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The Platform Grid

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SUMMARY

The Platform Grid is a reference architecture that leverages the Industrial Internet of Things paradigm to better operate utility distribution grids and lower the cost of service of electric utilities worldwide as they face increasing high penetration of distributed energy resources and active participation of prosumers willing to trade excess energy. In this paper, we discuss the business requirements, the fundamental architectural concepts, and the implementation of the Platform Grid.

KEYWORDS

Smart Grid; Industrial Internet of Things; Active Grid Management; Distributed Energy Resources; Renewable Integration; Microgrid; Virtual Power Plant; Transactive Energy.

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I. Introduction

This paper presents the concept of the Platform Grid in three sections. First we describe the business motivations to transform the smart grid and address the need for integrating distributed energy resources, optimizing grid operation, improving asset maintenance, and expanding wholesale energy markets. Second, we propose a reference architecture for the Platform Grid for sensing and controlling real-time processes, networking from edge to cloud, data processing, and integrating user applications. Third, we discuss an implementation methodology highlighting the unique aspects of deployment strategies for the Platform Grid.

II. Why a Platform Grid?

The motivation to rethink the smart grid as a Platform Grid is driven primarily by the need to integrate distributed energy resources (DER) connected at the medium and low voltage distribution networks. The Platform Grid digitally connects all grid assets to modernize distribution operations and reliably serve utility customers at a lower cost. Data hungry utility asset managers and traders benefit from high quality real-time situational awareness of the grid. Asset managers assess equipment health to optimize maintenance practices and improve planning decisions. Traders (aggregators, retailers, etc.) leverages this data to successfully trade distribution level resources into wholesale markets or as part of new transactive retail markets.

At its architectural core, the Platform Grid is an application of the Industrial Internet of Things (IIoT) technology concepts. Here, IIoT extends sensing, computing, data, and automation to the edge of the distribution system and beyond to the prosumer. Such a platform is essential if the industry is to successfully integrate DER resources into distribution grid operations and into wholesale/retail energy markets. At high levels of DER penetration on distribution systems, communication requirements, data volumes, and event response times necessitate a robust platform capable of scaling in size and of evolving over time accommodating relentless advancements in technology.

The Platform Grid will support the current and future needs of grid operations. In this paper, grid operations include all aspects of real-time operation, maintenance and planning of grid assets located at the medium (MV) and low (LV) voltage level of the distribution grid. Grid operations also include all processes necessary to support customer services - metering, billing, outage management and special prosumer programs.

Optimizing Real-Time Distribution Operations. The Platform Grid will improve real-time operation in quality, cost of service, reliability performance, and resilience to major events. First, it will support utilities who strive to continuously optimize real-time operation by minimizing losses, maintaining power quality, and dispatching generation, including flexible demand. With the advent of more automated feeders, demand response and the capability to store energy on demand, the grid operator will have more tools to optimize real-time operations. To this end, the Platform Grid will monitor power flows and voltages in every phase at feeder level and load level. It will also supervise the state and status of controllable loads – included connected DER - and automation devices inside substations and along feeders. While the Platform Grid operator will have full awareness of real-time measurements and status of the distribution grid, decision support systems will still be required to continuously take the best actions or alert the operator of the need for broader actions in this increasingly complex system. The Platform Grid will host distributed intelligent systems that will process data to first adjust control set points for local control systems according to predefined rules, and second, recommend supervisory actions to grid operator for broader regional actions.

To improve reliability, the Platform Grid will predict failures and will reduce the time to restore outages using pattern recognition based on accumulated historical data. The data collected in real-time will be continuously stored in a big data environment so that operation plans can be continuously improved by correlating root causes of failure with time to repair, type of equipment, and external environmental conditions (weather, etc.). Upon detecting a pattern of poor performance, such as the repetitive failure of a particular equipment, or longer restoration time in a particular area, utility planners and asset managers will devise better operational plans for the Platform Grid.

The Platform Grid will improve the resiliency of the grid, by anticipating and responding to major events such as catastrophic equipment failures or widespread storms. New operating modes under critical conditions will rely on islanded subnetworks where stored and local power generation can sustain critical loads. Restoration will be orchestrated with black start procedures synchronizing these energized islands to reconfigure the grid back to normal state while ensure the safety of all crews. To this end the Platform Grid control area will include all connected DER with the capability to supervise them as generators for islanded subnetworks. Intelligent points of common coupling will be capable to autonomously synchronize with the grid and perform automated switching procedures in emergency mode. Upon the restoration of communication links, a centralized operation will take over and start the procedure of reforming the grid.

Improving maintenance and planning of grid assets. A significant portion of the cost of service for utilities is maintaining grid equipment, overhead feeders and pole, and underground cables. This cost increases as more DER get connected, leading to more occurrences of high voltages and reverse loading of transformers, more switching operations and increasing short-circuit interrupting current. As the number of automation devices increase in the grid, utilities will face the new cost of maintaining communication and power electronics in hard to reach and harsh environments. The Platform Grid must therefore be designed for remote and safe manageability of automation devices and help asset managers prioritize the maintenance procedures as well as prepare them with the right tools and spare parts to execute the job. One critical requirement for utility operators is to ensure the security of the grid; so the Platform Grid assets will also include physical security systems such as video surveillance data processing and cybersecurity protection systems to prevent, detect and recover from all types of attacks on grid equipment systems.

Improving customer service. The Platform Grid will provide information with minimum latency to consumers and to prosumers and to their approved energy service providers who want to take an active role in electricity markets. It will be the infrastructure to read and manage smart meters and support all types of tariffs and incentives programs. The Platform Grid's big data environment will send all meter data to relevant enterprise systems (meter data management, customer portal, and billing systems) in standard format independently of specific metering devices and communication technology. Similarly it will support all on-demand queries from customer service representatives, including instantaneous reads and checks on current status at the customer premise. The Platform Grid will integrate other customer devices (load controllers, microgrid controllers, battery management systems, building management systems, smart inverter, electric vehicle chargers, and smart thermostats) which can be monitored via a secure gateway at the customer premise to implement automated demand management for industrial, commercial and aggregated residential customers. It will provide full transparency of the constraints on operational processes related to the implementation of market programs (see below) to ensure fair monetization of flexible loads and distributed generation. Such constraints include real-time local voltage limits, power factor limits and peak demand reduction goals. Maintaining operating constraints within limits using the customer assets will be monetized using accurate and verifiable data through the Platform Grid. This will create a new market place for services to the consumer to help them improve and benefit from their active consumption and production of electricity.

Market operation. At today's level of penetration of DER, the wholesale electricity markets are reasonably capable of accommodating these sources while balancing energy and assuring sufficient ancillary services for reliable grid operations. Combined with national energy policy and state electric regulation objectives, the emerging future of renewable goals of over 50% of bulk generation will necessitate a significant rethink of wholesale and retail markets and the business models for utilities who are requested to facilitate these new business models. Hence, New York REV and California DERP programs are now under development and refinement and we expect that the proposed Platform Grid can implement these programs.

At a high level, a number of concepts are essential components of future electricity markets. These concepts are important to consider for the architecture and design of the Platform Grid.

- Wholesale electricity markets must extend and be more closely connected to the distribution systems. In nodal markets, this means moving beyond several thousand price nodes in the transmission network to tens of thousands of price nodes at the low side bus in distribution substations.
- Localized retail distribution markets will be formed at the distribution feeder level enabling individual facilities or homes to generate, use, sell, or store electric energy. Locational prices (LMP) from the wholesale market, will be posted in near real time for each distribution feeder. We expect that these local markets will be based on bilateral transactions - scheduled ahead or executed in real time. Using these local prices related to their neighbourhood substation, Prosumers (buyers and sellers) will evaluate the risk / benefit of their energy trades.
- The retail markets will accommodate a range of customer profiles: individual homes, aggregated communities, demand response commercial and industrial customers, some with solar, some with storage, or a combination of two or more of these attributes as an integrated microgrid. Complex retail rate models will change while adapting over time as customer profiles and requirements evolve.
- Retail electricity markets will include energy, reserves, and reliability market products with specific attributes driven by simultaneous wholesale market requirements and localized constraints.

III. Architecture

The Platform Grid is an innovative reference architecture that enables the real-time monitoring and control of distribution grid assets and connected distributed energy resources. "Platform" indicates that it is capable of accommodating plug-and-play devices and applications to continuously improve existing utility processes and enable new business processes to support future service opportunities as discussed in the previous section. The key characteristics of the Platform Grid are that it is open, scalable and distributed, real-time and secure. It must also be economically designed to support the fundamental role of electric utilities – provide safe, reliable and affordable electricity to all – and thus it must demonstrate a cost / benefit ratio that meets the criteria for regulatory approval.

Overview. The Platform Grid is a system of systems which requires more than this paper to be fully described. We focus here on its key components deployed in the field: Smart Grid Edge Devices, Smart Grid Edge Gateways and Smart Grid Edge Servers. Figure 1 illustrates the Platform Grid for a European style distribution grid and Figure 2 shows the same concept for a US style grid.

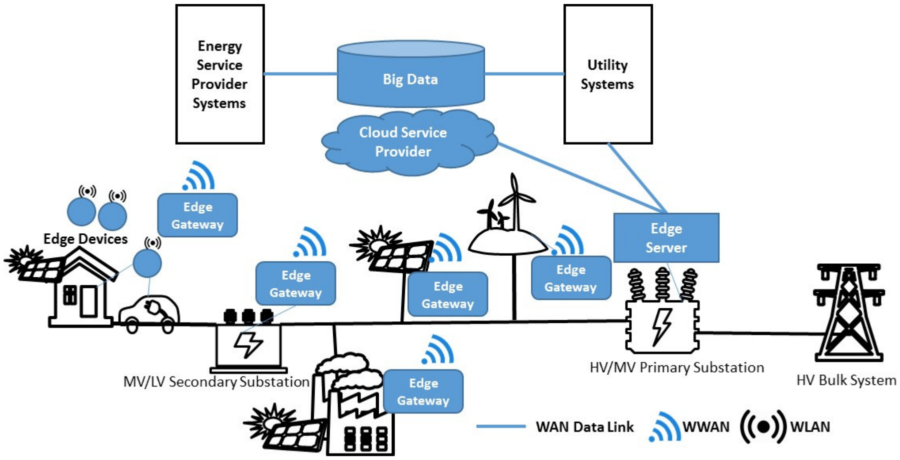

Figure 1: Overview of the Platform Grid (European Style Grids)

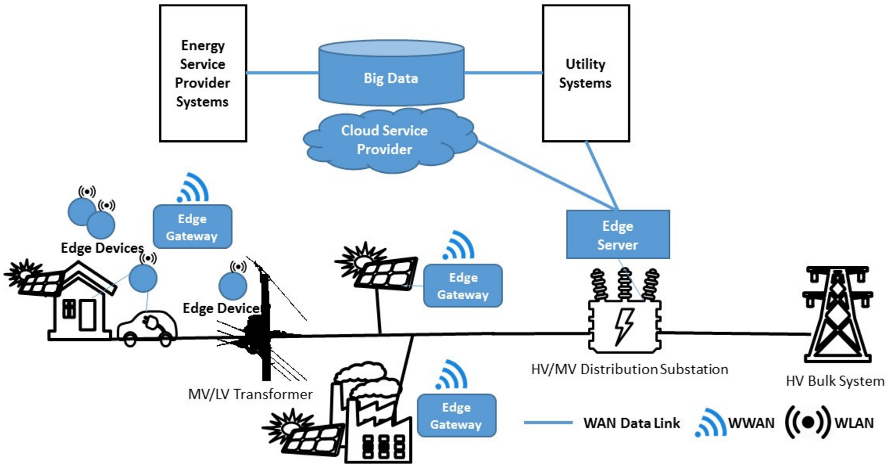

Figure 2: Overview of the Platform Grid (US Style Grids)

Starting from the edge of the grid, **Smart Grid Edge Devices** ("edge devices") act as sensor hubs to collect data from sensors. These devices supplement or replace traditional meters with IoT capability. They are software platforms capable of running local agents to provide immediate filtering and data processing and some local control actions. In its simplest configuration an edge device provides metering data to a meshed network. Through software update it can perform more complex functions such as implementing advanced rates and local control. The edge devices connect to sensor through wires or through wireless local network (WLAN) such as zigbee, wifi, etc. The edge devices form a meshed network or a star network with a super edge device acting as data concentrator which we referred to as a smart grid edge gateway.

The **Smart Grid Edge Gateway** ("Edge Gateway") collects data from surrounding Edge Devices, connected sensors and transmit this data to the Cloud via a wireless wide area network (WWAN). A single protocol map this data to models which are downloaded on the Edge Gateway and ensure real-time two way information between the Edge and the Cloud. For example, as OPC-UA is gaining momentum to become the converged smart grid and IoT protocol, we expect these Edge Gateways to implement OPC-UA as the standard edge-to-cloud data protocol. When sensors (substation meters, feeder controllers, solar inverters, microgrid controllers, etc.) are already installed, the Edge Gateway is connected to them and translate the legacy protocols into the common OPC-UA protocol. Thus, the deployment of the Platform Grid in a given area of the distribution grid will drastically simplify the management of grid data, as all data will be transmitted to the Utility Big Data Environment using a single protocol. The Edge Gateway is the main technology that provides full visibility into the low voltage grid for both grid and market operations.

The Smart Grid Edge Servers ("Edge Servers") are installed in primary substations and in large facilities which are connected to an IP WAN. Edge Servers are substation data concentrators which store models and data history to execute localized algorithms such as voltage-var optimization, fault isolation and restoration, demand response calculation and event notification as well as switching supervision of feeder automation loops and reclosers. Edge Servers monitor the condition of MV grid equipment, and status of various security devices including video surveillance data in critical areas. To support market operations, the Edge Server executes generation dispatch orders across its assigned area to maintain energy balance as per market orders as well as real-time energy balancing. Edge Servers act as combined components of bulk system SCADA and IoT gateways between the distribution system and the bulk system and between the retail market and wholesale market. All data exchanges between Edge Gateways and Edge Servers is performed through the IP network.

While establishing the role of these various components is necessary, it is of greater consequence to stress the notion of interoperability as a critical architectural and deployment design requirement. This is a fundamental aspect of a platform based architecture. Unless this interoperability is assured, then the ability to integrate devices and algorithms from multiple suppliers or sources is very limited and will slow the adoption of the IIoT paradigm.

In storm mode, the Edge Server runs in islanded control scheme for its assigned area and performs emergency load shedding, emergency dispatching of energy storage and microgrid systems. The Edge Server essentially becomes an emergency control center for its assigned distribution assets in storm mode and communicates directly to Edge Gateways via the IP network and cloud infrastructure.

To maximize the security of the Platform Grid and minimize the risk of cyber-attacks and loss of data privacy, all edge devices, edge gateways and edge servers are built with embedded hardware security features which include trusted execution environment using secure boot and a pre-defined list of authorized applications. All data transmission to and from the cloud is encrypted. All security features are managed at enterprise level by both the Cloud Service Provider and the Utility. As security standards evolve, upgrades of all security tools are performed remotely.

The choice of proper communication technologies which are constantly evolving is both an enabler and a barrier to the implementation of a large scale Platform Grid. Starting from the edge, it is often tempting to use the customer's Internet, however it usually has no guarantee of availability and reliability. It is better to devise a wireless local area network to connect local sensors to the Edge Devices, Zigbee, LoRa, or Wifi are good options where the Edge Device serves as the access point for the wireless sensors. Between Edge Devices, a meshed network using technology like 802.14.5g is recommended; a super Edge Device will then act as an Edge Gateway to transmit data to the cloud (sort of a generalized AMI architecture). From Edge Gateways to the Cloud, a broadband wireless technology must be selected. The evolution of carrier networks from GPRS, 2G, 3D to 4G/LTE and now NB-LTE and IOT-NB will support the scale of IoT. Thus we recommend that the Edge Gateways be registered on these networks. Assuming that the network carrier charges for the data plan once upon the registration of the gateway for its entire life (as long as the data does not exceed a threshold reasonable for the application), carrier networks adopting LTE and evolving to NB-LTE are probably the best option. Finally, it is expected that 5G networks will be backward compatible with 4G technology so that deployed gateways can survive this transition through their usage life.

While affordable data plans are necessary to deploy large scale Platform Grids, they are not sufficient. Smart management of data and of power consumption within the edge devices and sensors are required to ensure scalability and manageability. Sensors and edge devices will become more intelligent by running local machine-learning algorithms to filter out non-relevant data and transmit only high priority data to the Edge Gateway while waking up the radio only when necessary. Finally, standard and universal interfaces and data models are required to create an innovative ecosystem of interoperable sensors and analytics software agents in a truly plug-and-play Platform Grid.

III. Implementation

The implementation of the Platform Grid reference architecture, like many industrial IoT projects, is an endeavour that requires combined IT and OT project management expertise. With a combined 50 years of experience in deploying such IT and OT projects for utilities worldwide, the authors have designed a methodology that will reduce risk and ensure that the deployment is successful. In this paper, we focus only on the aspects that are unique and must be given special attention above and beyond traditional IT/OT projects.

The implementation must start with a comprehensive and specific *reference architecture* including currently deployed distribution assets as well as reference designs for new Edge Devices, Edge Gateways and Edge Servers. The implementation is an overlay to existing devices and systems that will progressively replace them as required. This is true for both the OT (Field) environment and the IT environment. The selected Utility Big Data environment to host all the Platform Grid data will also be the tool to progressively update, replace or add new IT systems. Selection of communication technologies is crucial and will require real-world testing prior to finalizing the best one. The reference architecture must present the end-state to all stakeholders and describe how re-engineering of operational plans and maintenance practices will be necessary with this new technology. Contrary to legacy OT systems, the Platform Grid relies on new IT concepts such as IP wireless networks, distributed and cloud computing, and big data. While distribution grids have been traditionally designed for 20 to 40 years or more, the Platform Grid introduces an accelerating pace of technology which must be carefully integrated into the reference architecture. Thus the reference architecture must support a continuous plan for regional deployments and upgrades. This includes updates to continuously protect against new cybersecurity threats. Similar to PC or mobile phone updates today, the reference architecture must take into account this principle of continuous updates and make sure it is feasible and manageable within the selected reference designs of devices and systems.

The proper selection of technology vendors and system integrators to implement the Platform Grid is of course essential to its success. A proof of concept with pre-selected vendors must determine which of multiple options will qualify for the final reference architecture and designs using sufficient field data to prove the value of business cases, as well as comprehensive testing scenarios to document the performance of the technology. Normal operation and abnormal operations must be tested, including the remote management of the complete lifecycle of edge devices and gateways. For the edge components deemed critical special test scenarios must be performed to verify high availability and security requirements. Thus a proof of concept will probably last one year and include at minimum 10 primary substations (HV/MV) to reflect a real-world scenario.

Upon lessons learned from the proof of concept, a deployment plan and scope of work must be agreed upon with comprehensive testing scenario and criteria for success. Upon installation of the big data environment, the deployment can be divided in sub-areas and run concurrently. Initial deployment areas will be driven by forecasted penetrations of DER on specific feeders and by forecasted prosumer behaviour adoption. The Platform Grid should not require a widespread deployment to achieve its return on investment because the recommended IoT technology does not require large private infrastructure but rely on already available Internet infrastructure. Instead a “walk now, so you can move faster” is the recommended paradigm which will eventually lead to a do-it-yourself deployment with utility field technicians and engineers performing all future incremental deployments and upgrades.

In summary the following artifacts are essential to the success of a Platform Grid implementation:

- Reference Architecture with all associated reference designs
- Scope of work and clear roles & responsibilities for all parties
- Data management plan – types of data, persistence strategy, interfaces, performance
- Quality plan with escalation procedures to the Executive Steering Committee
- Security plan including 3rd party audits
- Proof of concept plan with expected results and verifiable criteria for success
- Deployment plan – selected locations, budget, resource and schedule
- Continuous update plan – IT/OT system updates.

IV. Conclusion

Utilities can adopt the Industrial IoT technology to address the paradigm shift in smart grids and electricity markets. With a proven reference architecture and implementation methodology, utilities can start deploying the Platform Grid and demonstrate its costs / benefits to regulators while building an internal competent workforce and tools for continuous deployment and upgrade of this new technology. A universal open, scalable and secure Platform Grid will support the integration of distributed energy resources and enable new utility services such as flexible load aggregation and dispatching, connected microgrid operation and trading distribution level resources into wholesale electricity markets.