grid architecture, the importance of a centralized smart grid device, the Ambient Smart Grid Node® (the Node), as the catalyst for the architecture, and provide examples of applications that will benefit from distributed analytics and processing contained within the Node.

SECTION 2:
Case for a Distributed Architecture

A smart grid can be realized through the addition of monitoring, analysis, control, and communications to the electric distribution system in an effort to optimize its use over a variety of conditions and events. One of the major challenges to such an undertaking is that the resulting intelligent grid may consist of thousands of communicating devices. Enabling numerous new devices also creates an exponential increase in the volume of new data generated from those devices. These data will help a utility to understand its distribution grid operations at a granular level, which will enable more targeted operational decisions and ultimately more efficient operation of the distribution grid. The process of managing this data flow, and analysis will be integral to how grid modernization benefits are realized.

Thus far, the method of analysis of these data has involved bringing data from separate, isolated systems back to a central location for processing and evaluation. Practical obstacles of bandwidth limitations and cost have constrained the types and volume of data returned, inhibiting the granular understanding of distribution operations. Additionally, the isolated device implementation and operation being handled singularly, and not in the context of other device operations, has further restricted the overall value of any data returned from any one device. More efficient use of each device, and developing a deeper understanding of the data available, requires a method for not only overcoming the bandwidth cost challenge but also leveraging the data from disparate end points collectively. A method for gathering, aggregating, and analyzing data from these different end points at the edges of the network can meet these needs. For the purposes of this paper, this collection and processing of information at the edge of a distribution network, rather than at the utility’s central network operations center (NOC) is what we consider distributed intelligence, and a distributed architecture.

When developing and designing a smart grid architecture, a holistic utility-wide plan that accounts for all potential smart grid applications is extremely important. The underlying architecture must allow for modular, scalable, and upgradeable technologies, which is enabled through a distributed architecture. A distributed architecture can quickly and easily adapt to changing business and technology requirements while capitalizing on ever-decreasing communication costs. Furthermore, distributed architecture allows deployment of individual technologies today and upgrade of those technologies as they evolve tomorrow.

A distributed architecture requires the ability to: (1) communicate with smart devices, (2) extract data, (3) analyze those data, and (4) elicit action based on that data analysis, at the edges of the grid. Communications to and from end point devices may need to come in various types to operationally and economically connect every device. Leveraging multiple communications options in parallel, and managing these communication options within a single point like the Node, can enable all grid device data to be collected and provide the depth of analysis required to achieve the next level of smart grid value. For the Node, having local access to the many streams of available data is crucial to meeting the full potential of analyzing the data gathered at that distributed level.
Local Data Access

By definition, Local Data Access is the ability to extract data from one or more smart grid applications at a distributed aggregation point (the Node) for remote analysis, monitoring, or control. Local Data Access to information being collected from end points by various applications is a key requirement of the distributed smart grid architecture.

The architecture of most utility grid automation applications today focuses on collection and transportation of data from field devices back to a central data warehouse, where analysis may be performed by the application’s head-end management system. Recent industry discussions of analytics focus primarily on extracting data from the data warehouse for incremental analysis beyond what each individual application may be capable of. There is value in centralizing data storage and analytics. There is also value in performing analysis of data at the edge, where the data originates. Examples of this value that merit further investigation include the ability to:

- Perform real-time monitoring and analysis on data collected by a Node
- Reduce large volumes of raw data to smaller amounts of manageable and usable data
- Select specific types or subsets of data to be backhauled to central systems
- Collect data only on exceptions determined by utility-configured thresholds
- Reduce communication costs associated with transporting data back to a central data warehouse
- Optimize data warehouse storage costs

In summary, a distributed architecture with local data access affords enough flexibility for the utility to monitor and analyze data locally or centrally. Section 3 will highlight how operating value is realized by distributed intelligence with Local Data Access.
To realize the benefit of a distributed architecture, devices are required that are capable of collecting, aggregating, analyzing, monitoring, controlling, and communicating to end points and their appropriate central systems. These devices must possess the processing power, memory, storage and software necessary to handle the voluminous data from various types of end points and systems. They must be sufficiently flexible to incorporate multiple and appropriate protocols for local and backhaul communications. The device must have the ability to host and/or integrate developed applications, and allow remote upgrade of these applications and the device operating systems. Finally, the devices must meet the stringent utility requirements for deployment in an outdoor environment in multiple configurations.

The Ambient Smart Grid Node was built to meet all of these requirements, providing the local intelligence necessary to enable autonomous and manual decision-making controls based on a variety of inputs from the distributed ecosystem, as well as accepting centralized inputs from operators and systems. Today, the Node provides multiple communications options and an application platform that provides outage notification, power quality monitoring, partial discharge monitoring, GIS integration and much more.

Ambient has continually updated and improved its Node based on years of field experience with deployed devices in utility networks, and by working with those utilities to meet specific needs for operational efficiency. The Node can directly connect with any end point or other device using physical connections, such as Power Line Communication (PLC), serial or Ethernet, and has the ability to interface directly with wireless communication technologies and protocols, such as cellular, Wi-Fi, private radio, or any combination thereof. The Node is a flexible IP-based device and can leverage any communications path available as either downstream end point based communications, or upstream backhaul communications.

The Node is designed to serve different roles within a network, and to perform data collection, aggregation, and management. The Node can be configured in a wide range of hardware and software profiles to meet specific location and functional requirements. This flexibility allows the node to maximize functionality, and not burden every Node with costs associated to specific profiles. The Nodes, each with unique profiles work together to provide an open and flexible platform for grid modernization, all with standard and interoperable components. Additionally, third-party applications and devices can easily be integrated into the Node and a given Node profile. Combined, the communications and application features allow maximum flexibility in communications, use cases and functional deployment planning.

One Ambient developed Node application, the Ambient Power Quality Monitoring Solution (AmbientPQM™), expands on the Node’s functional flexibility. Composed of hardware and software, this solution can monitor voltage on the secondary, and current on the primary or secondary, as required. These data are constantly available on the Node and can be configured to provide an alert for a variety of events, including power sags, peaks, and outages. These data sets can be leveraged for multiple applications and can be especially effective when combined with information from other systems.

The Ambient Network Management System (AmbientNMS®) is an extensible network management system for managing the communications network between the devices and the existing back-office systems via Simple Network Management Protocol (SNMP). The NMS can monitor and manage tasks, run discovery and status checks, query devices, and store and relay information and instructions between the NMS and the Nodes. Additionally, it can manage distribution of software upgrades to the Nodes and connected third-party applications, such as a metering data concentrators. Finally, and most powerfully, the AmbientNMS can manage other downstream devices manufactured by others that conform to existing standards.
Given the potential for multiple applications and communications to be combined in a Node and managed through the NMS, the Node has been designed with security in mind to ensure availability, maintain integrity, and protect confidentiality through a combination of physical, system, and network security measures. The physical security of the Node is established by external Node design, as well as a built-in tamper detector set to alarm through the NMS. The system security is maintained, using an encrypted software image, disabling unconfigured physical ports, a specific-use command line interface, and SNMP v3-based management, among other features. Network security is achieved through an integral firewall, SSL-protected remote access (SSH), Wi-Fi protected access, and application access requirements enforcement. By taking a standards-based approach to the design of its Node, Ambient leverages the best practices of multiple areas of focus to create a comprehensive and flexible security profile for the Nodes and the entire system.

The Node’s performance is enhanced with additional features such as a watchdog process on the Node that monitors the system and applications, and forces a reboot if any are unresponsive. In addition, an optional battery module allows enough time to notify the NMS of an outage, protects against momentary outages, and provides a graceful Node shutdown.

Because the Node is based on open hardware and software principles, it provides a single, secure environment with which compatible third-party applications can be supported. The Node is designed with the future of technology choice in mind by providing the ability to support multiple communications networks, and the processing and storage capacity to incorporate multiple data applications.
SECTION 4:

Integrating External Applications into the Ambient Smart Grid Node

The Node’s flexibility is critical to its effectiveness as the foundation of a distributed architecture. Ambient has maintained an IP and standards-based structure in its Node designs to maximize that flexibility and allow the devices to support new applications and assimilate new technologies. This enables existing or desired utility applications to leverage the Node for backhaul and local communications as well as local data integration. Five examples of this synthesis demonstrate Ambient’s ability to afford its customers flexibility in technology selection through a variety of methodologies. In each of these cases, the initial functional requirement and integration request came directly from a utility.

Case 1: Advanced Metering Infrastructure (AMI) Data Concentrator (DC)

The utility made its AMI technology decision to meet its own technical and economic judgments, consistent with regulatory requirements. Ambient was asked to cooperate with the AMI vendor to integrate part of the AMI infrastructure into the Node to leverage its communications capabilities. The result demonstrates the Node’s capability to incorporate an outside solution seamlessly to sustain that solution’s core functions. The key advantage to the utility is that the Node does everything the AMI DC would do, and also enables new functions to be added in the future.

Ambient integrated an AMI DC into its Node to transport the AMI data to and from the meters, as well as exchange data between the AMI DC and its head-end server via the Node’s on-board backhaul connection. This effort provided the blueprint to integrate other AMI collection services into the Node.

This integration option provides technology selection independence to the utility while maintaining the functional independence of the AMI.

Case 2: Third Party Application Integration - Line Sensor System

The utility was evaluating a line sensor system in parallel with its other technology evaluations to establish parallel capabilities. The line sensor system employed a proprietary communications protocol, and the utility requested that the line sensor system vendor adopt a standard communications protocol to meet the requirements of the utility’s smart grid communications architecture. The utility further requested that the line sensor system’s communications infrastructure be replaced by the Ambient Smart Grid Node, and that the software application run directly on the Node’s open hosting environment.

Ambient worked with the line sensor system vendor to help them successfully convert to a standard communications protocol while seamlessly integrating the line sensor application into its Node. Once the sensor application was developed to the Node’s open API, it was sent over the air as a firmware upgrade to the Node, eliminating the need for a truck roll to add this application to the deployed infrastructure. This enabled the line sensor system to leverage both the communications (wide area and local) and the remote management services (e.g., over-the-air firmware upgrades) available on the Node. This effort also expanded the sets of data leveraging the Node, enabling potential future applications.

This integration example also demonstrates the capability of the Node to leverage its standards-based, open architecture to fully incorporate and manage another solution while maintaining the integrity of a customer’s communications architecture. The primary benefit is that the utility does not require a separate, single-purpose communication network to serve the line sensor system.
Case 3: Automatic Meter Reading (AMR) Integration

A relatively new, fully-installed AMR solution existed in the utility’s territory that would not be included in the larger smart grid implementation due to multiple factors. The utility requested that Ambient evaluate possible solutions for serving the AMR infrastructure through the Ambient Smart Grid Node. Given that this type of legacy infrastructure is not uncommon, the ability to serve that footprint represents a significant potential value, especially to the utility that desires a fully integrated smart grid solution.

Ambient developed the AMR capability to be vendor-agnostic. The AMR-enabled Node can gather AMR reads, record them locally, and compile the read data into an open format that can be adjusted to deliver to any number of head-ends or back office systems a utility may require. As a fixed network, the Node can be configured to collect AMR meter reads at configurable intervals, allowing for granular data that can be used for home energy portals and time-of-use billing.

This integration option also demonstrates the capability of the Node to incorporate a legacy infrastructure and allows a utility to gather the data from these legacy devices as part of the utility’s larger smart grid communications and data deployment strategy. This capability allows a utility to gather energy consumption data from these AMR devices while using the Node as part of its common smart grid infrastructure along with its other end point devices, as desired, thereby increasing the value and extending the life of an AMR deployment.

Case 4: NMS Integration into Outage Management System (OMS)

Ambient was asked to integrate its NMS into the utility’s existing, industry-standard OMS to capitalize on the distributed location information from the Nodes the utility had already deployed.

Ambient worked with the utility and the OMS vendor to provide Global Positioning System (GPS) location, and time-stamped outage and restoration alerts generated by field-deployed Nodes to meet the specific needs of the OMS and its operators. The combined data from both systems, and the Node’s ability to aggregate multiple data sources locally, provide greater ability to triangulate and determine root cause of a power delivery issue quickly.

This integration option demonstrates the capability of the NMS to integrate both its communications and data sets with utility back office systems. The data gathered at the distributed Nodes provide the additional value of granularity, which can be essential to resolving complex delivery issues such as nested outages.

Case 5: SCADA and DNP3

Ambient was asked to leverage the communications port on the Node to physically connect to SCADA devices to provide a communications alternative to traditional remote terminal units (RTUs). Ambient integrated a DNP3 stack on the Node that enabled SCADA communications for the legacy devices, but also provided the ability for the Node to serve as a master and control multiple DNP3 enabled devices downstream from the Node. In this fashion SCADA traffic and information can be aggregated for localized action.
There are a variety of applications that will utilize the Ambient Smart Grid Node. Due to the unique properties of the Node, either the applications can be centrally managed, or the applications themselves can reside on the Node. Below are examples of such applications.

The key feature of the Node as the enabler of a distributed architecture is the concept of Local Data Access, the ability to extract data from other systems as it passes through the Node. The ability to collect, combine, analyze, and act upon data from disparate sources at the edge of the distribution grid allows for a variety of new applications and value to be created for the utility. Below are several examples of applications that can be enabled with the distributed architecture and Local Data Access.

### Table 1: Applications that Utilize the Node

<table>
<thead>
<tr>
<th>Application</th>
<th>Description</th>
<th>Central or Distributed Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage Monitoring</td>
<td>Utilizes voltage sensing at the transformer and meter to generate exception reports which indicate voltage regulation problems</td>
<td>Distributed</td>
</tr>
<tr>
<td>Transformer Overload Monitoring</td>
<td>Monitors loading on transformers and provides real-time alerts when transformer is overloaded</td>
<td>Distributed</td>
</tr>
<tr>
<td>Remote Fault Detection</td>
<td>Three-phase line devices that measure current (amps) and identify the fault current and location of a fault</td>
<td>Both</td>
</tr>
<tr>
<td>Outage and Restoration Notification</td>
<td>Remote and automated notification of power outages</td>
<td>Both</td>
</tr>
<tr>
<td>Integrated Volt/VAR Management</td>
<td>Ability to remotely configure and control capacitor banks and regulators to achieve specific power factor and voltage objectives on the grid</td>
<td>Central</td>
</tr>
<tr>
<td>Demand Response Event Management</td>
<td>Remote control of customer equipment to manage peak capacity and grid operation issues</td>
<td>Central</td>
</tr>
<tr>
<td>Streetlight Monitoring</td>
<td>Monitoring of streetlights to confirm they are operating appropriately</td>
<td>Distributed</td>
</tr>
<tr>
<td>Plug In Electric Vehicle (PEV) Monitoring</td>
<td>Remotely identify in real time where PEVs may be located and charging</td>
<td>Distributed</td>
</tr>
</tbody>
</table>
Example 1: Voltage Monitoring

Secondary voltage monitoring can provide utilities with a wealth of information regarding how the distribution grid is operating closest to the customer. The Node is physically connected to the secondary grid and has the capability to measure voltage on both secondary conductors connected to a customer on a continuous basis. As a result, the Node can perform a variety of analytics in the field, with alerts and data being forwarded to the appropriate groups/users within a utility when certain thresholds are exceeded or predefined conditions are met. Additionally, data can be collected at pre-set intervals and either sent back to the utility data warehouse or used by other applications. A key point of this analysis is that the thresholds or intervals can be remotely configured for each Node. This allows the utility to set up monitoring criteria that reflect what is going on operationally on specific sections of the distribution grid.

The table below summarizes some examples of analytics that can be performed by monitoring voltage.

Table 2: Examples of Analytics that can be Performed by Monitoring Voltage

<table>
<thead>
<tr>
<th>Application</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>High/Low Voltage Alerts</td>
<td>Alerts utility when voltage exceeds operating thresholds. If the utility has deployed smart meters, it can also develop analytics on transformer versus meter voltages so it understands the effect of customer loading and secondary voltage drops at each customer site. This data could be analyzed in real time to help solve customer complaints regarding their electric service.</td>
</tr>
<tr>
<td>Transformer Failure</td>
<td>Erratic high-voltage activity on both legs of the secondary is a predictor of high side windings failure and eventual transformer failure. This information can be used to warn of impending failure before it happens.</td>
</tr>
<tr>
<td>Sag and Swell Alerts</td>
<td>Identification, documentation and alerts on voltage and/or current spikes and swells that occur during short durations (three cycles is the default setting). By tracking and counting the number of times these happen, the utility can begin identifying potential problems on the feeder, from vegetation issues, loose or cracked equipment, or incipient faults.</td>
</tr>
<tr>
<td>Secondary Neutral Failure</td>
<td>Alerts for open or loose neutral situations by analyzing the pattern and relationship between the two legs of the 120/240-volt service.</td>
</tr>
<tr>
<td>Feeder Voltage Imbalance</td>
<td>Monitors secondary voltages by phase on a feeder. Aids in identifying and diagnosing imbalanced load, bad phase on a capacitor bank; bad phase on a voltage regulator, or improper feeder design.</td>
</tr>
</tbody>
</table>
Example 2: Integrated Volt/VAR Control (IVVC) “Bellwether” Voltage Monitoring

IVVC recently attracted a significant review and discussion as an opportunity for utilities to manage and optimize the distribution grid. The successful implementation of IVVC on a distribution feeder requires the synchronous monitoring and operation of several devices, from load tap changers in the substation to capacitor banks to meters or other smart grid devices that measure secondary voltage at the end of the feeder where voltage will be the lowest.

IVVC is a relatively new opportunity in the sense that new smart grid technologies, communications infrastructure, and applications have been developed to manage and operate distribution grid devices in a coordinated fashion. For the successful implementation of IVVC, distribution operations need to be able to monitor voltages from the substation (where voltage is the highest) to the end of a feeder (where voltages may be the lowest). Initially, utilities assumed that voltage information from smart meters could provide the voltage information. However, due to the specific requirements of the IVVC application (frequent intervals, near-real-time monitoring), utilities have begun investigating installations of “bellwether” meters at strategic locations along the grid. The Node can actually provide all the information required, along with other benefits. Specifically with:

- The Node can measure voltages at any configured interval required by distribution operations and can be changed over time as conditions or needs dictate
- The Node can be remotely configured to “turn on” and become a bellwether device
- For Nodes that are already deployed, the utility can remotely assign or unassign them to become bellwether devices
- IVVC applications can be stored on the Node to perform remote analytics and proactively alert the utility if voltage conditions change
- The Node can provide on-demand reads of smart meters, as needed, to make sure the voltage at the home does not drop below the operating standard

Example 3: Transformer Load Monitoring

Distribution transformers represent some of the oldest utility assets deployed today. Many of these were installed during times when there was significantly less load at each home served by the transformer. Although conventional utility practices historically accounted for load growth through over-sizing the transformer, few would have forecasted the amount and load of appliances in most homes today. The result has been a steady increase in transformer failures, which result in customer outages and dissatisfaction. Until recently, there was no way to monitor transformer-loading. However, utilities deploying AMI and/or Nodes have two potential methods of calculating and monitoring transformer loads. However, utilities deploying AMI and/or Nodes have two potential methods of calculating and monitoring transformer loads throughout the year. The first method would be to use secondary current and voltage information collected from the Ambient Advanced Power Quality Monitoring (AmbientPQM®) module on the Node. Specifically, the formula for estimating transformer kVA is:

\[ kVA = \frac{(V \times I)}{1000}, \text{ where } V = \text{voltage and } I = \text{amps} \]

Since the power quality module has the capability to collect secondary current (with the installation of additional current transformers) and voltage data at configured intervals, the Node can incorporate an application locally that calculates transformer-loading each time it collects the data. More important, it saves these calculations for eventual delivery to the central data warehouse, where additional analysis and action could be taken. Once the calculations are complete, the application can alert distribution operations when specific thresholds are exceeded in order to avoid a catastrophic transformer failure due to overloading.

An alternative, less expensive, albeit less accurate, way to estimate transformer load would be to calculate transformer-loading using interval AMI reads for those customers being served by that transformer. Specifically, the application would again reside on the Node and using the Local Data Access feature, collect AMI reads at specific intervals throughout the day. For each interval, the meter read values for each customer would be summed and then multiplied by the number of intervals collected in the hour.
For example, if data were collected at 15-minute intervals, then the formula would be:

\[ \text{kVA} = \text{Sum(Meter(1)…Meter(n))} \times pF \times \text{Number of Intervals per hour} \]

- \( \text{Meter(n)} \) is the interval meter read for each meter served by the transformer
- \( pF \) is the power factor
- \( \text{Interval} \) is the number of times the data is collected each hour

The following is an example of how this calculation would work for a transformer-loading calculation that would occur at a specified interval. In this example, assume the readings below occurred at 14:00 hours.

<table>
<thead>
<tr>
<th>Meter</th>
<th>kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meter 1</td>
<td>0.2</td>
</tr>
<tr>
<td>Meter 2</td>
<td>1.0</td>
</tr>
<tr>
<td>Meter 3</td>
<td>3.0</td>
</tr>
<tr>
<td>Meter 4</td>
<td>5.0</td>
</tr>
</tbody>
</table>

\( pF = 0.96 \)

\( \text{Number of Intervals collected each hour} = 4 \)

\( \text{Transformer Rating: 50 kVA} \)

\[ \text{kVA Loading Estimate at 14:00} = (0.2+1.0+3.0+5.0) \times 0.96 \times 4 = 35.3 \text{ kVA} \]

\[ \% \text{Transformer-Loading} = \frac{35.3}{50} = 71\% \]

The resulting value will be a fairly reliable estimate of what the transformer kVA load will be at that interval. As with the first calculation, the Node application would monitor the transformer-loading at specified intervals and alert the utility if the loading threshold was exceeded.

Example 4: Outage Notification and Restoration

Outage notification and restoration has been cited as a fundamental and immediate benefit of most smart grid deployment plans. Utilities have historically relied on customers calling in power outages as the primary source of information for documenting outages. All leading edge OMS are predicated on converting customer calls into outage maps for crew dispatch purposes. Whereas these systems have been effective in giving utilities information for general restoration activities, they are still dependent on customers calling in.

Where the OMS is deficient is in the case of nested outages, which may be beyond a tripped fuse or a transformer. Crews may have solved the immediate and major issue, but missed pockets of outages, and are then required to return to the area when customers finally call in wondering why they are still without power.

Moreover, the process of recording outage times and events is still primarily a manual and subjective function performed within the dispatch operations. Specifically, the systems rely on linemen and dispatchers to report precisely on the start and end of outages; these times are then used to develop reliability statistics (CAIDI; SAIDI; MAIFI) for regulatory reporting. In short, the priority focus of the dispatchers and the crews is to restore service, not provide statistics and documentation. Yet there is no other way to collect and record the information today – a smart grid infrastructure will need to be installed.

A key operational benefit of a smart grid system with distributed architecture is that it has the capability to remotely determine when and where outages occur, to provide key information and a time stamp on when the outage occurs, and most importantly, to provide information as to when all customers will be restored. Embedded in a Node that has battery back-up capabilities, is functionality to send to the utility operations alerts when it is losing power, and when power has been restored. Furthermore, once restoration occurs at the Node, it then has the capability to communicate proactively with the meters to determine whether they are back on line. If they are not, the Node can then send another alert back to operations, informing them that an outage still exists. Most importantly,
Perhaps one of the most potentially disruptive loads that will be coming to the distribution grid is the PEV. The potential for disruption is high primarily because of the granular effect that just a few number of vehicles may have on the distribution grid. PEVs can be charged literally anywhere there is a 120-volt outlet or where there is Electric Service Vehicle Equipment (EVSE) installed. Research\(^4\) indicates that the majority of customers will want to charge their vehicles at home. As a result, certain areas of the distribution grid may see a substantial effect on the transformer-loading, phase-loading, even voltage impacts from vehicle charging. At this time, there is no way to monitor the grid proactively at the transformer level to determine when a vehicle is charging and if there is the potential for transformer overloading.

The opportunity exists to manage and monitor the EVSE using the Node; this could be done with or without a Home Energy Management System (HEMS) or AMI in place. Most EVSE manufacturers today have embedded communications into their charging equipment. Although the primary focus of this communications technology is to connect with the PEV or the EVSE back office, eventually the utility will want to be able to manage and monitor the EVSE. Strategically and operationally speaking, it would make sense to have the EVSE integrated with the Node for a few reasons:

- The Node can support multiple communications protocols
- Since the Node is located at and monitoring the transformer that serves the home(s) with the PEV, it would be able to determine quickly whether PEV charging is going to overload the transformer
- The utility could remotely install a PEV-monitoring application on the Nodes where PEVs are located and have the Node monitor the transformer load remotely

Example 4: Outage Notification and Restoration (CONTINUED)

these alerts and analytics are done in real-time, so the dispatcher has information to provide to restoration crews while they are still in the field. Finally, the Node and system can be linked to the OMS to provide the information automatically as it becomes available during an outage and restoration. Included in the information are the specific time-stamps for the start and end of the outage, allowing the utility to have specific documentation on the length of the outage, down to each customer. In summary, outage notification and restoration is the quintessential example of how a smart grid infrastructure takes advantage of distributed and centralized applications and analytics.

Example 5: Plug-in Electric Vehicle (PEV) Monitoring

Perhaps one of the most potentially disruptive loads that will be coming to the distribution grid is the PEV. The potential for disruption is high primarily because of the granular effect that just a few number of vehicles may have on the distribution grid. PEVs can be charged literally anywhere there is a 120-volt outlet or where there is Electric Service Vehicle Equipment (EVSE) installed. Research\(^4\) indicates that the majority of customers will want to charge their vehicles at home. As a result, certain areas of the distribution grid may see a substantial effect on the transformer-loading, phase-loading, even voltage impacts from vehicle charging. At this time, there is no way to monitor the grid proactively at the transformer level to determine when a vehicle is charging and if there is the potential for transformer overloading.

The opportunity exists to manage and monitor the EVSE using the Node; this could be done with or without a Home Energy Management System (HEMS) or AMI in place. Most EVSE manufacturers today have embedded communications into their charging equipment. Although the primary focus of this communications technology is to connect with the PEV or the EVSE back office, eventually the utility will want to be able to manage and monitor the EVSE. Strategically and operationally speaking, it would make sense to have the EVSE integrated with the Node for a few reasons:

- The Node can support multiple communications protocols
- Since the Node is located at and monitoring the transformer that serves the home(s) with the PEV, it would be able to determine quickly whether PEV charging is going to overload the transformer
- The utility could remotely install a PEV-monitoring application on the Nodes where PEVs are located and have the Node monitor the transformer load remotely

Example 6: Advanced Demand Response Initiatives

Demand Response (DR) has been part of most utilities’ demand-side management programs for the last thirty years. However, until the last couple of years, relatively little has changed, from a customer perception, technology adoption, or utility value perspective. Specifically,

- Most programs used one-way paging technology to operate a switch on an air conditioner or hot water heater
- There was no way to definitively verify whether the load control switch actually operated or, if it did, the amount of kilowatts that were saved
- The programs were designed primarily to help utilities manage system capacity constraints
- Customers were compensated to allow the utilities to operate pieces of their equipment during periods of time when customers may actually want to use them (like air conditioning during a hot summer day)

Over the last five years, significant technology and product advancements have been made in developing more customer-friendly HEMS. These systems, when coupled with usage information from smart meters, allow customers to understand, on a more discrete and timely basis, how they use energy. However, whereas technology and product development have flourished (there are over sixty companies and counting that make these types of products), there has been less work on standardizing communication and functional specifications across the utility industry. As a result, to date, there have been relatively few installations of HEMS in the industry. Furthermore, a significant amount of work still has to be completed with respect to calculating the potential customer and utility value associated with these systems.

Perhaps the one certainty with “DR 2.0” is that it will have significantly advanced two-way communications over its predecessors. The communications protocol choice [Wi-Fi, ZigBee® (ZigBee Alliance), HomePlug® (HomePlug Powerline Alliance, Inc.), Z-Wave® (Sigma Designs, Inc.), etc.] is still being determined and may very well vary from program to program. That protocol will need to be integrated with the Node to achieve the maximum of its potential customer and utility value. Having multiple communication options embedded in the Node will allow the utility to minimize the risk and increase its flexibility in choosing HEMS options.
In conclusion, highlights of Ambient’s Node-based distributed smart grid architecture are:

- To date, for both technical and economic reasons, the distribution grid is where utilities have had the least visibility regarding its grid operations.
- The key component to this distributed architecture is a hardware and software platform that provides Local Data Access, application management, data storage, analytics, and device monitoring at the edge of the distribution grid.
- The Ambient Smart Grid Node is a commercially available product. This Node is part of a comprehensive platform that can be remotely upgraded to incorporate new applications and analytics, and to integrate other smart grid devices and functions as they are deployed on the grid.
- Although there has been significant activity with respect to the installation and commissioning of smart grid systems globally, the industry has barely scratched the surface with regard to capitalizing on the value of new applications. This paper identifies several important applications that will rely on the distributed smart grid architecture. Many more high-value applications will be conceptualized and commercialized as utilities start to expand the use of their smart grid systems.
- Distributed intelligence allows the utility distribution system to operate most efficiently, in essence “delegating” decisions that can be made autonomously in the field rather than backhauling volumes of data to make a simple decision and issue a command accordingly. Certainly, many applications require central data presentation, processing, and command, but many do not.
- By delegating certain distribution monitors and control decisions to field devices, such as the Ambient Smart Grid Node, the distribution system becomes reliable and fault tolerant. The devices in the field can carry on, doing their job, even if a backhaul link is disrupted or equipment failure compromises central communications.
- The distributed architecture allows for scalability, expandability, and the addition of new applications as they emerge. This flexibility provides the greatest opportunity to extract value from both legacy and future systems.