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Geomagnetic Disturbances and their Mitigation

by David Hilt & Donald Morrow

Large Solar Magnetic Disturbances (SMDs) and their earthly effects, called Geomagnetic Disturbances (GMDs) can severely impact – even destroy – electrical systems. The largest and most notable GMD in modern history occurred in September, 1859. The aurora from this event produced red glows visible from within 23 degrees of the equator (Hawaii and Santiago) in both the Northern and Southern Hemispheres. During that event, electrical arcing caused fires within telegraph wires, significantly interrupting communications worldwide.

More recently, two very large SMD events have been recorded. The largest ever recorded occurred November 4, 2003. The second largest occurred April 2, 2000. Both occurred in locations on the sun's surface such that they did not hit the Earth directly with solar discharge. As a result, the GMD was negligible compared to the flare. Although these two recent events are the largest recorded SMDs, the direct trajectory of the SMD discharges toward Earth leaves the GMD impact from the 1859 event as the largest ever experienced in the modern era.

Solar magnetic activity occurs in cycles, typically every 11 years. While there will be a period of low activity, another cycle will occur. Currently, we are in Cycle 24, which some scientists estimate may be the most active yet, and expect to peak in 2012 or 2013.

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Voltage Stability Assessment Using Synchrophasor Measurements

by Muhidin (Dino) Lelic, Mevludin Glavic, Armando Salazar, & Frank Habibi-Ashrafi

In an effort to ensure secure operation of a power system, including addressing voltage stability and Fault Induced Delayed Voltage Recovery (FIDVR), voltage management has become an area of increased complexity and focus. Advanced voltage stability monitoring and instability detection schemes include two basic elements: collection of measurement data from Phasor Measurement Units (PMUs) or . . .

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Letter from the President

Quality, Stability, Depth, Breadth, Accessibility

Dear Colleagues,

As 2011 has come to an end, the depth and breadth of projects and initiatives we are working on across the globe finds us anticipating this new year with enthusiasm. As part of an industry that is revitalizing and reinventing itself for the 21st century, we are working with many of you on interesting, important, and intriguing projects and ideas. And although our team includes some of the most experienced in the industry, we are still learning and growing and innovating too – and we're having fun doing it!

These are just some of the reasons we are excited about 2012 – and beyond! Now in our sixth year of operations, we're more accessible than ever with offices in Raleigh, Boston, Chicago, Oakland, Toronto, and Rotterdam in the Netherlands. What's more, our team has been working in Macau, Taiwan, Chile, the Netherlands, India, Japan, Croatia, Bermuda, Switzerland, and of course, throughout North America and Europe.

As our industry continues to transform itself on a global scale, we are excited to partner with you – helping to accelerate important leading-edge enterprises in any number of areas. It doesn't matter where you are or what you do. We speak your language, know your needs, and we're accessible. We come from nineteen countries and a wide variety of backgrounds, including utilities, equipment manufacturers, system suppliers, R&D, teaching, testing labs, government and regulatory, and consulting. Yet for all that diversity – in fact, we think partly because of it – we enter 2012 as a solid, cohesive, and deep organization, with bright young engineers right out of college working alongside many of our industry's most experienced and recognized experts and leaders. Quanta Technology has grown to become the quality organization we envisioned, with the technical breadth to handle anything in the power T&D field, the adaptability to take on projects of any size, and a culture and team atmosphere of efficiency that make it a fun, exciting place to work.

Perhaps nothing exemplifies the quality of our work and its depth and breadth more than the variety of projects and work we report on in this newsletter:

- *Geomagnetic Disturbances and their Mitigation*, by Dave Hilt and Don Morrow, addresses a topic that is at once dramatic, important on a national and societal scale, and quite fascinating from a technical standpoint.
- *Voltage Stability Assessment Using Synchrophasor Measurements*, by our Dino Lelic and M. Glavic, and SCE's A. Salazar and F. Habibi-Ashrafi, discusses leading-edge ways to detect voltage instability in power systems to initiate control and protection actions that can prevent outages and system blackouts.
- *Energy Storage Systems for Renewable Energy and Utility Applications*, *by Farid Katiraei and Carl* Wilkins, highlights one of the major changes we expect on the future power system – energy storage used to convert "non-dispatchable" renewable energy into dispatchable power.
- *The Smart Grid Value Proposition: A Research Paper for the GridWise Alliance Implementation Work Group*, by Edwin Liu and Guorui Zhang summarizes work we did with the GridWise Alliance to determine the what, when, where, why, and how of Smart Grid benefits. What does Smart Grid do? It turns out it does a lot, but like anything big, it's complex and has to be planned and managed well.
- *Synchrophasor Measurements in Electric Power Distribution Systems*, examines how and why synchrophasor technology applications will make their way into the distribution system, and what benefits they will bring. Julio Romero-Aguero, David Elizondo, and Dino Lelic discuss the benefits and challenges this will have.

When you also consider our support of NIST and IEEE in standards development, participation in professional groups and industry conferences, the publications and books we've recently released, and the new projects we're beginning work on, we know 2012 is going to be a great year for all of us.

As always, if you have ideas or suggestions about how we could work for you, or improve what we are doing for you and our industry, don't hesitate to call or write.

Sincerely,

Damir Novosel and the Quanta Technology Team

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The QT e-News newsletter is published 4 times per year, in both electronic and printed form, and in special editions for important industry events. If you would like to receive your copy, please contact: John Wasilak at (919-334-3058) or at jwasilak@quanta-technology.com

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Geomagnetic Disturbances *Cont. from page 1 . . .*

GMDs can be problematic to power grids

GMDs can cause problems with communications, satellites, global positioning systems, and the power grid. The first recorded effects from GMDs on the electric power grid were from the March 24, 1940 solar event. Others occurred on August 17, 1959, August 4, 1972, and March 13, 1989. While the March 13, 1989 solar flare was smaller, it was a direct hit for Earth, resulting in an unusually catastrophic GMD that severely impacted the Quebec power grid. Within 92 seconds the grid completely collapsed, leaving six million customers without power. This same storm triggered hundreds of incidents across the United States, including the destruction of a major transformer at an East Coast nuclear generating station. This event demonstrated the susceptibility of North America's bulk power system to severe GMDs. Following the 1989 GMD and resulting Quebec outages, utilities reviewed their susceptibility to similar events, subsequently brainstorming and implementing numerous recommendations. Key among them was the recommendation for an early warning system for grid operators.

Technically sound research has been performed to understand the physics involved with GMDs and associated Geomagnetic Induced Currents. As a result, the physical aspects of GMDs are now well understood. Further, a number of research reports have been written, which describe the basis of developing models to analyze potential impacts on a given electrical system. Mitigation measures have been identified and implemented by utilities that historically have experienced these events. Certain regions of the U.S. have identified and adopted operating practices to address GMD events when such an event is forecasted to occur.

However, the drive of adopting mitigation measures and creating regional practices has been based primarily on the geographic scale experienced during the 1989 Quebec event. It is important to remember that the 1989 Quebec event was significantly smaller in scale than the 1859 GMD event and other SMD events, which did not hit the Earth directly. Moreover, it is not clear that mitigation measures have been adopted beyond certain regions, which have historically experienced these events (e.g., the Northeast and Upper Midwest). Also, not all regions have developed guidelines and/or operating practices. More critically, no system-wide approach to address the impacts of large-scale SMDs and resultant GMDs has been studied or implemented in North America. As a result, the North American electric system may still be exposed to extensive disruptions from a large-scale SMD event that would constitute a direct hit for the Earth.

How to prepare

In 2009, NERC issued an Executive Briefing, which suggested that, in addition to hardening system components (which if done by transmission system owners in isolation can result in undesirable consequences to the overall interconnection) operators could separate the present interconnected systems (particularly the Eastern Interconnection) into several non-synchronous connected sub-regions or electrical islands. This idea was premised on the knowledge that an impending SMD allows at least several hours to defensively posture the bulk power system for such an event. To effectively identify appropriate separation points, studies will need to be completed in advance of an SMD event and operational plans established. To be effective, system studies will need to be completed with sufficient regional and multi-regional scale to effectively model the effects of GMD events induced by the large scale SMDs, such as those of 1859, 2001, and 2003. Such a study will need to take into account the effects of hardening measures already implemented to understand and identify the logical separation points.

For industry participants, a study of this nature would better highlight the extent of the geographic exposure and, as a result, help these entities better coordinate with their neighbors. It would also provide meaningful insights for inter-regional coordination for additional analysis, standards, and mitigation strategies.

To be effective, such an assessment of GMD impacts should be, at a minimum, of sufficient scope to address the 2001 and 2003 SMDs, assuming a direct alignment of the event toward the Earth. For a worst case assessment, the analysis should also include the geographic area impacted by the 1859 event. An interconnection-wide study would also be prudent.

Once the geographic scope is understood, evaluation of the system can be performed to assess the possibility of separation to mitigate the GMD associated with each scenario. Actions such as the following can be tested:

- Evaluate transmission line options for openings. Start with the longest lines in geographic areas impacted.
- Evaluate load/generation scenarios to determine if islands can be formed without a need for load shedding.
- Identify alternative switching actions to create islands, given a typical warning time period (e.g., 24 hours).

All entities, regardless of size, should consider a review of their planning, engineering, and equipment standards in light of GMD exposure. A benchmark study would aid in understanding industry best practices, cataloging mitigation strategies, and determining where they have been deployed. Some of the methods used by utilities to limit and manage the effects of GMDs and the Geomagnetic Induced Currents include:

- Modification of protective relay settings
- Installation of neutral blocking and bypass devices for transformers
- Use of series capacitors

Here are some key preparations utilities can take to recover from an SMD event.

- Assure adequate communication assets dedicated or available to electrical system operators.
- Protect emergency power supplies and fuel delivery, and importantly, provide for their sustained use as part of the protection of critical loads.
- Review and identify black start generation units coupled with specific transmission that can be readily isolated to balancing loads.
- Improve, extend, and exercise recovery capabilities.

Bulk power system operators have been extremely fortunate in that significant GMDs have not occurred in recent years. However, as Solar Magnetic Activity progresses through its various cycles, preparing for and minimizing the inevitable impacts of GMDs with effective, low-cost operating approaches, makes sound economic sense.

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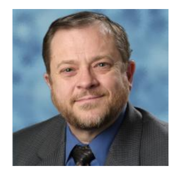

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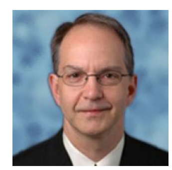


Voltage Stability Assessment *Cont. from page 1 . . .*

. . . Supervisory Control and Data Acquisition (SCADA), and preprocessing and computation of the proximity to voltage instability (voltage stability limit).

The voltage stability limit is closely related to the notion of maximum deliverable power that can be drawn by the system loads, while preserving a stable operation of the combined generation-transmission system. Voltage instability occurs when the combined generation-transmission system is unable to provide the power requested by the loads, which may happen due to system

Voltage Stability Assessment *Cont. from page 4 . . .*

outages and/or limitations of reactive power generation. Once this happens, it can further evolve into voltage collapse and cause system disruption.

FIDVR is a phenomenon wherein the system voltage remains at significantly reduced levels for several seconds (or tens of seconds) after a transmission, sub-transmission, or distribution fault has been cleared.

The Voltage Instability Prediction (VIP) method, described here is an enhancement of the concept developed in the late 1990s. This new methodology results in major improvements in accuracy, numerical stability, implementation variants, and ease of use. This methodology offers the following benefits. They:

- offer simple, real time, voltage instability margin detection that is model free
- are better than voltage-only methods and simpler than any other method
- are much faster than Energy Management System (EMS) contingency analysis
- are easy to interpret and combine with other methods and indices
- enable tracking for both slow changes and system dynamics using PMUs (10-120 frame/s) or other measurements

Our team has developed several implementation variants: bus, transmission line, transmission corridor, and, depending on the system needs, load center. Those variants show excellent results based on comprehensive, actual system tests using real-life PMU and SCADA measurements and off-line simulations.

The general VIP methodology is based on representation of the power system as a two-bus equivalent circuit, illustrated in Figure 1.

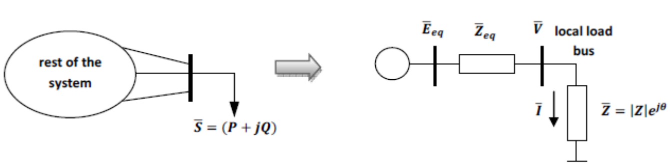


Figure 1. Two-bus equivalent circuit

The maximum deliverable power for such a system, under the given load power factor, is reached when the absolute values of the Thevenin and load impedance are equivalent, i.e.,($|Z| = |Z_{eq}|$).

The Thevenin and load impedance values are not constant, but vary slightly reflecting changes in the power system operating conditions. It is critical to identify and follow these changes as they occur in real time. This simple representation of the system parameters and their recursive estimation at the rate that the phasor data is measured enables a model-free approach in calculation of the stability margins in real time. The most interesting for control center operators are power margins (e.g., MVA, MW, and Mvar). A simple representation of these margins is the P-Q plane, shown in Figure 2. Two sets of margins are presented: *loading margins*, inherent to the concept of VIP, whereby the reactive loading margin, $\Delta Q_{loading}$, is of most interest. The active power loading margin is denoted as $\Delta P_{loading}$.

Another set of reactive power margins, *Q-margin*, represented as ΔQ is shown in Figure 2. It is related to the known concept of QV-analysis, but in this case, it is computed and tracked in real-time. The Q-margin is particularly suitable for FIDVR cases, since it provides the amount of reactive power that can be pulled out of the bus, corridor, line, cut-set, etc. This is exactly what happens in FIDVR cases when motors are pulling reactive power due to the drop on voltage magnitude.

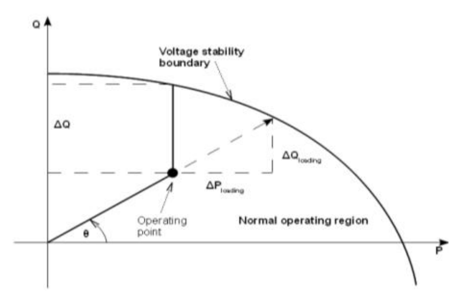
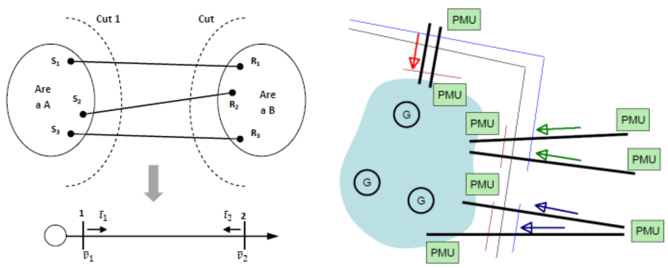


Figure 2. Voltage stability power margins in P-Q plane: loading ($\Delta Q_{loading}$) and Q-margin (ΔQ)

In addition to the classic VIP approach, in which power margins are monitored at individual system load buses, our improved method can be implemented on transmission corridors and load center topologies, shown in Figure 3-a and 3-b, respectively.



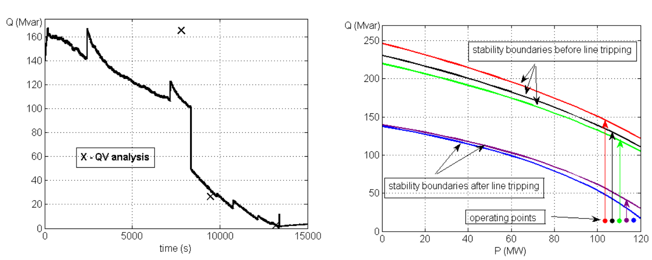
(a) Corridor **(b) Load Center**

Figure 3. Corridor and Load Center Concepts

To illustrate the performance of the newly developed real-time voltage stability monitoring, two cases are included in this article: unstable systems and FIDVR cases.

Unstable system

In this example, a load ramping occurs, followed by turning on shunt capacitors to improve the voltage profile. Both the generation-dominant area and load center are equipped with shunt capacitors, but it is not known which shunt capacitor is turned on, as its status change is recognized only by the jump of the Q-margin (Figure 4-a). Around the time instant of 8000(s), a line was tripped by a protection device in the generation-dominant area (at the sending end of the system), which resulted in a large drop of the Q-margin, as shown in Figure 5.



(a) Reactive Margin **(b) P-Q Curve Progression**

Figure 4. (a) Reactive margin; (b) Load and voltage stability boundary for five different time instants: red-2500 (s), black-7000 (s), green-7990 (s), purple-9400 (s), blue-13000 (s)

After the line tripped, the system deteriorated further with several additional shunt capacitors switching in an attempt to restore the system voltage. However, this was not sufficient to restore the voltage profile, and the system collapsed at the time instant of 13500 (s). Figure 4-b shows how the P-Q stability boundary evolved during this process and how the operating points (colored dots) were approaching this boundary.

FIDVR

A typical FIDVR followed by a transmission network fault in Southern California Edison (SCE) is illustrated in Figure 5 (substation Valley: 500 and 115 kV). Margins visualization in the P-Q plane presented (Figure 5-b) correspond to the station Valley, 115 kV side. Voltage stability boundaries and the loads are computed for two time instants: t=133 seconds, right after the disturbance occurred; t=158 seconds, when reactive power margin recovered to a high value. Note that the stability boundaries and the load visualized in this way provide indication of a dangerous situation approaching (reactive margin dropped below 200 Mvar, but the system preserved its stability).

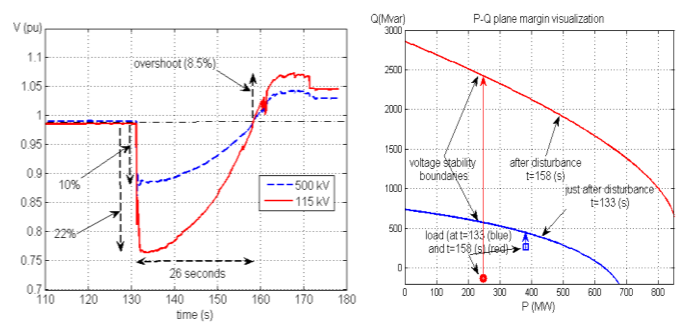


Figure 5. Discrimination of FIDVR case for SCE Valley station

Real-time voltage stability monitoring application

Following the successful initial testing of improved VIP method, the Quanta Technology and SCE teams began implementation of the real-time version of the method. A snapshot of the SCE Voltage Stability Monitor GUI for 500 kV Valley station is shown in Figure 6.

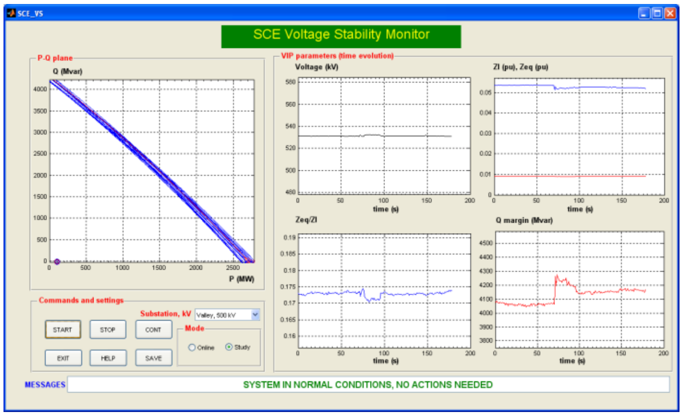


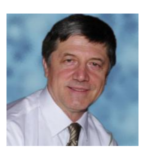
Figure 6. Voltage stability monitoring application GUI – study mode, for 500kV Valley station

Advantages of PMU-based VS monitoring

This method offers the following advantages:

- Simple real-time implementation and interpretation of results
- Timely detection of changes in the system and initiation of appropriate control action or contingency analysis
- Simple to implement in various hardware devices and control center software tools
- Ability to process data from different sources (PMUs, SCADA, simulation outputs – both static and dynamic
- Capability to discriminate between FIDVR and rapidly developing voltage instability

For further information,



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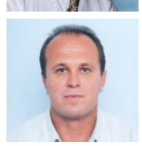

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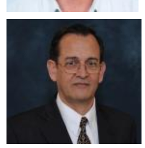

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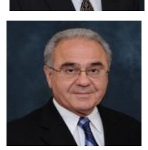

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Energy Storage Systems for Renewable Energy and Utility Applications

by Farid Katiraei & Carl Wilkins

As an emerging advanced technology, large-scale battery-based energy storage systems (BESSs) are introduced and recognized as a beneficial addition to future grids. Targeting a variety of grid supporting applications, implementation of an energy storage project involves many new technical and non-technical challenges that require detailed investigations by utilities prior to wide-scale utilization of the technology. Due to the limited knowledge of design requirements, field operation, and performance of these systems, several utilities in North America, with support of government funding, have initiated energy storage pilots and demonstration projects. The principal objective of these projects is to examine the technology, quantify the benefits and gain firsthand experience in design and operation of utility scale energy storage installations.

Centralized large energy storage facilities, such as pump hydro systems, have been in use for many years and have proven to be valuable resources. Pump hydro has served as emergency reserve units and/or ramp rate controllers, providing real-time power balancing between actual load demand and forecasted generation at high voltage transmission levels.

In recent years, the trend has changed toward utilizing distributed energy storage systems for distribution system applications, closer to the source of the problem where the grid is more vulnerable and/or power quality enhancement is needed. Many of the proposed storage applications are targeting better management of renewable energy resources (RES) and increasing the penetration level and/or size of RESs on distribution systems, while maintaining (or even improving upon) power quality.

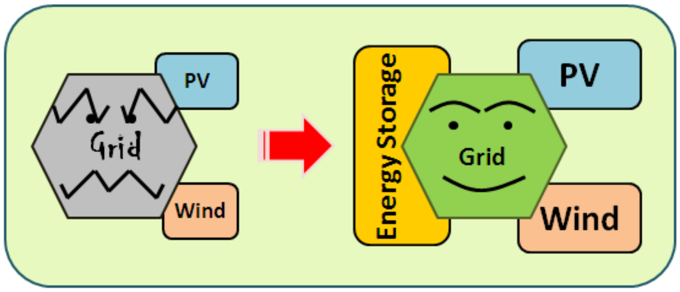

Figure 1. Energy storage in support of the grid

Two types of energy storage systems have become popular for medium- and low-voltage distribution system applications: battery energy storage and flywheel energy storage systems. Traditionally, the flywheel system has been recognized as an energy storage source for supplying large momentary power. High speed flywheels have been tested in several pilot projects for frequency regulation (e.g., PJM frequency regulation project) and power quality conditioning (e.g., a shock absorption device for weak systems). Similarly, conventional BESSs have been used for applications requiring large energy capacity for charge and discharge over several hours, as backup power supplies or peak-shavers. The new battery technologies (e.g., lithium ion) can effectively compete with a flywheel as short-term energy storage sources, providing fast-response charge and discharge. Moreover, many advanced battery technologies are currently offered in modular blocks (e.g., lithium ion, sodium sulfur, advanced lead acid, or flow batteries) that can be stacked and sized to achieve continuous and long-term grid supporting solutions with several hours of storage capacity.

BESS applications cover a variety of value-added benefits, making them an attractive investment for both utilities and customers (commercial entities and end users). BESSs are deployed in centralized or distributed platforms as:

- Large scale (MW size) BESS for supporting the grids
- Medium and small size BESS for community energy storage for reliability and power quality enhancement
- Small on-site storage for residential/commercial and hybrid (off-grid, microgrid) systems

Applications in support of renewable energy resources

Proliferation of large solar photovoltaic (PV) and wind generation facilities may drastically change distribution feeder voltage levels, power flow direction, and number (frequency) of operations of conventional voltage regulating devices (tap changers, switched shunt capacitors). In addition, the PV generation intermittency and large power fluctuations during cloudy days may affect the power quality of the grid, causing sudden voltage excursions and flickers due to significant rate-of-change of output power. Similar issues are identified and associated with variability of wind speed and rate-of-change of power output for wind farms connected to transmission systems. For example, deploying BESS on a feeder that has a large amount of solar PV generation (centralized or distributed PV) can be used to resolve the types of issues noted. BESS can counteract the effects of fluctuations by:

1. Limiting the rate-of-change of output power and voltage at point of common coupling (PCC). An unacceptable rate-of-change of voltage and possible flicker can be mitigated by smoothing the rate at which the PV plant power fluctuates when using BESS. The reactive power output of the BESS can be dynamically adjusted to compensate the undesirable voltage variations.
2. Maintaining the voltages within permissible ranges. The amount of power supplied by a PV plant determines the voltage at PCC. By regulating (limiting) the maximum PV output power, the voltage can be maintained in a given range. The

excess PV power is stored in BESS and gradually supplied back to the grid when the PV output power is lower than a threshold.

3. Limiting the maximum reverse power flow on a feeder. Large amounts of PV generation, especially during low load conditions of a feeder, may cause significant reverse power flow and impact on voltage regulator operations. Absorbing the balance of power (PV generation with respect to load and reverse power flow limit) can adjust (or completely eliminate) the reverse power flow and potential for back feeding to sub-transmission systems.

Typical arrangements of BESS on a distribution feeder are shown in Figure 2. BESS may be located at the substation or on downstream circuits, close to a PV plant. There may be several control approaches applied to a BESS (e.g., power dispatch, feeder relief, etc.). However, the primary objective is to smooth PV output fluctuations and limit the rate of change of PV output power at a certain level. In addition, the reactive power of the BESS can be controlled to further adjust PCC voltage and support the grid. When there is no generation by associated RESs, part of the BESS available capacity can be used to offer ancillary services, such as frequency regulation and spinning reserve. Although the ancillary service market is still in its infancy, a few major transmission system operators in North America have established and currently operate synchronized reserve and regulation markets at attractive prices, which can be provided by centralized or distributed BESSs with aggregate capacity of 1 MW or higher.

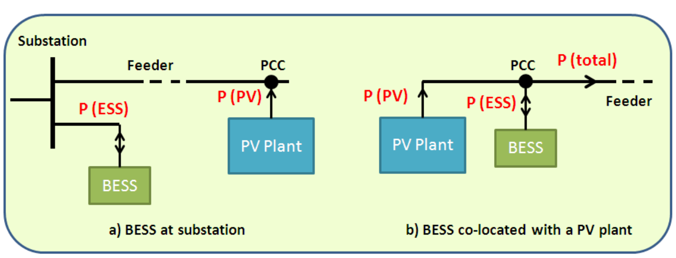

Figure 2. BESS arrangement on distribution feeders for RES smoothing and system support

Without a BESS, the PV plant size may be limited by the permissible range of voltage rise and/or by the maximum allowable rate-of-change for the PCC voltage before causing any power quality issue. By adding a properly sized BESS, and depending on the control strategy of a BESS, the PV plant capacity can be increased significantly without any adverse effect on the feeder.

Figure 3 shows the effect of applying a PV smoothing control strategy to the large power fluctuations of a PV plant on a hypothetical day. Quanta Technology developed the proposed control scheme for a BESS unit, which was co-located with a PV plant, as a mitigation method. The PV plant was installed close to the end of a feeder, causing voltage quality issues due to fast cloud alternations. Power averaging and rate-of-change control methods, as calculated over a pre-defined period (power averaging over 10 to 15 minutes), were used to determine the desired power output for each smoothing period. The BESS control measured changes in the PV plant output and adjusted the battery power injection and/or absorption level to mitigate fluctuations and maintain a pre-defined power per step. In order to track variations in the PV generation, the transition from one power level to another level is controlled by the BESS power compensation, based on the desired rate-of-change of power for the combination of PV plant and the energy storage, as well as system limits related to voltage levels and power flow.

By using high resolution historical PV generation data (one- to four-second resolution) the BESS operation for various days and patterns of PV fluctuations (actual field measurements) were analyzed to optimize the design and control parameters, such as minimum and maximum allowable battery state of charge (SOC), rate-of-change of power (ROC), and power thresholds. The study outcome was used to determine adequate battery size and control modes to achieve a cost-effective BESS solution.

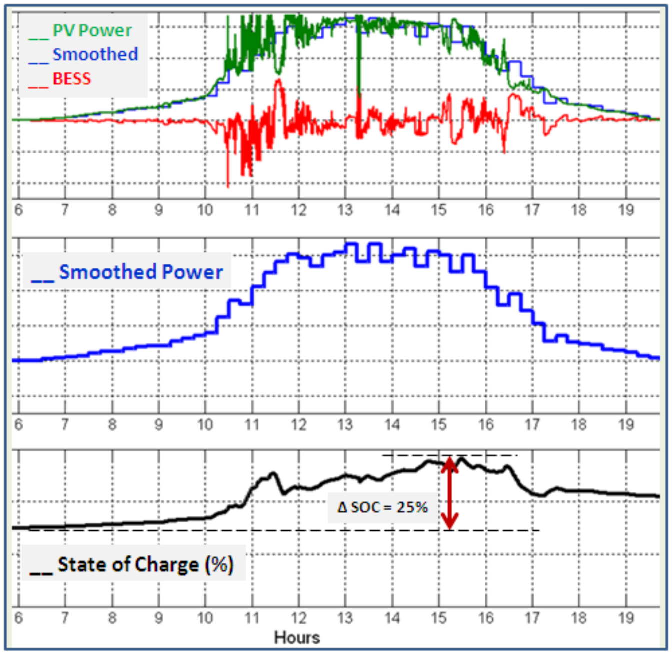

Figure 3. BESS application for smoothing out variations in the PV output power (hypothetical day)

Figure 4 offers yet another example showing the effect of combining a rate-of-change control and power limiting on the total power output delivered to the grid. The PV plant power output was measured and feedback provided to the BESS controller. BESS controller estimates the rate-of-change in real-time and determines contribution from the energy storage unit to limit the rate of variations for the total power injected into the grid. The difference between PV generation (P_PV) and the power actually injected into the grid (P_total) is supplied (if negative) or absorbed (if positive) by the BESS.

To maintain the voltage at PCC below a certain range (e.g., 1.05 pu) or limit the reverse power flow for high PV generation conditions, the BESS control strategy may include a secondary control scheme to enforce a limit on the total power output (example 2000 kW limit in Figure 4). BESS will absorb the difference between PV generation and the given maximum power generation threshold. The threshold is determined based on the maximum power injection to the grid before the voltage increases above the standard limit.

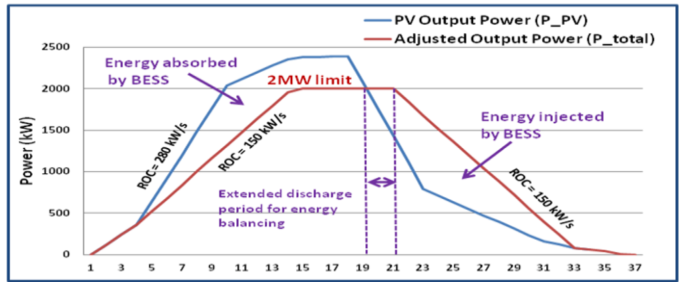

Figure 4. BESS control, based on the maximum power limiting and the rate of change

Analysis and testing of energy storage systems

BESSs in many respects are much more complex than their distributed generation (DG) counterpart. For one reason, BESSs are bi-directional power sources, which can supply or absorb both active and reactive power simultaneously (four-quadrant operation). BESS integration at distribution levels also uses hybrid controls incorporating two or more energy storage applications to achieve additional benefits and improve the revenue stream. The superior control capabilities (as required for BESS with respect to DG) add-to-the-design complexity and operational/supervisory control provisions. As an emerging technology, not only is there a need for detailed analysis and scrutinizing commissioning and system integration testing, BESS performance and system response to various operator (or automated) commands should be monitored and evaluated for an extended period of time after deployment to ensure proper design and suitable performance is achieved.

Another distinctive aspect of BESSs is lack of design standards or properly defined specifications to help guide manufacturers and utilities in the process of planning and assessment of BESS operation. Presently, each BESS project is unique in design and expected application. This aspect emphasizes the need for extensive tests and performance analysis prior to field deployment to ensure the BESS will operate as desired and respond to the control commands and system transients in a timely fashion.

Extensive BESS performance analysis and testing of real-world behavior should be applied from the early stage of the design, throughout the implementation and final integration. In the early design stage, use of off-line simulation and optimization tools are beneficial to assist with the proper selection of control schemes, based on the analysis and comparison of the base-case system operation, versus expected performances and targets for power quality enhancements. As the system implementation advances, closed-loop real-time simulation techniques (e.g., RTDS testing), and ultimately field testing, are needed to evaluate BESS interactions with the distribution grid, and subsequently fine-tune the controls.

Although many aspects of BESS interconnection with the utility grids are similar to those of integrating distributed generation systems, there are major distinctions that need to be examined and fully understood to develop a proper design for reliable and sound operation with the rest of the system. To name a few, the grid interface design, communication requirements, and protection methods for a BESS are the main areas of differences to enhance BESS tolerance to large transient events. As an example, a BESS may not necessarily operate at unity power factor or a fixed reactive power set point. In fact, the ability to supply a wide-range of reactive power (positive or negative) to support a dynamic voltage regulation scheme is one of the value-added features and promising benefits of BESS applications to advance distribution systems. Many BESS applications require active participation during system contingencies and/or the grid restoration process.

Service offering

In recent years, Quanta Technology experts have worked closely with several utilities and battery manufacturers in North America during the process of planning, design, sizing, implementation, and testing state-of-the-art large energy storage systems. As part of these projects, various simulation and optimization tools were developed to perform a comprehensive assessment of energy storage systems during the planning and design stage and/or after deployment in the field. Quanta Technology also provides advanced testing capabilities and unique application evaluation plans to examine the performance of energy storage systems during site testing and the integration process.

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GridWise Alliance Implementation Work Group

by Edwin Liu, David Boroughs, & Guorui Zhang

The GridWise Alliance (GWA) is a forum for expanding the sphere of stakeholders and engaging leaders of industry, government, and community. With its diverse and experienced membership, the GWA is in an ideal position to define and demonstrate the value proposition of Smart Grid projects and applications to important and highly influential stakeholders.

After a lengthy selection process, the GWA chose Quanta Technology to research and develop a whitepaper, which supports the Smart Grid value proposition. The Quanta Technology team was led by Dr. Edwin Liu, VP of Strategic Initiatives, with support from David Boroughs, Guorui Zhang, and other Quanta Technology experts. In an effort to foster and support prudent investments in energy, the paper is intended to help Smart Grid policymakers and regulators more clearly identify and understand the value proposition, which will sustain and accelerate the transformation needed to modernize the energy ecosystem. The scope of work for this project includes:

- Surveys and interviews with selected utilities, vendors, and regulators to gather case study data on successful implementation of Smart Grid projects and their impacts on consumers
- Discussions with the primary audience (regulators, policymakers) to understand their visions and expectations on qualitative and quantifiable value propositions for Smart Grid
- A comprehensive search and survey of available industry documents and literature in the public domain

Results from the research were jointly presented by GridWise Alliance and Quanta Technology at the GridWise Global Forum in November, 2011. Quanta Technology's final deliverable – a whitepaper – summarized research results, highlighting how the Smart Grid Value Proposition was supported, was completed and submitted in December, 2011. The final paper will be released by the GridWise Alliance in January, 2012.

Through interviews and industry documentation surveys, the Quanta Technology team reviewed and analyzed a number of Smart Grid strategies, roadmaps, deployment plans, experiences, lessons learned, costs and benefits. Five key value propositions for Smart Grid development and implementation were identified, including:

- Grid reliability and security
- Customer energy management opportunity
- Asset and resource optimization
- Health, safety, and environment
- Productivity and economic growth

Many case study examples that support these themes, as well as performance metrics that can be used to measure the success, were included in the paper. Both quantitative and qualitative value propositions were identified, which are being used successfully by utilities to demonstrate the benefits or priorities of grid modernization projects. Operational, regulatory, and commercial drivers were identified, which determine scope, allocation of resources, and priorities in the deployment and implementation of various Smart Grid technologies.

The Quanta Technology team concluded that expected or realized benefits are important to show to regulators as well as consumers. Success of the initial Smart Grid deployment projects will set the direction for further steps in developing the grid of the future. As was evident from case studies reviewed, many more potential benefits can be identified and realized as technology is deployed and experience gained. Most companies realize that customer acceptance of Smart Grid innovations is critical to the success of the current grid modernization attempt. To provide momentum for utilities to continue Smart Grid investment, regulatory support is required both policy-wise and financially. The key is to find the right balance in sharing costs, benefits, and risks.

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Thoughts and Considerations About Synchrophasor Measurements in Electric Power Distribution Systems

by Julio Romero-Agüero, David Elizondo & Muhidin (Dino) Lelic

Smart Grid Investment Grants (SGIG) offered at the transmission level by the U.S. Department of Energy (DOE), are focused primarily on synchrophasor technology based in Phasor Measurement Units (PMUs). These grants offer an ideal platform to initiate the paradigm shift from SCADA-based (Supervisory Control and Data Acquisition) real-time monitoring at a five to fifteen seconds updating rate to synchrophasor-based real-time monitoring at a 30-120 samples per second updating rate. Current projects in the U.S. are marking the initial state of a transition for synchrophasor applications toward its integration to the Energy Management System (EMS) at the control center.

In addition to the considerable efforts to apply synchrophasor technology in transmission systems, application of this technology in distribution systems has emerged. This article highlights a number of potential applications of synchrophasor measurements, which could prove to be valuable to distribution systems.

The last decade has witnessed growing interest and research in the implementation of wide area monitoring with PMUs at the distribution system level. This has been prompted by an ongoing and rapid evolution of the distribution system from passive to active networks. Specifically, the proliferation of intermittent distributed generation (DG) and an increasing demand for premium power quality has driven research in potential applications of PMUs for monitoring distribution systems, including distribution state estimation, Distributed Energy Resource (DER) integration (islanding), voltage stability, post-mortem analysis, harmonic and voltage sag analysis, and fault location. This growing interest has been prompted not only by the formidable measurement accuracy of PMUs, but also by the expectation that large scale deployment of these devices becomes economically feasible at some point, which is what happened, for instance, to microprocessor-based relays,.

Among the most noticeable impacts of the growing penetration of intermittent DG in the distribution system (photovoltaic, wind) is increased voltage and power fluctuations, particularly when large DG units are interconnected to weak distribution feeders. If the penetration level is significant and encompasses numerous feeders and substations, such impacts may also affect transmission and sub-transmission operations. Evidently, under this condition, an accurate monitoring and control system plays a critical role to ensure the secure operation of the system. However, conventional measurement technologies may not be able to provide a precise depiction of distribution system variables. For example, power and voltage fluctuations caused by intermittent DG can occur in a matter of seconds. Conventional SCADA systems, on the other hand, usually refresh every five to fifteen seconds, after gathering and processing data provided by unsynchronized measurement technologies and transmitting it to the control center via diverse communications systems (with different latencies). PMUs can play an important role under such conditions to provide faster and more precise estimation of system variables. Most likely, the implementation of this technology would occur gradually and would not target all distribution system components. This means that distribution state estimators will have to deal with a combination of conventional measurements, Advanced

Metering Infrastructure (AMI) and PMUs, either on a temporary or permanent basis. This is a topic that requires further research.

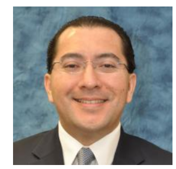
Similarly, voltage and active power fluctuations driven by DG units can also impact the operation of voltage regulation and control equipment such as Load Tap Changers and capacitor banks. This can have a direct impact on reactive power and voltage stability. Additional complexities must be taken into account if DG units are also used to regulate voltage or provide reactive power support. This is another application for which PMUs can provide value.

The high sampling rate of PMUs (30-120 samplings per cycle), which is naturally suited for power quality monitoring, and their synchronization capability, open the door for a comprehensive assessment of distribution system harmonic pollution. Since many modern Smart Grid technologies, such as photovoltaic and wind DG, distributed energy storage, plug-in electric vehicles and Flexible Alternating Current Transmission Systems (FACTS) devices such as Distribution Static Synchronous Compensators (D-STATCOMs), rely heavily on inverters and power electronics for interfacing with the distribution system, it is becoming more important to conduct an accurate assessment of the injections of these harmonic sources and their potential interactions and impacts on the distribution system. PMUs could also play a vital role in this area. The same applies to monitoring other power quality phenomena, such as flicker and voltage sags.

Finally, fault location algorithms that depend on fault current and voltage measurements to pinpoint the location of distribution system faults can also benefit from high sampling rates of PMUs to capture precise waveforms.

It is important to consider that, due to economic reasons, PMUs cannot be installed on all distribution feeder nodes. Therefore, a critical aspect of utilizing these devices as a solution to the challenges noted is to be able to optimally allocate them, while complying with individual application constraints, such as observability. While the applications of synchrophasor measurements are predominantly implemented at the transmission level, some strategic applications at distribution systems may prove valuable and extend beyond R&D pilot projects. One can expect that this technology will gradually become less expensive and potentially incorporated into other devices, which are routinely installed in distribution systems. A great deal of this achievement will be attributable to success of currently ongoing SGIG projects.

For further information,



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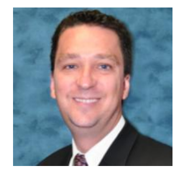

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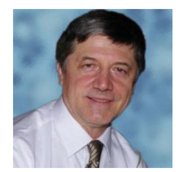

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International Business: Where We've Been, Where We Are Now, Where We Are Going

by Bas Kruimer, Bryan Gwyn, David Elizondo, Hans Candia, & Srijib Mukherjee

As our international business development becomes more defined, and as we engage with more utility customers across the globe who increasingly recognize the vast array of services Quanta Technology experts offer, you are likely to see the names of our consultants and other experts emerging more frequently.

Projects in Macau, utility meetings in Japan and Vietnam, IEEE leadership meetings, keynote speeches at the IEEE Smart Grid Conferences, the UK and Colombia, protection-related studies in Latin America, just for starters, are helping to impact growth, change, protection, and modernization / innovation within our industry.

Latin America

Of specific interest in Latin America and the Caribbean regions is the importance of assessing the protection of electric power systems from a systemic perspective. This includes traditional coordination of protection systems, evaluation of System Integrity Protection Schemes, and the newer wide area monitoring and control options, which can have a very valuable contribution with the availability of synchrophasor measurements.

Quanta Technology is leveraging the diverse technical experience of its professionals by participating in several business opportunities for protection-related technical studies in Mexico and Latin American countries, including Ecuador, Brazil, Colombia, San Salvador, and Chile. Some of the projects we pursue include:

- Distribution Planning Criteria
- Voltage Instability Prediction
- Integration of Regional Control Centers
- Wind Farm Development
- Distribution Cable Failures
- Electricity Market Design and Implementation

India

Srijib Mukherjee is expanding Quanta Technology's presence in the region of India by engaging in offering our: Smart Grid Roadmap services, which include:

- AMR – Automatic Meter Reading
- OMS – Operations Management System
- DMS – Distribution Management System
- TCM – Transmission Control Measure
- Smart Grid Feasibility studies
- WAMPAC Roadmap study and planning
- PMU – Phasor Measurement Unit – Proof of Concept Laboratory
- Solar Park study
- Smart Grid system architecture design
- Smart Meter and communication technology procurement and deployment

Europe

As we move from 2011 into the first quarter of 2012, Quanta Technology Europe finds itself in active discussions with various European utilities on a number of timely and important industry-related topics including:

- State estimator analysis and improvements – static and dynamic modeling
- Protection inventory workshops and protection coordination strategy, with an eye toward the future
- Substation automation, IEC 61850 – improving engineering effectiveness and introducing the process bus in substation projects
- WAMS: Wide area measurement system – exchanging data with neighboring control regions
- Integration aspects of DA/DMS (Distribution Automation / Distribution Management Systems) in existing regional control systems
- P/C Asset Management set-up and supporting tools
- Interconnection studies and scenario analysis
- System aspects of dynamic line rating
- Smart Grid assessments

Quanta Technology continues to provide technical support to Quanta Energized Services (QES) in the pursuit of international opportunities. Hans Candia is currently focusing full time on international and the live work activities in many regions throughout the world. He is following up on responses from Energized Services and Maintenance on Overhead Lines (ESMO) in Rhode Island, as well as the International Conference of Live Maintenance (ICOLIMX) in Zagreb, Croatia, where Quanta Technology demonstrated a live work exchange of a 110kV insulator in an overhead line tower using its specialized method and process and the innovative LineMaster robotic arm.

The need for transmission infrastructure improvements is not only a unique challenge in North America, it is also a major unmet need in Emerging Economies across Latin America, the Indian Subcontinent, the Pacific Rim, Africa, and the Middle East. Also, Europe encounters the same transmission infrastructure improvements to accommodate new renewable energy projects. QES provides transmission infrastructure solutions by performing live work in high-voltage tower repairs or replacements, re-conductoring existing lines with higher capacity conductors to allow higher power transfers to cope with the increasing energy demands. QES consulting services can help our customers identify transmission paths that are in need of upgrades and identify the economic benefits of performing this work under energized conditions.

Robust Conference Participation

As always, we continue to be highly active in international conferences – speaking, leading, and organizing.

IEEE PES, Smart Grid Technologies Conference, Colombia

Judging from the respectable attendance, interest, and audience participation at the IEEE PES Conference on Innovative Smart Grid Technologies in Medellin, Colombia, last October, David Elizondo's "Challenges and Experiences in Protection of Interconnected Electric Power Systems," was an extremely well received presentation. Plan to addend David's upcoming presentation on the technical arena in robotic arms and their future use and developments at CARPI 2012 – the 2nd IEEE International Conference on Applied Robotics for the Power Industry, September 11-13 in Zurich, Switzerland.

10th International Wind Integration Workshop, Aarhus, Denmark

In October, 2011, Tom Gentile, Executive Advisor Transmission, delivered a presentation on wind integration, "Large Scale Renewable Energy Integration: Recent Experiences in the USA," for the Solar and Wind Integration Workshops in Aarhus, Denmark, in which he and Bas Kruimer, Quanta Technology, MD, Europe, participated (www.windintegrationworkshop.org).

IEEE ISGT, Manchester, UK

In December, 2011, IEEE organized its European version of ISGT (Innovative Smart Grid Technologies) in Manchester, UK. In addition to Quanta Technology Europe organizing two panel sessions at this event, Quanta Technology President and IEEE PES Technical Council Chair, Damir Novosel, delivered one of the keynote speeches, "Revitalizing the Power Grid – Needs, Benefits, and Advancements."

We organized the panel session titled, "Managing Next Generation Distribution Systems," with speakers from Stedin, Alliander and Locamation (Netherlands) and from Electricity North West in UK. Edwin Liu, Executive Advisor Enterprise Systems, delivered a presentation, "Evolutions in Power Distribution Systems – Integration of DER and RE."

Damir Novosel and Vladimir Terzija, EPSRC Chair, Professor in Power System Engineering at the University of Manchester, delivered presentations at the panel session, "Wide Area Measurement Integration into Grid Operations." Bas Kruimer led both sessions. These presentations can be accessed at:

Keynote: http://www.ieee-isgt-2011.eu/wordpress/wpcontent/uploads/2011/12/ISGT-IEEE-ISGT-Manchester-Novosel-Keynote-Dec-5-2011.pdf

DA Panel: http://www.ieee-isgt-2011.eu/program/panels/1850-2/

WAMPAC: http://www.ieee-isgt-2011.eu/program/panels/bas-kruimer/

We've been attending the European Network of Transmission System Operators for Electricity (ENTSO-E) meetings in Brussels, where the European TSOs are currently working on the next version of the European Ten-Year Network Development Plan, the progress and process of which was explained to the stakeholders.

January 24 we will be representing Quanta Technology at the Intelligent Energy Europe Information Event 2012 in Brussels where over 300 experts will be discussing energy related topics of the near future.

February 29 and March 1st Bas Kruimer and Senior Associate Consultant Gerard Thijssen will be presenting a paper on Quanta Technology experiences in a number of utility storage projects at the Energy Storage 2012 Conference in Luxemburg. For program details please check http://www.wplgroup.com/aci/conferences/eu-ees2.asp

Finally, check out our expanded website: www.quanta-technology.com with more detailed information about Quanta Technology's European office and endeavors, highlighting activities for this coming year, specifically:

- Integration of New Technologies – Innovation – Strategies
- Smart T&D Applications – RD&D – Roadmapping
- Reliability – Performance – Ageing Assets
- Modeling, Impact Studies & Testing
- Renewables Integration

With so many projects on the horizon, we look forward to continuing our current relationships and developing new ones, as our industry seeks to improve and advance.

Please feel free to contact any of us at Quanta Technology if you would like our industry experts to help you address topics of interest or concern.

Rotterdam Erasmus Bridge

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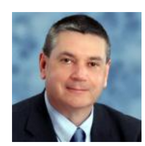

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Quanta Technology Staff Announcements

John Bryant, CPA to Controller for Quanta Technology. John joined our organization in April 2011 and in the short time he has been here he has put together a strong Accounting team to support the Quanta Technology organization.

Deonna Richardson has joined Quanta Technology as an Accountant. Deonna has several years of accounting experience, most recently as Accounting Manager at Environments, Inc. in Beaufort, SC. We are very glad to have Deonna onboard.

Patricia Hinson has joined Quanta Technology as a Payroll Administrator. Prior to Quanta, Trisha worked as an Employee Tax Specialist at Fidelity. She is a Certified Payroll Professional and a Notary. We are pleased to have Patricia join our team.

Dr. Shengnan Shao joins Quanta Technology as a Senior Engineer in the Distribution Business Area. Shengnan recently completed her PhD in Electrical Engineering at Virginia Tech. Her expertise includes modeling and analysis of distributed energy resources, plug-in electric vehicles, demand response, Smart Grid and high-voltage engineering. She will be based in our Oakland office. Please join me in welcoming her to Quanta Technology.

Dr. Ali Moshref has joined Quanta Technology. Ali is well known in the industry and has a wealth of relevant experience. He most recently was at Powertech Labs, serving as Manager of Power System Studies. Before that, Ali was at CYME where he played a critical role in the formation of the company, as he was one of the original founders. He has many talents and interests, and is known as an industry leader in transient stability analysis. Ali will be based in Vancouver, BC and will be focusing on clients in western North America and will run the special studies group within the transmission team.

Recent QT Publications

"A Simple Computation and Visualization of Voltage Stability Power Margins in Real-Time,"
by M. Glavic, M. Lelic, D. Novosel, E. Heredia & D. Kosterev

"Experiences with Deployment of Smart Grid Projects,"
by D. Novosel

"Integration of Photovoltaic Distributed Generation in the Power Distribution Grid,"
by M. Begovic, I. Kim, D. Novosel, J. Romero-Aguero & A. Rohatgi

"Revitalizing the Power Grid: Needs, Benefits and Advancements,"
by D. Novosel

"Workforce Needs for Smart Grid Technologies,"
by D. Novosel

www.quanta-technology.com

Curious what a pig has to do with Smart Grid? See Hahn Tram or any of us at DistribuTECH 2012 Booth #4323 and we'll explain!

Please Join Us

Utility University (at DistribuTECH)
January 22-23, 2012, San Antonio, TX

DistribuTECH
January 24-26, 2012, San Antonio, TX

NASPI
February 29-March 1, Raleigh, NC

Grid ComForum West, 2012
March 7-9, 2012, San Diego, CA

EEI TDA Meeting
April 12, 2012, Providence, RI

Utility Telecom Forum (Region 8, 9, 10)
February 6-8, 2012, Reno, NV

Energy Storage 2012 Conference
February 29 – March 1, 2012, Luxemburg

IEEE PES Transmission & Distribution Conference and Exhibition,
May 7 – 10, 2012, Orlando, FL

Details to be posted at **www.quanta-technology.com**

About Quanta Technology

Quanta Technology, LLC, headquartered in Raleigh, NC, is the expertise-based, independent consulting arm of Quanta Services. We provide business and technical expertise to energy utilities and industry for deploying holistic and practical solutions that result in improved performance. We have grown to a client base of nearly 100 companies and to an exceptional staff – now over 100 persons – many of whom are foremost industry experts for serving client needs.

Quanta Services, Inc., headquartered in Houston, TX (NYSE:PWR), member of the S&P 500, with 2010 revenue of $3.9 Billion, is the largest specialty engineering constructor in North America serving energy companies and communication utilities, according to McGraw Hill's ECN. More information is available at www.quantaservices.com.