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Executive Summary
Quanta Technology is an expertise-based, independent consulting services company providing business and technical expertise to the energy and utility industries. We can assist with deploying strategic and practical solutions to improve your company’s business performance. Our mission is to provide value to our clients in every engagement with the industry-best technical and business expertise, holistic and practical advice, and industry thought leadership.

Quanta Technology’s client base is well established in North American and in numerous international markets. Our clients include energy delivery utility companies, large industrial companies, energy suppliers, Regional Transmission Operators and Independent System Operators (RTOs/ISOs), and energy industry research and support organizations. We strive to provide an environment that attracts and develops the best energy industry professionals, and attribute our success to our exceptional staff, many of whom are industry leading experts in Smart Grid, Asset Management, System Reliability, Storm Investigation and System Hardening, Sustainable Energy and Workforce Development.

Quanta Technology, LLC is headquartered in Raleigh, NC with offices in Boston, MA; Chicago, IL; Oakland, CA; Toronto, Ontario in Canada and Ecuador in South America. It is the independent consulting arm of Quanta Services, headquartered in Houston, TX, (NYSE: PWR), member of the S&P 500, with 2014 revenue of $7.85 billion, the largest specialty engineering constructor in North America, serving energy companies and communication utilities.

Commitment to Quality
Quanta Technology's commitment to high quality, performance and customer satisfaction is supported and enforced through the authority of the highest levels of our company management. Our contract/project management approach is based on the following quality and performance process:

- **Define** customer requirements and objectives for business/technical, product or service.
- **Measure** and match performance to customer requirements.
- **Analyze** and assess process of business/technical strategy product or service implementation.
- **Design** and enforce array of steps required for successful implementation of product or service.
- **Verify** results and maintain high quality performance and customer satisfaction.
- **Deliver** product or service on time in a cost-effective way.

Service Offerings
Quanta Technology experts have guided major utilities as they evolve and update their designs and organizational support for transmission and distribution system/substation protection, control and communications. The multidisciplinary team works with clients to assess state of existing systems and collaborates with the organization that deals with them. The strategic offering is structured for collaboration and organizational absorption of new designs and approaches, and aims at solving problems and bringing benefits that are uniquely relevant in each utility’s situation.
Statement of Expertise

Quanta Technology’s expertise in the area of T&D system protection, control and communication solutions can greatly benefit utilities and their customers by improving reliability, adding flexibility and increasing security of the grid and its equipment in a cost-effective manner. Specifically, the services we provide in the area of T&D system protection, control and communications include:

- Protective relaying methods and application in depth.
- Relay product and vendor offerings and evaluation.
- Communications systems and equipment for protection of transmission and distribution lines.
- Data communications for system/substation and enterprise integration including Ethernet networking.
- System/substation integration for SCADA, EMS, and enterprise users using communications, RTUs, host devices, concentrators and substation servers.
- Communications protocols for system/substation integration including services of IEC 61850.
- Enterprise integration of information extracted from relay and Intelligent Electronic Device (IED) data describing power apparatus measurements and events.
- NERC and Regional Reliability Organization (RRO) standards – technical requirements and documentation for protection system maintenance, reliability and redundancy, disturbance monitoring equipment and methods, generator coordination, and other standards in effect or under development.
- Power system modeling and relay testing, including Real-Time Digital Simulator (RTDS) testing.
- Wide-area protection coordination requirements, performance modeling and software tools including Aspen OneLiner and CAPE.
- Power system and equipment studies and software – PSS/E and other tools.
- Synchrophasor technology and applications for wide-area observation and recording, control and protection.
- Distributed Energy Resource (DER) and Renewable Energy Resources (RER) integration and impact on protection, automation and control.
- Industry practices benchmarking, condition assessment and on-site data collection.
- Conducting on-site seminars with multidisciplinary utility teams for instruction in basic principles and new technology, and for information gathering to support development of new programs, designs and technical strategies.
- Development of technical roadmaps in light of the specific situation at the client utility, industry and technology trends, and management of risk in a multistep migration to new approaches.
- Implementation support – development of specifications, requests for proposals and proposal assessment and vendor selection.
- Implementation support – owner’s engineer oversight of suppliers, installations and testing.
- Development of documentation and test plans for operations, maintenance and regulatory compliance.
Wide-Area Protection Coordination

Power system protection is a well-established field of study that deals with the protection of the system through the isolation of faulted transmission equipment from the rest of the system. Protection systems are an integral part of the Power System and are designed to monitor conditions, detect abnormalities and react in an autonomous fashion to isolate problems in fractions of a second. The design of these protection systems is a challenging undertaking because reacting at the wrong time or in the wrong way can exacerbate the problem rather than prevent it.

As a result of advances in software and computing power, there are commercial software-based tools available in the market today that make it possible to model a power system, simulate an array of problem scenarios and study how the protective schemes will react. Quanta Technology has developed and executed a process to diminish the challenges with successful utilization of these tools:

- Errors in system modeling can skew or invalidate the results.
- These tools generate such large volumes of data that interpreting the results in a non-automated fashion is impractical, especially when the system to be analyzed consists of more than a few transmission lines.
- Reaching a conclusion on whether the system passed or failed the simulation, as well as assessing the risk and prioritizing the remedial actions is difficult because of data overload.
- Comprehensive documentation of the work and the results is a critical activity that is mandated by regulatory entities such as the National American Electric Reliability Corporation (NERC) for some types of studies.
- Protection expertise required to identify and correct issues identified by the available tools.

Advanced Protection System Modeling & Analysis

Today’s complex and integrated protection and control systems require more sophisticated modeling and study tools to simulate and analyze the dynamic behavior of interconnected transmission and distribution systems along with the interactions that occur among numerous sets of intelligent electronic devices simultaneously. The traditional approach of coordination among relay pairs on adjacent lines may not ensure the high level of system reliability and resiliency required by NERC/FERC compliance regulations.

Quanta Technology can assist utilities to meet and overcome protection system design and coordination challenges with our:

- Industry renowned protection staff.
- Knowledge of NERC standard and regional requirements, including renewable energy resources.
• Use of advanced protection modeling software and related protection assessment tools to accurately model complex vendor specific protective relays (rather than conventional generic protection schemes), incorporating detailed trip logic and actual protection settings.
• Unique approaches to verify wide-area protection coordination based on combination of pilot and direct trip protection schemes during normal and worst case conditions (N-1/N-2 contingencies).
• Ability to verify and update system network short circuit models utilizing original construction and nameplate data.

**Methodology**

The utility’s own standards and practices, combined with requirements and standards mandated by regulatory bodies guide the protection audit process. These requirements are then embodied in two of the major components of the review: *Sensitivity Studies* and *Coordination Analysis*.

The sensitivity studies and coordination analysis portions are CAPE macros (batch processes developed by Electrocon) that can be applied on any CAPE database whose primary network and protection models have been suitably populated. The *Protection System Model* is the utility’s CAPE database, consisting of the primary network and relays, with up to date relay settings, protection schemes, tripping logic, etc.

A typical audit will consist of the following steps:

1. Evaluate utility protection standards, industry guidelines, and regulatory requirements and develop a set of criteria to use for the sensitivity studies and coordination analysis.
2. Simultaneously, prepare the CAPE database for the studies by verifying and updating the primary network, relay settings, protection schemes, etc.
3. Perform sensitivity analysis on the system, and identify relay elements that do not meet the criteria developed for them. For example, a zone 1 ground distance element over-reaches the remote bus under certain contingency conditions. This will require the reach of the relay to be shortened to avoid over-reach.
4. Classify the identified settings problems according to severity, and make changes to the settings to mitigate them.
5. Perform coordination studies on the system with the updated settings. Note that the coordination study tests relay selectivity. A relay that meets its sensitivity criteria need not necessarily meet the selectivity criteria – this aspect is thoroughly tested by the coordination review process.
6. Use the results of the coordination study to further improve relay settings to mitigate selectivity problems.

Please note that at the end of the sensitivity analysis, the utility might well choose not to update relay settings (Step 4), and go directly to the coordination study (Step 5). This is certainly a valid approach and allows relay selectivity to be evaluated with the settings that are in use at present in the field.
**Approach & Strategy**

Based on our past experience, wide-area coordination studies have four major phases. The Preliminary Phase consists of creating customized or modifying existing control documents such as CAPE specification philosophy, modeling procedures, contact logic/trip logic standards, master tracking sheet detailing all transmission lines requiring coordination study, and most importantly defining and making all changes to the automated macros to be utilized in the latter stages of the project.

**Phase 1** of the modeling will be able to use the control documents and master tracking sheet generated in the preliminary stage for a smooth transition into completion of modeling of protection CAPE model. This step will focus on adding protection of transmission lines, station transformers, as well as any load tap infeed within the specified areas.

**Phase 2** will focus on ensuring all protection schemes within the study area are modeled correctly for the purpose of coordination macro studies. This step has been developed to catch all modeling issues prior to starting any major automated macros. Our experience has shown incredible increase in efficiency by the introduction of this phase to our trademarked Holistic Assessment of Protection Settings (HAOPS™) approach. We want to make sure that we catch all modeling issues prior to spending increased resource at the more complex stages of coordination process.

**Phase 3** will consist of a sensitivity analysis which tests the settings of protective relays against the criteria chosen to set them. The results of this phase will assist our protection engineers with preliminary status of potential coordination issues as sensitivity failures tend to get repeated as miscoordination issues. In addition to setting issues, this phase will assist in catching any missing relays/LZOP as well as incorrect contact/trip logic codes that the sensitivity macro was unable to pick up for each terminal.
Phase 4 will consist of the coordination studies of the protection schemes to the contingencies specified in Step 1, along with the number and type of faults applied. The output of the system simulator will be put into our post processing tool and any violations will be presented in an easy to ready list ranked by severity.

The first three phases focus on getting the CAPE database ready for coordination process. They have been developed to ensure the least amount of time is spent in re-running automated macros due to a missing or incorrect protection model. For example, for coordination macros which could take hours to complete, all the lines within the simulation depth of 1 require re-run and condensation of raw results if a missing LZOP still exists within the study area by this stage.

Quanta Technology utilizes their trademarked approach, as well as post processing tools in order to automate the summarization of the raw data for the sensitivity and coordination macros.
Wide-Area Protection Coordination - Reference Projects

The following is a selected list of relevant projects and industry activities that members of the Quanta team have participated in recent years. Brief project descriptions are provided below and detailed descriptions are available upon request.

1. National Grid – Wide-Area Protection Simulator Development & Coordination Study

Quanta Technology (prime contractor) and Electron International have been engaged to develop a wide-area system protection simulator tool and perform a dynamic wide-area protection study for the National Grid 115kV-345kV transmission systems in New England and New York. The project goal is to determine appropriate protection settings to assure secure wide-area protection coordination and system reliability in the event of local and wide-area faults.

Our project scope includes gathering data, validating and developing a database from National Grid, 12 neighboring utilities and ISO databases for computer modeling. The database will be used to develop the protection coordination modeling system, perform project studies and be retained for future reuse by National Grid. The database will include:

- Primary power system of National Grid transmission line and substation equipment design and operation characteristics.
- Protection system (secondary system) device types, connections, operational characteristics and settings for the entire National Grid area, which includes traditional electro-mechanical relays and contemporary “smart” relays.
- Similar data from neighboring utilities and ISOs of interconnection equipment.
- Validation of the updated power system (primary) model data through comparative results and benchmarking against actual recent fault recordings.
- Primary system database in new (CAPE) and legacy system (Aspen OneLiner) formats.

Design, use and deliver a computer-based modeling tool that generates relay settings and data bases using parameters for approximately 650 line terminals, associated transformers and generators within National Grid’s territory. The system will enable dynamic simulation of short-circuit faults at thousands of locations in the National Grid system and neighboring utility systems to assess protection system responses and develop appropriate settings.

2. AltaLink – Risk Assessment Approach in Wide-Area Protection Coordination

Quanta Technology proactively determining which areas of the protection system have coordination deficiencies and assess the amount of risk associated with each deficiency. These deficiencies included any miscoordinations, CTI violations, lack of redundant protective relays and current/voltage transformers for half of AltaLink’s transmission network.

In addition, AltaLink seeks assurance of compliance with all applicable laws, regulations and government legislation. The results were presented in three mitigation categories of setting change, protection upgrade, and system upgrade and were prioritized based on an automated risk method using AltaLink's customer, electric
Wide-Area Protection Qualifications

system, safety and environmental impact scores. Project scope – over 600 transmission lines, transformers and busses (69kV & above).

3. Xcel Energy – Automated Wide-Area System Simulator Assessment

In 2014, Quanta Technology, LLC completed a project for Xcel Energy to provide CAPE System Simulator studies on Bulk Electric System (BES) stations (100kV and above). As part of this study, a detailed coordination review under different fault types and contingencies was performed on approximately 1000 transmission lines in the three operating regions of Xcel Energy.

A specially customized CAPE macro was used to automate the study. For each scenario, the macro evaluated the sequence in which the fault is cleared, and recorded protection problems – coordination time interval (CTI) violations, and mis coordinations. The results of the simulations are stored in rich text format (RTF) files. Quanta Technology, LLC then developed post-processing tools that condensed the large amounts of data contained in the RTF files (raw macro output), and produced easy-to-understand spreadsheets with information about the protection elements that misoperate, the conditions under which they do so, and a corresponding risk score. The next steps are to study the post-processed output spreadsheets, to understand the reasons for CTI violations and misoperation of protection elements, and determine the actions needed to mitigate the problems found.

Consequently, the specific tasks for review of protection deficiencies developed are:

- Review the post-processed output generated by running Quanta Technology’s post-processing tool on the RTF files produced by the CAPE macro.
- Where miscoordination and CTI violations are seen, analyze and provide recommendations to help mitigate the problems, taking into account Xcel Energy’s protection standards.
- Perform a re-coordination study to show that the problems have been mitigated.

4. Con Edison – Protection System Sensitivity Assessment

There was a concern that due to changes in system topology, load, generation and fault duties over the years may have resulted in a number of latent protective relay setting issues. There was a risk that these issues will manifest themselves during times of power system stress and lead to wide area disturbances. A system wide transmission protection assessment of the protective schemes for correctness, adequacy, dependability and security aspects was conducted focusing on relay operating characteristics, set points, tap selections time delays, harmonic-restraint; and system adequacy of thermal capability, line constants and mutual coupling calculations. Scope of work - 4 transmission substations (100kV & above).

5. Southern California Edison – Sub-transmission Coordination Review

Performed a protection wide area study on one of SCE's sub-transmission areas with an option to improve the modeling on one of the areas. Detailed bus configuration modeling and protection software platform tool enhancement were an integral aspect of this sub-transmission review project.
Project included wide area system studies, development and implementation of “Out-of-Step” protection alternatives for 500kV and 354kV transmission system as recommended by PG&E’s Planning Department. Quanta Technology provided system studies/analysis and evaluation of protection devices/schemes available in the industry in order to recommend suitable Out-of-Step (OOS) blocking and tripping schemes for all 230 kV and 500 kV transmission lines. Additionally, the project team reviewed PG&E’s existing protection device in order to identify their blocking and tripping usability. A proposal for new devices to ensure Out-of-Step functionality in the designated power sub-system and OOS coordination and selectivity with existing RAS (SPS) was also performed. New devices were evaluated for future capability to implement Phasor Measurement Unit (PMU) or synchrophasor technology and to interface with PMU data concentrators.

Designed architecture and developed strategies for deployment of fully integrated RAS schemes for 110kV, 230kV, 345kV and 500kV transmission systems. Based on system specification, products to fulfill stringent system requirements were selected. Deployed HW/SW to support latest technology developments (such as IEC 61850 protocol) enabling future-proof solutions and positioning the system for functionality and reliability upgrades.

8. Southern California Edison – Short Circuit & Protection Coordination Studies
This project assessed the impact of several new generation units (from 50 to 700 MW) on the Southern California Edison protection system. Quanta Technology performed protection coordination study at the 66 and 115 kV busses/lines for more than thirty 220 kV substations to evaluate possible protective relay misoperation due to added generation units. Based on the finding new/revised protection settings were recommended.

9. PG&E – 500 kV Protective Relaying Redesign
Quanta consultants began with a seminar among the Quanta team members and many departments of PG&E including protection, automation, communications, IT, operations, maintenance, and planning. Quanta assessed the diverse generations of equipment installed in the field, and evaluated features of new relays for testing. Quanta carried out a major industry benchmarking survey of 20 major utilities on EHV protection and control practices and experience. A Quanta team ran a comprehensive RTDS relay testing program for PG&E, which included selection and contracting of a test lab, creation of a test plan, implementation of a system model for a group of series compensated lines with nearby facilities, cooperative test arrangements with four relay vendors for six products, development of settings, and performance and documentation of the tests. Final products were selected based on performance, strategy roadmap developed by Quanta with PG&E, and benchmark results. Quanta provided specific design requirements for new protective relaying systems, protection communications, and substation networking and integration functions. Quanta interactively developed a business case, and supported the PG&E project team in management presentations and project result presentation to the organization. The work continues with detailed standard design development and deployment across the PG&E 500 kV system, in cooperation with a panel building and engineering firm contracted by PG&E.