Field Testing of 3G Cellular and Wireless Serial Radio Communications for Smart Grid Applications

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This paper was presented at the 2016 IEEE Rural Electric Power Conference and can be accessed at: http://dx.doi.org/10.1109/REPC.2016.22.

Presented at the
IEEE Rural Electric Power Conference
Westminster, Colorado
May 15–18, 2016

Previously presented at the
DistribuTECH Conference, February 2015

Previous revised edition released March 2014

Originally presented at the
Power and Energy Automation Conference, March 2014

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Abstract—**Smart grid solutions are increasingly making use of wireless communications as a core component for moving information to make more intelligent decisions. This paper considers a synchrophasor system implemented on a distribution feeder that uses two different wireless communications technologies to transmit synchrophasor measurement data simultaneously. This system was implemented to demonstrate advanced distributed generation control and its impacts in terms of grid support on the broader electrical feeder. A wireless serial communications solution and a 3G cellular solution were implemented, allowing a comparison of the performance of these different technologies. Because phasor measurement unit data are continuously streamed at up to 60 messages per second, these data provide a means to continuously evaluate the communications systems. Performance data were measured and archived over a one-week period, providing detailed information to compare the wireless communications technologies implemented. Using this information, recommendations are made in this paper about which wireless technology may be better suited for a variety of utility applications.**

Index Terms—**Availability, cellular modem, IEEE C37.118, ISM band, radios, synchrophasors, wireless communications.**

I. INTRODUCTION

Wireless communications are increasingly being used for teleprotection, power delivery automation, monitoring, and control applications. This is especially true for communications that are required or deployed outside the substation perimeter. The primary reasons for using wireless versus wired communications include cost, right of way, location, and deployment time. Initial wireless system installation costs are generally lower than installing copper or fiber systems. In some cases, depending on the location, it may not be feasible to obtain the right of way needed for wired communications. Lastly, deployment time of the system can be part of the decision criteria. Some of the wireless options available today allow for deployment in as little as a few hours.

While wireless communications provide some advantages over wired communications, there are some caveats that users need to be aware of. One of the primary concerns with using wireless communications is the availability of the communications channel. Because wireless systems send information that is modulated on a carrier frequency and transmitted through free space, they are susceptible to radio frequency interference (RFI) and changing environmental conditions [1]. While using licensed communications can significantly reduce the likelihood of interference, it does not eliminate it. Furthermore, severe weather or physical obstructions can reduce availability due to increased signal attenuation or physical damage to antennas. Both interference and environmental factors that impact availability can be difficult to identify due to the intermittent nature of availability. To ensure optimal performance, wireless systems need to be set up properly and require ongoing periodic maintenance to better ensure continuous reliable operation.

This paper summarizes the results of using two different wireless technologies, serial radios and cellular modems, to simultaneously stream synchrophasor data from four different locations along a rural feeder to a photovoltaic (PV) generation site. A phasor data concentrator (PDC) located at the PV site concentrates all of the data from four phasor measurement units (PMUs), as well as data from a fifth PMU located at the PV site. Because the serial radios and cellular modems send time-stamped data, these data provide a means to compare the performance of the two wireless technologies over time.

II. CHOOSING A WIRELESS COMMUNICATIONS SYSTEM THAT MEETS THE REQUIREMENTS

There are many wireless communications options for utility engineers to choose from for power delivery automation communications. As is discussed in [2], the end application requirements should be the primary driver for selecting a wireless system. Key performance attributes of the various wireless technologies to consider include communications latency, security of the information, availability, communications bandwidth, and physical distance, as discussed in Table I. Given the performance attributes, several different wireless technologies or systems can be deployed by a single utility to meet the communications requirements for various applications.

Another decision criterion for the utility is whether to install and maintain the wireless system or subscribe to a wireless provider. While owning a system provides increased control and configurability, it also requires designating personnel and equipment to adequately maintain the system. Subscription-based wireless systems allow the utility to pay for use and leave the overall system installation, maintenance, and equipment upgrades to a third party that can amortize the cost over many subscribers.

III. IMPROVING VOLTAGE REGULATION ON A RURAL FEEDER USING DISTRIBUTED GENERATION

A. SEGIS-AC Project Summary

Advanced Energy Industries, Inc. was awarded a U.S. Department of Energy (DOE) project under the Solar Energy Grid Integration System – Advanced Concepts (SEGIS-AC) program. Advanced Energy Industries partnered with Portland General Electric (PGE) and other companies on the project.

In brief, the program award contains three interrelated projects, each of which benefits from geographically dispersed PMU measurements. The PMU data are collected

TABLE I
POWER DELIVERY AUTOMATION APPLICATIONS AND ASSOCIATED COMMUNICATIONS PERFORMANCE REQUIREMENTS

Application Area	Latency Requirement	Bandwidth Requirement	Distance	Availability Requirement
Traditional restoration	Seconds	Low: occasional commands	~10 miles	Medium: control needed in seconds
High-speed restoration	~50 to 100 milliseconds	Low: occasional commands	~10 miles	High: high-speed control action required
Faulted circuit indicators	Seconds	Low: small, infrequent messages	~2 miles	Low to medium: may lose data; data can be retransmitted
Supervisory control and data acquisition (SCADA) communications	Seconds	Medium: steady operational data; occasional large file transfers	Wide variation	Medium to high: need reliable data access; transport protocol retransmits lost data
Feeder-level load shedding	Seconds	Low: occasional small messages	~2 miles	Medium: control needed in seconds; retransmit if data lost
Teleprotection	4 to 60 milliseconds	Low: small packets with time determinism	~20 miles	High: high-speed control action required
Distributed generation island detection	20 milliseconds to <2 seconds (IEEE 1547)	Low to medium: small packets for transfer trip (TT) signal; more bandwidth needed for streaming PMU data	~10 miles	High: high-speed control action required
Voltage control	Seconds to minutes	Low: infrequent control commands and voltage telemetry updates	~10 miles	Medium: control needed in seconds or minutes; retransmit data if lost
Meter reading	Minutes to hours	Low: infrequent messages	Varies	Low: data resent in next transmission
Remote personnel access	Seconds	Medium: command interaction and large file transfers	~10 miles	Low to medium: can tolerate dropouts
Local personnel access	Seconds	Medium: command interaction and large file transfers	5 to 300 feet	Low to medium: can tolerate dropouts
Synchrophasor data	<400 milliseconds	Medium to high: continuous streaming of PMU data; depends on amount of data sent	~10 miles	Medium to high: data lost when there are dropouts in radio communications; when used for control, high availability required

at preestablished physical points of interest along a radial distribution feeder and sent to a PV site. There, the data are leveraged for optimizing system output to benefit the broader electrical circuit (primarily voltage stability, reductions in electromechanical switching cycles, and overall system efficiency). The PMU data allow for the total output of the PV plant to match system needs (both local and remote from the point of interconnection) to demonstrate the advantages of a system approach to distributed PV installations. Leveraging the remote PMU data for control of the plant output has a number of unique advantages, each of which is being measured and prioritized from the points of view of PGE and their customers. In addition to being leveraged for control, the PMU data provide a live response curve of the feeder performance to a host of smart inverter functions. These functions are being tested to show the advantages of power electronics-based distributed generation as part of the SEGIS-AC program award. The PMU data and corresponding Global Positioning System (GPS) time stamps allow the analyzing of upstream impacts of VAR and watt generation as well as cycle count reductions or additions caused or alleviated by installing the PV facility.

One of the first phases of the project was to install five IEEE C37.118 PMUs along a rural feeder (as can be seen in Fig. 1) to provide high-resolution parametric measurements of system frequency, voltage phasors, and current phasors. These data are being leveraged to build and validate a system model for the feeder as well as provide detailed measurements for gauging the success of the project, essentially providing a live test bed. A previous DOE SEGIS project successfully demonstrated the use of synchrophasor measurements for an anti-islanding protection scheme for a distributed generation site [3].

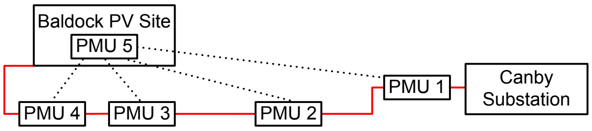

Fig. 1. The rural feeder with PMUs communicating with the Baldock PV site using serial radios and cellular modems (distance to closest PMU is 0.68 miles; distance to farthest PMU is 1.96 miles).

B. *Using Synchrophasor Data*

The overall system (shown in Fig. 2) includes four PMUs spread out along a rural feeder. Both a serial radio and a cellular modem are located at each PMU along the feeder, each transmitting data back to a PDC located at the PV site. There is also a fifth PMU located at the PV site that is sending data via serial and Ethernet cables to the PDC. Data from all five PMUs are concentrated and sent via fiber Ethernet back to the PGE control center, where the measured data are analyzed.

Using synchrophasor measurement data provides several benefits for the project. Synchrophasor measurements can be made as fast as 50 to 60 times per second, depending on the system frequency. Additionally, measurements made by each PMU are time-synchronized down to 1 microsecond, thus providing streaming snapshots of the feeder, which are useful for determining intermittent or transient behavior on the feeder. Traditional SCADA measurements cannot be used because they are much slower, providing measurements every few seconds, and are not time-synchronized, further masking the actual voltage response. One additional noteworthy benefit of sending data via the IEEE C37.118 standard is that a user can configure a PMU to only send as much data as the communications channel will allow [4]. This is important because the serial radios used in this project are limited to a maximum data rate of 38.4 kbps.

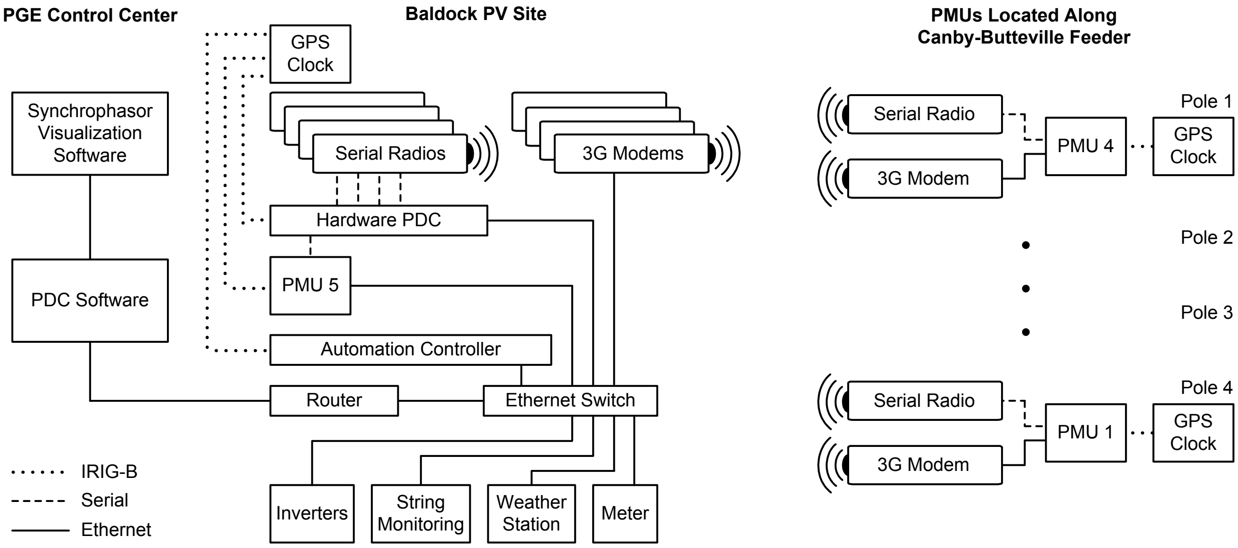

Fig. 2. Communications system diagram.

For this project, 900 MHz unlicensed serial radios and 3G cellular modems were used to simultaneously send synchrophasor data from each PMU. Looking through the various comparison parameters of these two devices, shown in Table II, provides a good summary of their similarities and differences. Note that the performance of each of these devices is manufacturer-specific and that the user must evaluate devices based on the application requirements. The serial radio sends IEEE C37.118 data from the serial port, and the cellular modem sends IEEE C37.118 data from the Ethernet port of the PMU. Both devices streaming time-stamped data allows for a direct comparison of the performance of the devices in several areas.

C. *Comparing Wireless Technologies*

The two wireless technologies used for this project are very different, and as such, each technology has unique capabilities, advantages, and disadvantages, depending on the application it is being used in. PGE required redundant communications for the project in addition to diversity in the types of communications used. The serial radio is designed for use in time-critical protection schemes and thus has several features and capabilities that allow it to fill this role. Some of the more relevant features and capabilities include the following:

- Pseudorandom frequency hopping with user zone selection to avoid interference and provide secure communications.
- Optional 256-bit AES encryption of payload data.
- Continuous wireless performance monitoring using signal strength and channel availability.
- Low-latency serial communications with support for utility protocols (e.g., DNP3, Modbus®, MIRRORED BITS® communications, and IEEE C37.118).
- Reliable communications for up to a 20-mile line-of-sight range.
- Built-in alarm contacts that indicate a diagnostic or power failure.
- Proprietary radio-to-radio communications that allow for collocation of several radios.

The 3G cellular modem is designed for general purpose machine-to-machine communications and thus has a feature set and capabilities that address general purpose data transport applications. Some of the more relevant features and capabilities include the following:

- 10/100BASE-T Ethernet and EIA-232 communications ports.
- Comprehensive Ethernet gateway settings (e.g., security settings, VPN, firewall, and Internet Protocol [IP] configuration).
- Support for many machine protocols, including Modbus.
- Several management services that allow the modem to integrate with a large variety of applications (e.g., shipping, surveillance, and digital sign information updates). These services include the following:
  - Short Message Service (SMS).
  - Simple Mail Transfer Protocol (SMTP).
  - Simple Network Management Protocol (SNMP).
  - Multiprotocol serial communications interface (MSCI).

IV. WIRELESS SYSTEM PLANNING AND IMPLEMENTATION

In any wireless system, up-front planning is required to ensure that a reliable communications link can be established between the devices. This typically involves conducting a path study as the first step in determining if the communications link is feasible. Path study software uses the GPS coordinates for the radio locations, terrain data, and known physical structures to determine the path feasibility and estimated reliability between points. It should be noted

TABLE II
COMPARING THE SERIAL RADIO AND THE 3G CELLULAR MODEM

Comparison Parameters	Serial Radio	Cellular Modem
Target application	Teleprotection, distribution automation, and point-to-point or point-to-multipoint communications	General purpose machine-to-machine data communications using the cellular network
Frequency	902–928 MHz (industrial, scientific, and medical [ISM] band)	800/1900 MHz for 3G 1xEV DO Rev A (cellular frequency bands)
Wireless technology	FM (GFSK) frequency hopping	3G 1xEV DO Rev A CDMA/TDM 16QAM with fallback to 2G CDMA 1X
Radio data rate	38.4 kbps (Serial Port 1) + 19.2 kbps (Serial Port 3); bidirectional	3G 1xEV DO Rev A downlink/uplink: 3.1/1.8 Mbps
Data encryption	256-bit Advanced Encryption Standard (AES) available	Internet Protocol Security (IPsec) virtual private network (VPN)
Size	19 x 6.3 x 1.75 inches	5.6 x 3 x 1.5 inches
Operating temperature	–40° to +85°C	–30° to +70°C
Initial equipment cost	$1,500 per device	$750 per device
Monthly cost	NA	$59 per device

that, as with any simulation software, it is important for the user to properly configure the software and know what it is using for various parameters (like terrain classification and granularity of the obstructions), as well as how recently the site data were updated.

In addition to a path study, a site survey should be conducted to verify the terrain and obstructions as well as allow for any adjustments that may be needed in radio and antenna placement. A path study may show that the signal propagation is adequate, but unexpected details discovered as part of a site survey can have a significant impact on the availability of the wireless link. Some examples of unexpected details include traffic moving through the signal propagation path, sources of RFI, or inability to locate the antenna where desired. To ensure the best results, the site survey should include setting up temporary radios at the desired locations and involve some spectrum measurements to ensure that there are no sources of interference.

Both path study simulations and site surveys were performed for each set of serial radios to ensure that each radio link would provide the needed signal propagation. The path study graph between the radio located at Pole 4 and the radio located at the Baldock PV site is shown in Fig. 3. Some adjustments were made to the original path study to reflect actual pole locations and changes in antenna height due to overhead power lines, causing minor changes in the simulated results.

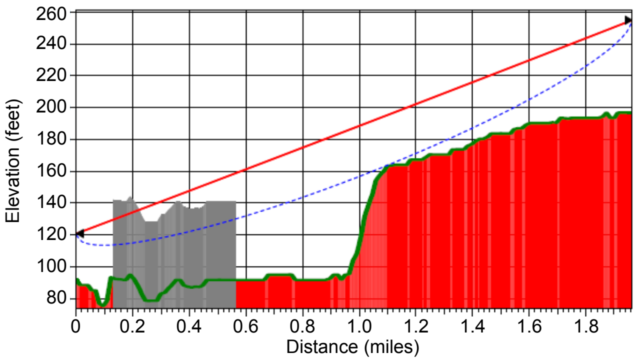

Fig. 3. Path study from radio located at Pole 4 (PMU 1) to the Baldock PV site.

One other challenge with this installation was having four radios all collocated at the Baldock PV site. Whenever radios are collocated, they can interfere with each other, significantly reducing the availability of the wireless link. The serial radios in this application are designed to operate when collocated and include a transmit/receive (TX/RX) synchronization capability. The TX/RX synchronization allows all of the collocated radios to transmit and receive at the same time so that one radio is not transmitting at full power while the next radio is trying to receive a distant signal. The initial installation was done without TX/RX synchronization enabled, and significant data dropouts were observed for the two radios located farthest from the Baldock PV site. This meant that the closer radios were frequently interfering with or overpowering the more distant radios. Once the TX/RX synchronization was enabled, a significant improvement was seen in the link availability and the received data quality.

The serial radios also allow the user to restrict frequency zones. Each radio uses 50 different hop frequencies across a band that has 80 available frequencies. For this application, using four radios and configuring the radios with an offset skip frequency zone provided approximately a 5 percent reduction in interference between the radios. Another technique to minimize interference between collocated radios is to use vertical and horizontal polarization on the antennas. Configuring the collocated antennas using both vertical and horizontal polarization on adjacent antennas provides an additional 20 dB of separation, further reducing the interference between them. This installation of four radios used both of these techniques to minimize collocated radio interference and improve availability of the channel between the radios.

Up-front planning for the cellular modems did not include a path study, but did include a site survey and verification of cellular signal strength. For this installation, received signal strength was measured by a cell phone at each of the proposed locations and found to be adequate.

V. PRACTICAL EXPERIENCE SETTING UP THE RADIOS AND MODEMS

Setting up both the serial radios and the cellular modems was straightforward. However, it was important to have training on the serial radios to understand the various features and capabilities supported in them. The training helped the PGE engineers and technicians become comfortable configuring and using the devices as well as tuning them for optimal performance. Performing a path study and a site survey up front provided valuable information about pole locations and antenna heights, making the installation go smoothly and without requiring significant changes.

The cellular modems use a web-based user interface that made configuration of the devices quite simple. Because the modems use Ethernet transport protocol, it was important to get the information technology (IT) support teams involved early for addressing both networking and security aspects. In this application, the VPN tunneling that was available in the modems was used for additional security.

VI. COMPARISON OF WIRELESS OPERATIONAL PERFORMANCE (FIELD TESTING)

Both wireless communications systems streaming data from common PMUs and sending time-stamped measurement data 30 times per second provided a good means to compare the 900 MHz serial radios with the cellular modems using

3G 1xEV DO Rev A. Data were streamed to the PDC at the Baldock PV site, which was configured with a 1-second waiting period for all incoming data streams. A 1-second waiting period means that only data that arrive at the PDC within 1 second are concentrated and thus considered good data. The 1 second is measured from the time that the first data with a given time stamp arrive. In addition to concentrating the PMU data, the PDC made latency measurements to compare the time when the PMU data were time-stamped with the time that the PDC received the time-stamped measurements. Thus, the latency measurement includes all latency times from the point of measurement to the time the latency measurement is processed in the PDC. This latency time includes the PMU processing time, the serial (or Ethernet) communications time, the transmit radio (or cellular modem) processing time, the wireless transit time, the receive radio processing time, the serial (or Ethernet) communications time, and the PDC processing time. The cellular modem time includes sending the data to the cellular base station and going through the cellular network before being transmitted to the receiving modem. PMU 5 was located at the Baldock PV site and only used wired communications (both serial and Ethernet) to the PDC, thus providing a baseline for comparing the latency due to using the radios or modems.

Based on the average latency of the received data, it appears that both devices could be used for streaming synchrophasor data, with the serial radios providing significantly lower latency than the cellular modems. The wireless portion of the latency can be calculated by subtracting out the wired communications times measured from using PMU 5 (serial radio latency: 168 milliseconds – 112 milliseconds = 56 milliseconds; cellular modem latency: 351 milliseconds – 109 milliseconds = 242 milliseconds). Table III provides a summary of the latency of the serial radios, the cellular modems, and the wired connections as measured by the PDC.

However, another critical aspect of the wireless communications was reliably getting the data to the PDC in less than the 1-second waiting period. All of the serial radios consistently provided reliable delivery of PMU data, while all of the cellular modems had dropouts in the PMU data being delivered within the set waiting period. Fig. 4 shows PMU data from both the serial radios and the cellular modems.

The lower portion of the plot shows PMU positive-sequence voltage magnitude data delivered by the serial radios. Each color represents a different PMU along the feeder. Note the drop in voltage the farther the PMUs are located from the substation. In the middle portion of the plot, it is easy to see several dropouts of the same data delivered by the cellular modems. In this 5-minute plot, three of the cellular modems show that data have been dropped. Most of the dropouts were about 0.5 seconds long, with one dropout lasting for about 30 seconds. After reestablishing the

Fig. 4. PMU voltage magnitude V1 data plotted using serial radios (bottom) and cellular modems (middle) and the latency of each (top) over time.

TABLE III
COMMUNICATIONS AND PROCESSING LATENCY TIMES FROM PMU TO PDC USING SERIAL RADIOS, CELLULAR MODEMS, AND WIRED CONNECTIONS

Communications	Link	Average Latency (ms)
Serial radios	Radio 1 to Radio 5 (PMU 1)	168
	Radio 2 to Radio 6 (PMU 2)	167
	Radio 3 to Radio 7 (PMU 3)	169
	Radio 4 to Radio 8 (PMU 4)	167
Cellular modems	Modem 1 to Modem 5 (PMU 1 secondary)	334
	Modem 2 to Modem 6 (PMU 2 secondary)	351
	Modem 3 to Modem 7 (PMU 3 secondary)	353
	Modem 4 to Modem 8 (PMU 4 secondary)	353
Wired connection to PDC	PMU 5 (serial)	112
	PMU 5 secondary (Ethernet)	109

TABLE IV
SERIAL RADIO REPORTED VALUES VERSUS PATH STUDY ESTIMATES (RX SENSITIVITY SPECIFICATION OF –97 DBM)

Serial Radios at Baldock PV Site	Radio Reported Values		Path Study Estimates	
	RSSI (dBm)	Availability (%)	RSSI (dBm)	Availability (%)
Radio 1 communicating with Radio 5 (1.96 miles away)	–80	98.87	–81.01	99.99
Radio 2 communicating with Radio 6 (1.90 miles away)	–77	97.13	–61.41	99.99
Radio 3 communicating with Radio 7 (0.68 miles away)	–65	99.99	–50.46	99.99
Radio 4 communicating with Radio 8 (0.68 miles away)	–51	100	–50.44	99.99

wireless link, the latency of the data being sent through the cellular modem jumped up to 1.9 seconds and eventually returned to about 350 milliseconds, as can be seen in the upper portion of the plot. The cellular modems were sending data via TCP/IP; thus the transport protocol was able to recognize that data were not being acknowledged by the receiving end and was able to resend some of the lost data at a higher rate and eventually catch up. While the average latency of the cellular modems was about 350 milliseconds, it was observed that the latency varied over time, sometimes becoming as large as several seconds. In addition, while the cellular modems delivered data most of the time, they consistently lost data as well.

It should be noted that the latency of the serial radios remained very consistent over the week that the data were captured. Furthermore, the serial radios never dropped data, even though the radio reported availability was less than 100 percent. The radios include a feature that, if enabled, retransmits the data if an error is detected. Because the actual data rate being sent was 17.4 kbps, the radios were able to resend data when interference caused some data loss, providing a robust and reliable wireless link.

Information available from the radios and modems themselves also provides some additional insight. Note that the serial radios report received signal strength indicators (RSSIs) and availability (as can be seen in Table IV) and that both indicate good signal strength relative to their specified receive sensitivity of –97 dBm and very good availability, allowing the radios to reliably deliver PMU data. As can be seen from Table V, two of the cellular modems show marginal signal strength relative to their specified receive sensitivity of –104 dBm and warrant additional investigation to determine if it is an antenna or receiver issue. The modem at the Baldock PV site is suspect because the other modems that are collocated show a much higher signal strength, leading the authors to believe that it is likely an antenna or cabling problem. The lower signal strength might also explain why data were dropped by that modem.

TABLE V
CELLULAR MODEM REPORTED RSSIS AND CALCULATED AVAILABILITY
(RX SENSITIVITY SPECIFICATION OF –104 DBM)

Reported RSSI at Baldock PV Site (dBm)	Reported RSSI at PMU Sites (dBm)	Calculated Availability Based on PMU Data (%)
–64	–95 (PMU 1)	99.60
–64	–58 (PMU 2)	99.78
–96	–73 (PMU 3)	99.24
–68	–62 (PMU 4)	98.30

VII. RECOMMENDED APPLICATIONS FOR 900 MHZ RADIOS AND 3G CELLULAR MODEMS

Based on the performance of these two different wireless devices, each has unique strengths that can be leveraged as part of a smarter grid that uses communications to make more intelligent decisions. Furthermore, synchrophasor-based systems are being used to improve operation and efficiency, even at the distribution level [5]. For applications that require deterministic, low-latency, and highly available communications, the serial radios are an excellent choice. For applications that require higher data bandwidth and can handle lower link availability, the cellular modems may be a good choice. The cellular industry has demonstrated 3G cellular systems delivering greater than 1 Mbps data rates and 4G cellular systems delivering greater than 10 Mbps data rates, providing outstanding wireless data transfer speeds. Table I provides some of the criteria that should be considered when selecting a wireless system. Additionally, while this project uses serial radios and cellular modems, there are many other wireless systems that should be considered.

VIII. CONCLUSION

Wireless communications can be used as a cost-effective and reliable alternative to wired communications for teleprotection, power delivery automation, monitoring, and control applications. It is critical to choose a wireless technology that meets the specific requirements for the end application because the performance of the various systems and technologies can vary greatly. As demonstrated in this paper, a wireless system that is optimized for data throughput may not be well suited for applications that require low latency—such as teleprotection and control applications. Additionally, understanding how to properly configure and optimize the wireless system is paramount to achieving and maintaining a reliable, high-fidelity, robust communications system. While path studies provide an initial indication of system performance, completing a site survey that includes all relevant spectrum measurements and testing antennas and radios at the proposed locations can greatly improve the assurance that the system will operate as expected, avoiding costly communications problems later in the project. Similarly, if cellular is selected as the wireless system, it is important to verify the service type available in addition to the actual signal strength at the specific locations in which the cellular modems will be used.

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X. BIOGRAPHIES

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Robert Ferraro is a Project Engineer for Portland General Electric (PGE). He was the Engineering Project Manager for PGE's 1.75 MW Baldock Solar Station. He has also led PGE's efforts with SEGIS Phase 3 and SEGIS-AC projects. Robert has Bachelor of Science degrees in Mechanical Engineering from Purdue University and Renewable Energy Engineering from Oregon Tech. He is also earning a Master's of Science in Electrical Engineering from Portland State University, specializing in electrical power. Robert is currently focused on transmission and distribution synchrophasor-based system integration and new project planning.

Chris Steeprow is the Project Manager for Portland General Electric's (PGE's) Customer Specialized programs that include PGE's owned and operated solar installations and PGE's customer-owned dispatchable generation program. Chris has over 20 years of IT infrastructure and system experience as well as 15 years of control systems design and implementation experience. He has worked for PGE for the last 13 years and has been involved in all of the PGE SEGIS efforts to date.

Michael Mills-Price is the technology development lead for the solar energy business unit at Advanced Energy Industries, Inc. Michael is the principal designer responsible for bringing new technologies to market and continues to lead teams toward advanced systems control to broaden the scope and lessen the impacts associated with widespread photovoltaic adoption. Michael received his Bachelor of Science and Masters of Science in Electrical Engineering from Oregon State University (OSU), is a registered professional engineer, and is an active member of IEEE. Michael is also an adjunct professor at OSU, teaching senior level energy storage and energy distribution systems courses.

JW Knapek received a B.E.E.E. from Vanderbilt University in 2007. JW went to work for a consulting company in Nashville, Tennessee, where he focused on substation and control system design. In 2012, he earned his P.E. for the state of Tennessee and joined Schweitzer Engineering Laboratories, Inc. (SEL). As an application engineer in automation, JW assists customers with integration and communications needs using SEL products.

Previously presented at the 2016 IEEE Rural Electric
Power Conference, Westminster, CO, May 2016.

20151207 • TP6640