Unmanned Aerial Systems (UAS), The Internet of Things (IoT) and Modernization of the Electric Grid – An Overview

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The North American bulk power system is comprised of more than 200,000 miles of high-voltage transmission lines, thousands of generation plants and millions of digital controls. More than 1,800 entities own and operate portions of the grid system, with thousands more involved in the operation of distribution networks across North America. The interconnected and interdependent nature of the bulk power system requires a consistent and systematic application of risk mitigation across the entire grid system to be truly effective.

The Southeast is unique when compared to any other geographic region of the United States. The Southeast energy mix of Coal, Hydro, Natural Gas, and Nuclear is seeing a transformation with more coal coming off line and much more natural gas coming into the mix. This change has created coal plants to be load following, putting more stress on them and likely expected to see more failure. There is also a growing trend of solar generation that can present significant challenges and obstacles to grid operations. In addition, the Southeast faces the extreme weather condition. This region has the highest frequency of Hurricanes in the U.S. Recent ice storms have inflicted significant damage to transmission and distribution lines due to the vulnerability of trees and their proximity to power lines. Combined with relative conservatism of the utilities, grid modernization has lagged other regions of the US.

There are numerous challenges – some technical, some operational - to modernizing wide scale power networks. A 2015 Black and Veatch survey of utility companies lists aging infrastructure and reliability as the two most important concerns of utilities [1]. Power system distribution infrastructure is inherently vulnerable to outages considering that thousands of miles of critical current-carrying distribution lines are of radial configuration. This fact coupled with the realities of an aging infrastructure and continuously changing operating dynamics and constraints render the distribution power grid fully exposed to the vagaries of nature. Additionally, large numbers of extreme weather events such as hurricanes, ice storms, tornadoes coupled with a relatively high population density have been known to cause massive disruptions in power leading to significant loss for both utility companies and customers in the Southeast. For example, the immediate aftermath of hurricane Sandy was approximately 9,000 downed utility poles and more than 6.5 million customers from North Carolina to New Hampshire lost power [2]. In the days that followed, about 8.5 million were without power, some for more than three weeks [3]. In December 2002, a major ice storm struck the Carolinas and nearly 2 million electric customers lost power with average outage duration of 9

days [4]. The resiliency of the Southeast power system distribution network infrastructure hinges on its ability to anticipate, absorb, and/or rapidly recover from a disruptive event.

There has also been an increase in the interest in renewable generation sources throughout the nation due to factors including clean energy regulatory goals. Incorporation of these DER sources will create new challenges to utilities due to the stochastic nature of many renewable generation sources which creates generation forecast uncertainty and increased intra-hour variability. Renewable energy sources will impact reliability, power retail markets, security, safety, and regulatory models [5].

The Modern Grid: Power and Communications

As the nation's electric grid undergoes modernization in-place (while in operation), a topic frequently discussed is the intertwine of the electrical infrastructure and the associated communications network. This situation is illustrated in the represented graphic of Figure 1. The conversation associated with this Figure typically revolves around sensor readings and control settings/commands being sent to/from the "electric side".

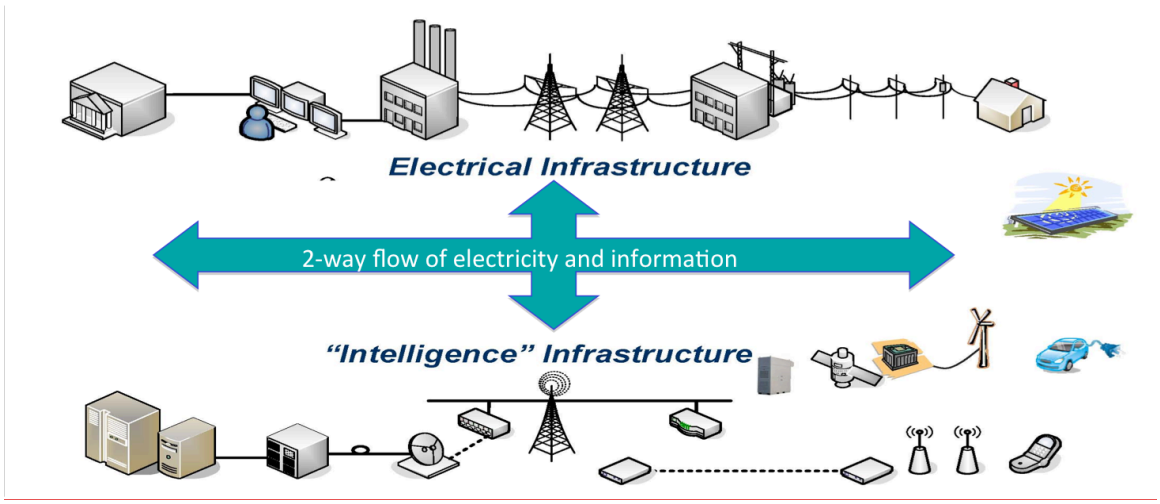

Figure 1. A simplistic view of the electricity delivery system and associated communications network.

The reality is a much more confusing situation with an assortment of communications technologies (leased line, microwave, fiber optic and the many flavors of wireless) and associated protocols being used to deliver electricity safely, securely and reliably. This cacaphony of technologies and protocols is exemplified in Figure 2.

Figure 2. An array of communications technologies and protocols are intertwined (to varying degrees) in an advanced modern electric grid.

The modern Utility is faced with the ever-present problem of energy delivery while the return on investment (ROI) or simply their profit margin is fixed. Meanwhile, data analytics companies are providing various "services" with profit margins significantly higher (~40% per UC Berkeley Haas School of Business assessment, 2014, of Google's acquisition of residential energy use company Nest). A few utility companies – most notably EPB (Chattanooga, TN) – examined the combined Figures 1 and 2 communications networking infrastructure required for next generation grid monitoring (and control) and realized the financial opportunities associated with a high bandwidth communications network to support grid operation while delivering high quality data services to their customers at a significant profit margin (>80% per Wired magazine article, 2014).

This approach to a dual-use communications infrastructure helps provide a financial means for potentially significant expansion of grid sensing and control capabilities through a cost model that actually supports the delivery of energy through the delivery of information (as an internet service provider and cable TV provider). The communications backbone allows for sensing of utility operational parameters far above those traditionally associated with power engineering (exemplified by a phasor measurement unit).

Grid Sensing and the Internet of Things (IoT)

With an aging infrastructure and increased complexity of the electric grid, it is critical to understand the state of health of the system and components. Improved knowledge of equipment condition will allow asset owners to better manage their

fleet. It has been well recognized that low-cost sensors are needed in combination with historical performance information and operational data, to better allocate resources and predict failure prior to end of life, thus, improving reliability while reducing costs. Novel, low-cost devices may enable an improved understanding of the operational state and condition of large capital assets (e.g. transformers, grid-scale energy storage, power electronics, and transmission / distribution lines). Components such as inverter-based generators and its power electronics controllers are equipped with various sensors but for individual control purposes. Sensors at each individual generator level and at the power grid interface that captures the faster dynamics and potential of the power electronics interfaced plant can improve the performance of those generators grid service dramatically.

Coupled into this situation is the utility's needs associated with Asset Monitoring. Low cost sensors to monitor real-time health status of components, stress accumulation leading to loss of life, and real time loading taking local environmental conditions into account. This includes sensing and measurement of components such as energy storage devices and power electronics as well as the power distribution infrastructure – emphasizing power poles and related distribution assets. Again, central to the Asset Monitoring Task is the requirement that the price points for deployed/installed devices and systems must be very low relative to current technologies to increase the use throughout the building infrastructure.

IoT is being touted as the next significant step change in sensing and analytics with applications throughout the energy domain. The emergence of (relatively) inexpensive IoT devices, when layered in the modern utility's IP-everything communications network, provides grid-centric sensing with unprecedented parameter visibility. Examples of two specific opportunities related to IoT for Utilities are: (1) reliance on NERC-CIP compliant secure (and computational complexity appropriate) protocols for sensor module authentication/(re)connection in a multimedia IP-centric network, and (2) categorizing and utilizing/analyzing the varied timescale, varied sensed parameters to be installed within the core and to the edge of the utility's communication network infrastructure. Use cases indicated by numerous utilities range from sensors on mobile platforms (way beyond simple cameras on drones) to substation and vault monitoring (corona discharge, cellsignal detection, chemical, acoustic, thermal, ambient environment anomalies) to automated, control-center controlled mobile platform inspection of transmission/distribution lines and poles.

Unmanned Aerial Systems (UAS) for Grid Visibility (GridViz)

The use cases highlighted in this document include monitoring and maintenance of the grid physical delivery infrastructure (lines, poles, related equipment). To date, a variety of line and vegetation management "examples" of UAS – or the more general area of "mobile platforms" – for visual inspection have been conducted by public, private and academic sector organizations for utilities. These typical situations rely on a camera that is used to inspect the status of the asset. Illustrated in Figure 3 is a

situation where multiple sensor-laden UAS systems are inspecting the operational status of a variety of components at a utility training ground.

Figure 3. View from above a utility training ground – multiple UASs with IoT sensors are "airborne".

While most noteworthy, it is the need for a wide variety of appropriate sensing technologies for monitoring of the modern grid status that the ORNL UAS Research Center is addressing. Advanced sensors and communications components are integrated into sensor modules that are then coupled to UAS platforms. The UASs are then flown to the location and grid assets that are under inspection. In addition to thermal images, such as that shown in Figure 4, these advanced sensors can measure a wide variety of parameters of interest including the ambient RF (radio frequency) environment (Figure 5), detect cellphone signals, coronal discharge from operational grid components, ambient environmental sensing.

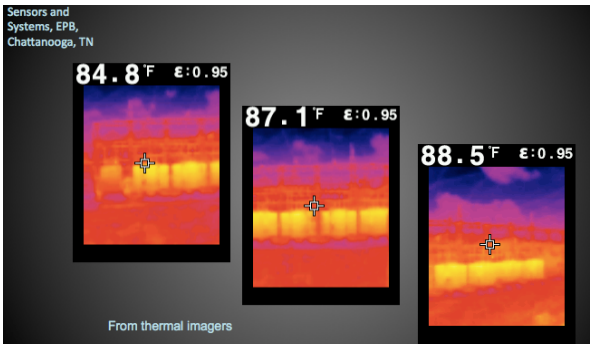

Figure 4. Measurement of thermal images of substation transformers from UAS mounted IoT sensors.

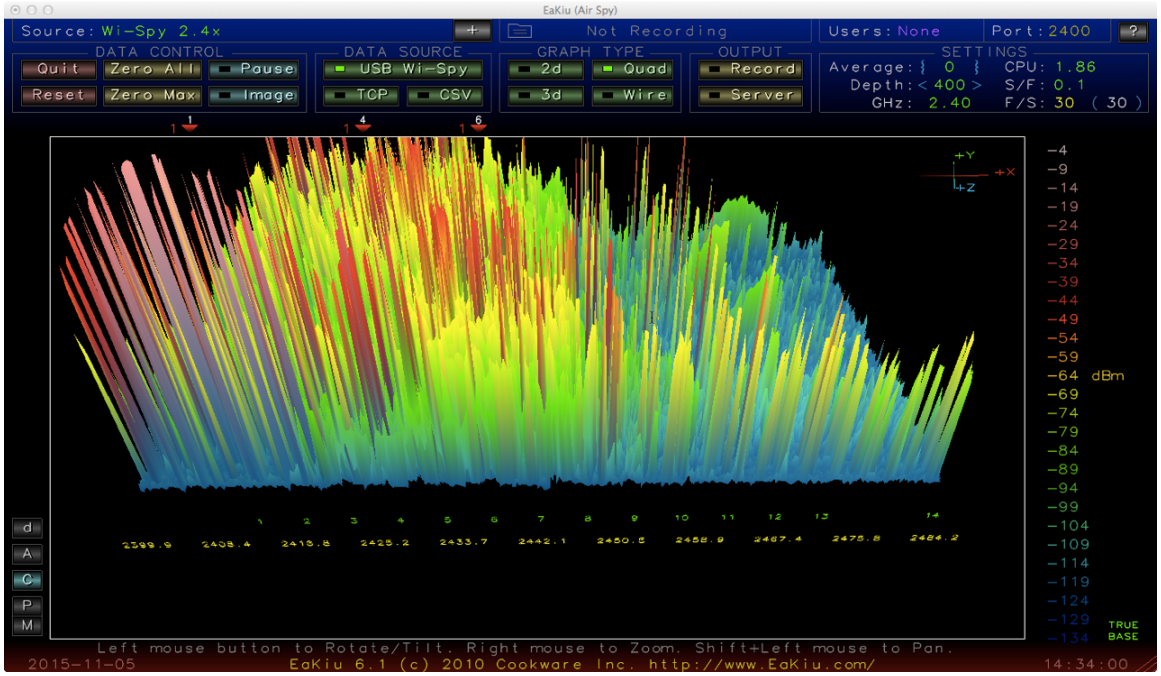

Figure 5. Ambient ISM band radio frequency spectrum near Riverside Substation, Chattanooga TN, 6NOV15.

Summary

The combination of advanced sensors, secure communications, integrated into UAS platforms (drones) provides Utilities (and others) with capabilities to enhance system operation in a cost-effective manner – the Modern Grid.

For More Information

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