INDUSTRIAL CONTROL
Pillar of Success
Foundation of
Energy Resilience and Security

Operational Technology (OT) Intelligent Control Systems
for
Energy Production Assets

SECTION 1: INTRODUCTION

The purpose of this document is to communicate a philosophy and expectations for development of third-party contract-executed energy production projects, including the industrial control systems and associated communications networks. For the purposes of this paper, Operational technology (OT) is hardware and software that detects or causes a change through the direct monitoring and/or control of physical devices, processes and events in the enterprise, whereas Information Technology (IT) is considered to cover the technologies that transform data but does not interfere with the physical world (hardware, infrastructure, and software applications used to accept data flows as an input to deliver a new data flow).

Criteria for design and construction of these systems is found in: International Codes (e.g. International Building Code, IEC 61850 (Series), etc.); government standards such as Unified Facility Criteria Standards (UFCs), National Institute of Standards and Technology; and industry standards such as the National Fire Protection Association, Institute of Electrical and Electronic Engineers, the American National Standards Institute, National Electrical Manufacturers Association (NEMA), and the American Society of Heating, Refrigeration, and Air-Conditioning Engineers. Depending on the project, other guidance to be consulted (for application intent) includes federal government guides, directives, and policies for specific aspects of system design, architecture, information control, or function.

Operational Technology (OT) Intelligent Control Systems include integrated protection, control, automation, and communications via intelligent electronic device-based (IED-based) hardware and software for the operation of an intelligent control solution (defined as microgrid-ready) or a microgrid. These systems are designed for projects with electric generation, combined-cycle generation, distributed energy generation resources (DERs) and utility operating requirements, including multiple points of common coupling (PCCs) with other grids. The distinguishing discriminator between these systems and simpler, standalone systems is the need to provide rapid control actions that promote safety, availability, and operability where multiple sources are connected, and decisions are programmed based on many system parameters. This guidance is directed toward design and construction of integrated control systems.

The primary function of the OT Intelligent Control Systems in the microgrid context is to allow a small grid section on the site to operate independently by preventing, detecting, and mitigating system blackouts and brownouts caused by unforeseen events on a privately owned primary power distribution system. Automated, very fast acting electric system components are protected by relays (Intelligent Electronic Devices (IEDs)) and flexible control systems; while simultaneously protecting and controlling all on site major and secondary power system assets. Further providing for optimal on site operation and control, economic dispatch, safety, maintenance, environmentally sound operation, which include reliability, availability, maintenance, resilience and security.

The OT Intelligent Control Systems include utility system intertie protection, local power factor control, distributed generation sharing and optimization, load shedding, load management, bidirectional power flow management, peak shaving, grid decoupling, grid autosynchronization, monitoring, and alarming.

Operational Technology (OT) Intelligent Control Systems Objectives

With the increase in intermittent power sources, such as wind and solar power, OT Intelligent Control Systems are being implemented to provide both environmental and economic benefits. OT Intelligent Control Systems are typically implemented for medium-voltage distribution systems with multiple power sources, and they are capable of islanding using local distributed generation. OT Intelligent Control Systems designs objectives are to achieve the following goals:

- Increased energy efficiency
- Reduced greenhouse gas emissions
- Grid resiliency and reliability
- Energy storage integration
- Independent operation from the main electric grid
- Decentralized energy generation
- Grid investment deferment
- Grid Security and protection
- Increased level of safety (personnel and equipment)

Typical power sources in an OT Intelligent Control Systems include a wide mix or single deployed solution of steam, solar, wind, diesel, and hydroelectric power, as well as energy storage systems, such as batteries.

In addition to other standards for design of electrical systems (e.g. IEEE 242, NFPA 101, NFPA 70, ANSI/IEEE C2, IEEE 37.1, IEC 61850 (Series), etc.), an OT Intelligent Control system must satisfy the requirements of IEEE® 1547, Standard for Interconnecting Distributed Resources with Electric Power Systems, which requires: studies and signed agreements by all involved parties/agencies; automated system protective devices (over- and undervoltage, over- and underfrequency, and overcurrent protection; synchronism checks; reverse power); and islanding mitigation. Local generation and possible islanding scenarios pose protection sensitivity and selectivity issues related to relay fault protection inside an OT Intelligent Control System.

Besides the intermittent nature of green energy generation such as wind and solar power, there are several challenging technical issues with regard to OT Intelligent Control Systems operation that traditional grids do not have. Several of these are detailed in the following subsections.

REDUCED INERTIA

High-voltage power electronics are commonly required on wind and solar systems to convert power to distribution-level ac voltages. These systems do not contribute any spinning inertia to the electric power system, thus allowing for a faster rate of decay in power system frequency. The OT Intelligent Control Systems therefore will respond in less than one power system cycle (16 or 20 milliseconds) to prevent frequency and/or voltage collapse.

REDUCED FAULT CURRENTS

Nonconventional power sources do not generate continuous fault current at levels similar to those of synchronous generators. This can create serious (and dangerous) protection coordination problems due to the reduced selectivity and sensitivity of overcurrent protection elements. OT Intelligent Control Systems will be dynamically tested with real-time, Electromagnetic Transients Program (EMTP) modeling of the combined protection and controls system to validate that all protection and control systems function dependably, securely, and safely these test results will be submitted for review and signed acceptance by the USACE, HNC Electrical Power System Engineer assigned to the program of

record.

INTERMITTENT POWER SOURCES

Economic operation of OT Intelligent Control Systems are complicated by the high penetration level of intermittent energy sources. These sources require the OT Intelligent Control Systems to continuously adapt to new environmental conditions (e.g., wind, water, sun) and dispatch other energy sources to compensate. The OT Intelligent Control Systems must minimize the cost of power by fully utilizing green energy sources.

DISTRIBUTED ENERGY RESOURCES

The electric power sources in OT Intelligent Control Systems can and will be in remote regions, either densely distributed in a small footprint or dispersed across a large geographic area. Wireless Solutions for remote communications and controls must obtain a J/F 12 number from the Defense Information Systems Agency (DISA) Spectrum Management Office. The location or site Local Spectrum Manager has to approve the use of wireless communication solution, first. The DISA J/F 12 process can take upward to 12-24 months for approval. USACE, HNC Energy Division integration team has a J/F 12 completed that supports passing critical power quality metering data such as voltage, current, power factor, etc. to help monitor, control and operate, for example, reclosers to quickly isolate a fault and minimize power outage durations the description identifier number is J/F 12/10990. The designer of record will be required to provide a design solution for integrating wireless solutions into the OT Intelligent Control Systems defense in depth framework and obtain all approvals; if the approved J/F or new solutions are desired for use. The OT Intelligent Control System must contain secure communications equipment and/or approved capabilities that seamlessly interfaces into the defense-in-depth strategy which controls the following distributed power sources in order to be considered at a minimum Microgrid-ready:

- Diesel generators
- Wind generators
- Sheddable loads
- Dispatchable loads
- Energy storage
- Solar photovoltaics
- Capacitor and reactor banks
- Reactive power compensation, including static volt-ampere reactive (VAR) compensator (SVC) and static compensator (STATCOM) devices

SECTION 2: EXCUTING PRINCIPLES FOR RESILIENCY AND ENERGY SECURITY

OT Intelligent Control Systems must be provided as complete, functional systems composed of the following components:

- Communications system infrastructure
- Intertie and source protection
- Control systems, which include the following features:
  - Grid-connected control
  - Grid separation
  - Island operation control
  - Automatic resynchronization
- Coordinated and bidirectional protection systems
- Power quality monitoring and metering systems
- Visualization systems
- Engineering tools
- Full documentation
- Proven project execution and quality control procedures
- Cybersecurity

The following subsections describe principles used in the OT Intelligent Control Systems executing for Resiliency and Energy Security.

TESTING AND COMMISSIONING

Testing and commissioning must be performed as a sequential, iterative process. Each component must be functionally tested. Subsystems must be functionally tested to verify operability and functionality. Ultimately, all subsystems must be testes as a whole to prove operability and functionality for the design modes of operation. The goal is to ensure safe and reliable operation.

A key standard for electrical system testing is the ANSI/NETA Standard for Acceptance Testing Specification for Electrical Power Equipment and System, 2017 edition or latest update. It provides that:

- The contractor will provide the testing organization and Government COR with the following at a minimum but is required to meet all requirements outlined in the above NETA standard:

- A short-circuit analysis, a coordination study, and a protective device setting sheet as described in Section 6.
- A complete set of electrical plans and specifications, including all change orders.
- Drawings and instruction manuals applicable to the scope of work.
- An itemized description of equipment to be inspected and tested.
- A determination of who will provide a suitable and stable source of electrical power to each test site.
- A determination of who will perform certain preliminary low-voltage insulation-resistance, continuity, and low-voltage motor rotation tests prior to and in addition to tests specified herein.
- Notification of when equipment becomes available for acceptance test. Work will be coordinated to expedite project scheduling.
- Site-specific hazard notification and safety training.

Note: The testing organization will be an independent, third party entity which can function as an unbiased testing authority, professionally independent of the manufacturers, suppliers, and installers of equipment or systems being evaluated to include prime contractor.

The Contractor is responsible for all costs associated with any required studies, NETA testing, parallel operating agreements, interconnection application and agreement.

All control systems and visualization systems will be designed for easy testing in the laboratory and in the field. All OT Intelligent Control Systems centralized dispatch controls and distributed I/O and protection systems will have a proven history of being safe and practical to test.

All centralized controls are specifically designed for fast and safe commissioning. All outputs have hardware and software inhibits. Software inhibits are accessible from the user interface, allowing those with password access to apply and remove them. No form of communications error or loss of power will allow the system to operate incorrectly.

Most OT Intelligent Control Systems are brought online as partially constructed systems. This can pose some complications for control systems that are designed for all grid assets to be online. The OT Intelligent Control Systems will be pre-engineered around this problem by using OT software-defined switch solution to enable the power system flows to be enabled and commissioned incrementally effectively withstanding and protecting the solutions from cyber-attacks. For example, the load-shedding algorithms will be pre-engineered to operate properly with only part of the I/O commissioned.

EXPANDABILITY

OT Intelligent Control Systems will be designed for future expandability using the Foundation and Process to support all Energy Division programs and all related Energy Conservation Measures (ECMs) in accordance with Office Management and Budget (OMB) goals and approaches for energy solutions. For example, with the ability to pre-engineer OT traffic Energy Division programs will address cost reduction at installation as the Master Plan address add, moves and changes to migrate from simple OT Intelligent Control Systems into more complex Microgrids. Cost reduction will appear in all four pillars

based on standardization, flexibility and visualization with upfront use of the Department of Defense (DoD) Architectural Framework (AF) layout.

SCALED SOLUTIONS

Three tiers of Operational Technology Intelligent Control Systems, which are summarized in Table 1. This document describes the functionality of Tier 2.

Table 1 Operational Technology Intelligent Control System Concepts

	Tier 1	Tier 2	Tier 3
System	Relay protection	Real-Time Automation Controller (RTAC)	OT Intelligent Control System Solutions
Description	All control and protection systems are provided via protective relays.	Centralized control systems are provided using an RTAC, and protection systems are provided using relays.	. Centralized control systems are provided inside Complex OT Intelligent Control System Solution controllers, and protection systems are provided using networked relays.
Typical Application	OT Intelligent Control System that include one or two power sources. Typical application is a battery facility.	Most microgrids that include two or more power sources. Has limitations on expandability.	Only very large or complicated microgrid projects.

SECTION 3: ARCHITECTURE

OT Intelligent Control Systems architecture will follow, at a minimum, a layered approach, as shown in Figure 1. This architecture is proven to be easily constructed, tested, and maintained to address "functionality of a Microgrid Ready" network solution. Layer 1 equipment interfaces with power system assets, such as generation, distribution, and loads. Layer 2 equipment with OT Software-Defined Network implementation aggregates flow status information and provides additional security and resilience from Layer 1 into Layer 4 and processes commands from the controller down to the Layer 1 equipment. Secure gateways form a virtual security perimeter and aggregate data from communications equipment for interfacing with a one way approach to other business systems. The approach must address security with a one way flow of data and defined routes availability "Only" design solution. Layer 3 is the centralized control system. Layer 4 comprises the visualization and engineering tools. All internal and external traffic within the OT Intelligent Control System will be within the OT Software-Defined Network design site solution enclave. All routes and flows will be approved by the OT Intelligent Control System configuration and control board.

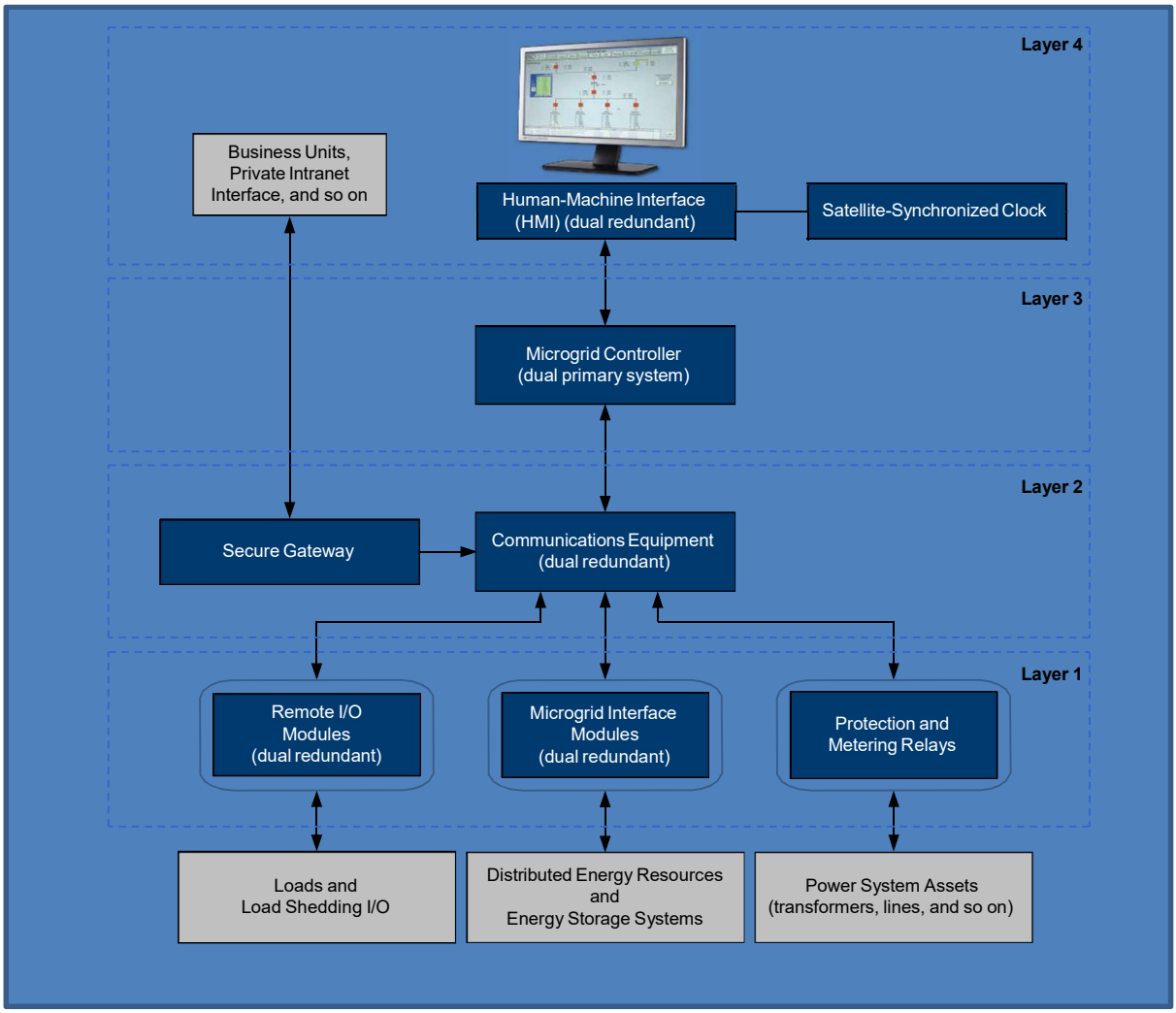

Figure 1 Microgrid Ready Enclave Architecture

HARDENED COMPUTING

Used in Layers 3 and 4, hardened computing platforms will use easily-accessible, hot-swappable solid-state technology with a ten-year warranty at a minimum. These OT computing solid-state devices will have an operating range of –40° to +75°C will be used as microgrid controllers that are programmable with IEC 61131-3-compliant function block programming, structured text, instruction lists, and sequential function chart programming languages. The hardware will be powered directly from the substation or battery dc voltage.

Substation Synchrophasor System Architecture will use easily-accessible, hot-swappable solid-state technology which meet the dynamic disturbance recording requirement by archiving Phasor Measurement Units (PMUs) at > 30 messages a second.

The Synchrophasor System solution PMUs through continuous monitoring of grid parameters will be used for wide area protection & control, oscillation monitoring, auto-mated event diagnosis, state estimation, postmortem analysis, model validation, data analytics and operations planning.

Continuous/DIAGNOSTIC and MONITORING

All protective relays, power quality monitors, revenue meters, serial and Ethernet communications devices, time-synchronization devices, hardened computers and solid-state devices will be capable of continuously self-test and report internal errors. They can also signal if their functionality has been disabled through normally closed output contacts.

DIRECT BATTERY CONNECTION

All controllers, protective relays, power quality monitors, revenue meters, serial and Ethernet communications devices, time-synchronization devices, solid-state hardened computers are powered directly from battery dc voltage if applicable. All power management hardware if located in the substation will be powered directly from the substation battery dc voltage. Provide direct dc-powered systems which have proven to provide the highest system reliability and require the least amount of maintenance.

VIRTUAL SECURITY PERIMETER

Ethernet communications will be in a closed-loop restricted network isolated from outside Ethernet networks. Security firewalls and/or gateways are used at all interfaces to other networks. All access will be granted first administratively with the approval of the Change Configuration Board for OT Intelligent Control Systems.

REMOTE ACCESS

The system hardware firewalls will provide secure remote administrative access to all Layer 4 equipment. Virtual private network (VPN) hardware at a minimum will provide

60 Mbps of firewall throughput, 3 Mbps of Triple Data Encryption Standard (3DES) VPN throughput, and 4.5 Mbps of Advanced Encryption Standard-128 (AES-128) VPN throughput or otherwise specified.

SERIAL COMMUNICATIONS TO LAYER 1 DEVICES

OT Intelligent Control Systems will use serial connections to relays and I/O modules. These serial connections support administrative remote access, data collection, and control operations. These same serial communications simultaneously send IRIG-B time-synchronization signals.

SECURE CONTROL MESSAGING

System control operation messages include information redundancy, data shifting, and cyclic redundancy checks to provide data security and prevent false operations.

PEER-TO-PEER, HIGH-SPEED COMMUNICATIONS

Serial Communications

Layer 1 equipment can communicate peer-to-peer using high-speed serial communications. This is done exclusively through encoded, periodic, 4 ms, unsolicited point-to-point serial data transferred directly between the IEDs.

Ethernet Communications

Layer 1, 2, and 3 equipment can communicate peer-to-peer using high-speed, User Datagram Protocol-based (UDP-based) Ethernet communications exclusively through double-key encrypted messaging. All messages leaving the OT-SDN must be via routable protocols.

MICROGRID CONTROLLER

The microgrid controller provides centralized control of the microgrid system. The controller runs in a real-time controller with a real-time thread (task interval) of 2–8 ms.

OPERATING SYSTEMS

Microsoft® Windows® operating systems are not used in any part of Layers 1, 2, or 3. They are only used on substation-hardened equipment at Layer 4. The control and protection systems will not be depend on the Layer 4 operating systems.

REDUNDANT CONTROLLERS

Microgrid controllers can be supplied in a dual-primary or hot-standby configuration.

REDUNDANT MEASUREMENTS

Microgrid controllers will accept multiple measurements for critical quantities such as power flow at interchange points, system voltage, and system frequency. When multiple measurements of a quantity are configured, the OT Intelligent Control Systems will uses the best-quality measurement available.

COMMUNICATIONS EQUIPMENT

The communications equipment will be designed for the harsh conditions found in energy and industrial environments. The equipment will support communications infrastructure built for engineering access, supervisory control and data acquisition (SCADA), and real-time data communications, while offering the same reliability found in microprocessor-based protective relays. The equipment must meet or exceed industry standards for vibration, electrical surges, fast transients, extreme temperatures, and electrostatic discharge for communications devices in electrical substations.

COMMUNICATIONS REDUNDANCY

The OT Intelligent Control Systems design will at a minimum of two separate hardware and/or cabling failures must occur to lose communications to any Layer 1 IED.

SATELLITE-BASED TIME SYNCHRONIZATION

The OT Intelligent Control Systems design satellite-synchronized network clock will receive Global Navigation Satellite System (GNSS) time signals and distributes precise time via multiple output protocols, including IRIG-B and Network Time Protocol (NTP). The advanced capabilities of the clock will be well-suited for demanding applications, such as synchrophasors and event recording, as well as for larger microgrids with multiple time-synchronization requirements.

REMOTE I/O MODULES

The OT Intelligent Control Systems will use remote I/O modules that are designed to withstand harsh physical and electrical environments and that are built and tested to meet mission-critical IEEE and IEC protective relay standards. All I/O modules include Sequential Events Recorder (SER) reporting, programmable logic, remote communications, ac metering, and low-level signal interfaces. Scan times for these are 2–4 ms.

SECTION 4: GRID-CONNECTED OPERATION

The OT Intelligent Control Systems will simultaneously manage several Point of Common Coupling (PCCs) to the adjacent utility grid. The OT Intelligent Control Systems will provide support to the utility when operating in this connected mode.

AUTOMATIC GENERATION CONTROL (AGC)

The AGC algorithm will dispatch the power output of distributed power resources to maintain power interchange at the PCCs within predetermined limits. The system will dynamically recalculate energy resource set points under all system bus configurations. Dispatch of resources will be accomplished via a number of methods including economic dispatch, renewable prioritization, grid resiliency, utility operating reserve, or demand response.

PEAK SHAVING

The peak shaving algorithm will dispatch energy sources, such as batteries and conventional generation, to relieve transmission corridor congestion. The Battery system when discharge during peak usages times will charge during minimal usage times.

POWER FACTOR CONTROL SYSTEM

The power factor control system will be used to regulate the local reactive power output of distributed energy resources to maintain reactive power interchange at the utility intertie(s) and system voltages within predetermined limits. This system dynamically dispatches on-load tap changers (OLTCs), capacitors, excitation systems, STATCOM devices, and other reactive current producing assets. The power factor control system follows IEEE 1459-2000, the standard for calculating the power factor.

SECTION 5: GRID SEPARATION

The OT Intelligent Control Systems will detect island formation and, in some cases, actively decouple a power system to create an island. These two functions are described in the following subsections.

AUTOMATIC ISLAND DETECTION

Breaker status indications, disconnect switch statuses, voltage measurements, current measurements, and synchrophasor measurements are used to automatically detect when grid islands are formed. The island detection system will handle any number of system topology and bus connection scenarios. The Contractor solution must address two possible outcomes of an island detection (1) shutting down the islanded microgrid by stopping generation (known as anti-islanding) or (2) modifying the mode and dispatch of islanded generation sources to keep the microgrid alive (known as islanding).

AUTOMATIC DECOUPLING

Automatic decoupling intentionally islands a microgrid from a utility. Decoupling is most commonly performed in the case of a fault on the main grid, to stop intergrid instabilities, to prevent damage to distributed energy supplies, or for a contractual requirement between two entities. This intentional islanding can have a cascading effect, forming many dozens of microgrids that are each composed of their own distributed energy sources and loads. This decoupling is typically accomplished by opening circuit breakers at the PCCs.

SECTION 6: ISLAND OPERATION

After a microgrid island is formed, the OT Intelligent Control Systems will modify the mode and dispatch of islanded generation and loads to keep the microgrid alive. The system will keep the frequency and voltage within allowable parameters for any number of islands. A number of techniques are used to keep these islanded microgrids alive, as described in the following subsections.

FAST LOAD-SHEDDING SYSTEM

The Contractor design solutions will address a load-shedding system which provides automatic load reduction in response to island events or loss of distributed power generation. As well as, low-inertia microgrids (described in Reduced Inertia in Section 1) which require ultra-fast load reductions to prevent cascading losses of distributed power generation. The scheme will equalizes the system load and generation, typically within 70 ms. This system will operate in every combination of system topologies and bus configurations by dynamically tracking the system state. The system will use Ethernet, multiplex, and/or serial communications to propagate status and control signals over any distance (hundreds of kilometers is common).

UNDERFREQUENCY LOAD-SHEDDING SYSTEM

The Contractor will address underfrequency load-shedding scheme and us it as a backup to a fast load-shedding system. Fast load- shedding systems do not identify impeding load-to-generation disparities caused by some types of equipment failures. For example, fast load-shedding systems do not detect broken wiring, shorted current transformer (CT) windings, dc battery failures, turbine problems, or control system problems.

Underfrequency load-shedding schemes will equalize load and generation sources by using frequency and rate-of-change-of-frequency (ROCOF) measurements. More advanced inertia compensation and load-tracking (ICLT) schemes incorporate inertia, load composition, frequency, and ROCOF in their calculations.

AUTOMATIC LOAD MANAGEMENT

Load management is an umbrella term used to describe several methods of equalizing load to generation for stability or economic reasons. The OT Intelligent Control Systems will perform load management via load restoration, load shedding, and adjusting of controllable loads. All load-management schemes will dynamically select load based on live power measurements, operator selectable prioritization, and changing bus topology conditions.

STANDBY GENERATION

The system will bring standby generation online after an island formation or loss of a distributed energy source. The amount of generation automatically brought online depends on the risk, load- to-generation balance, and spinning reserve values of the islanded microgrid. Note; Batteries and diesel generation are the most common standby generation sources.

GENERATION RUNBACK AND SHEDDING

Some islanding events result in greatly excessive generation on a microgrid. Under these conditions, power system frequency quickly rises out of control and results in a power outage. The OT Intelligent Control Systems will generate runback schemes to reduce the output of distributed generation while keeping the generation online. The systems generation shedding schemes will trip generators offline. Fast runback and shedding schemes will use island detection, while slower schemes use overfrequency thresholds, inertia, and ROCOF measurements.

SYSTEM FREQUENCY CONTROL

The OT Intelligent Control Systems must address islanded microgrids when a strong utility source to control the power system frequency is in question. For this condition, the OT Intelligent Control Systems will use advanced feed-forward AGC techniques to hold the system frequency at nominal while simultaneously maintaining distributed generation outputs within predetermined limits. When a distributed generation source is switched into stiff frequency control, the system will dispatch all non-frequency-regulating sources to keep all distribution within limits.

SYSTEM VOLTAGE REGULATION

The system will regulate the reactive power output of distributed energy resources to maintain islanded bus voltages within predetermined limits. The system will dynamically dispatch OLTCs, capacitors, excitation systems, STATCOM devices, and other reactive current producing assets.

SECTION 7: AUTOMATIC RESYNCHRONIZATION

The Contractor design will supply both unit synchronization and system synchronization systems, as described in the following subsections. After either a manual or automatic initiation, these systems automatically reduce slip, phase angles, and voltage differences before automatically closing a circuit breaker.

UNIT SYNCHRONIZATION

Unit synchronization schemes will adjust slip, phase angles, and voltage differences by sending control set points to a single distributed energy supply. These schemes will be provided in a single protective relay if applicable. The relay will automatically close the circuit breaker once acceptable slip, phase angles, and voltage differences are detected.

SYSTEM SYNCHRONIZATION

System synchronization schemes will resynchronize two or more islanded microgrids. These systems will adjust slip, phase angles, and voltage differences between the two grids by sending control set points to any number of distributed energy supplies. These schemes require several relays, I/O modules, and a central controller. A relay at each synchronization point will automatically close the circuit breaker once acceptable slip, phase angles, and voltage differences are detected.

SECTION 8: PROTECTION AND METERING

The OT Intelligent Control and Protective relay systems will be engineered for the safe operation of an electric power system. Metering systems are required for commercial and regulatory monitoring purposes. Protection and metering devices will provide system data for centralized controllers to process. The primary requirement for metering is for power quality, however, revenue meters are required for measurement and verification of power delivered to the customers.

PROTECTION SYSTEMS

The OT Intelligent Control Systems protective relays are highly reliable microprocessor-based devices, demonstrated mean time between failures (MTBF) in excess of 300 years. These devices will tolerate an operating temperature range from –40° to +85°C, and have a ten-year, worldwide warranty. The OT Intelligent Control System relays will provide comprehensive phasor measurement-based protection for buses, feeders, interties, transformers, motors, and generators. Protection will be coordinated across all high-, medium-, and low-voltage electric power systems and will be time-synchronized to the millisecond for accuracy and oscillographic event analysis. All front-panel target LEDs and pushbutton controls will be configured to operate as a local control interface and as a backup to a remote visualization system.

The OT Intelligent Control feeder protective relaying systems will include subcycle arc-flash detection and incident energy mitigation schemes. These technologies are a combination of light sensing and 4 ms overcurrent protection. These schemes will protect personnel and reduce equipment damage by significantly reducing the incident energy released during an arc-flash event.

POWER QUALITY MONITORING AND METERING SYSTEMS

The OT Intelligent Control Systems will use revenue-class metering and power quality monitoring devices separate from the protective relaying equipment. These highly reliable microprocessor-based devices will have a demonstrated MTBF in excess of 300 years and tolerate an operating temperature range from

–40° to +85°C. These devices will have a ten-year worldwide warranty and contain power quality (PQ) analysis and trending of all IEC 61000-4-30 PQ factors. These factors include voltage, current, frequency, harmonics (up to the 63rd), total harmonic distortion (THD), unbalance and symmetrical components, sags, swells, interruptions, flicker, and waveform capture up to 512 samples per cycle.

UTILITY AND GRID INTERCONNECTION

IEEE 1547 Interconnection. The contractor will follow this standard which provides the minimum functional technical requirements that are universally needed to help assure a technically sound interconnection of **technology neutral** Distributed Generation (Synchronous Machines, Induction Machines, Inverters) to the electric grid.

As part of an OT Intelligent Control Systems project, the contractor will provide the necessary support to add microgrid sources to an existing electric power utility or other distribution system, including requirements determination, local state rules review, microgrid sizing and facilities studies, electric power system studies, impact studies, limitation and upgrade studies, submission of applications to interconnect, cost estimates, IEEE 1547 compliance, and negotiation of the technical and commercial aspects of a mutually acceptable interconnection agreement for microgrid operation.

SECTION 9: VISUALIZATION AND ENGINEERING SYSTEMS

The OT Intelligent Control Systems visualization will properly collect, manipulate, and present power system data as usable information. These systems enable operators, maintenance staff, and engineering staff to operate and manage the microgrid system as well as diagnose system events, predict equipment failures, and minimize unnecessary maintenance.

HUMAN-MACHINE INTERFACE

The OT Intelligent Control HMI will provide graphical representations of systems and its sub-systems, access to real-time data, the ability to override points in a system, an interface with external management systems, and access to all supervisory monitoring and control functions. These systems operate at Layer 4 and do not influence the protection, control, and metering systems at lower levels. These systems display SER information, alarms, communications statuses, oscillography data, and trending and provide for set-point administration.

All necessary documentation, configuration information, configuration tools, programs, drivers, and other software are licensed to the end user. This allows the end user to repair, replace, upgrade, and expand the system without dependence on a specific manufacture. The OT Intelligent Control -supplied software licenses will not require periodic fees and are valid in perpetuity.

ALARM MANAGEMENT

Active alarm screens will visually indicate the state of alarms, including time-stamp, acknowledged, and return-to-normal indications.

OPERATOR LOGS

Operator action log screens will contain tabular display that documents every action a user takes while logged in to the system, including security items such as incorrect password entries or attempted unauthorized actions.

TRENDING

Trending screens will allow the user to display how selected values are changing as a function of time.

SEQUENCE OF EVENTS RECORDINGS

Sequence of Events (SOE) recordings will show binary state changes with 1 ms time stamps. The OT Intelligent Control Systems include software that collects SOE information from all devices on a microgrid. This software provides powerful viewing, analysis, and organization tools.

CONTROLLER LOG FILES

Controller log files are text file reports of controller actions that have occurred.

Daily Metering Report Logs

Daily metering report logs are text file reports of generation, kilowatt and kilovolt-ampere reactive outputs, and operation modes taken at 15 min intervals.

Oscillographic Event Recordings

Oscillographic event recordings will be collected by protective relays to show subcycle data sampling of currents and voltages associated with an electric power system fault. The Contractor OT Intelligent Control Systems include software that collects and displays time-coordinated oscillography data from the relays across the microgrid.

IEEE C37.118 Synchrophasor Reports

IEEE C37.118 synchrophasor reports will be 60-sample-per-second reports of voltages, currents, and other user-selected metrics. The OT Intelligent Control systems will include software that stores and views IEEE C37.118 synchrophasor data from all the relays.

Synchrophasors

Synchronized phasor measurements (synchrophasors) will provide real-time measurements of electrical quantities from across the microgrid. GPS satellite-synchronized clocks, phasor measurement units (PMUs), phasor data concentrators (PDCs), communications equipment, and visualization software are used to collect and consolidate these data. The protective relays used in high- and medium-voltage applications will include PMU capability.

Settings Management

The OT Intelligent Systems will include software that contains all the communications, protection, and automation settings and all the attributes of every protective relay, meter, controller, gateway, Ethernet switch, and I/O module in the system. The software will allow the user to connect to any device in the system; view online diagnostics; and modify (edit, add, or delete), upload, or download all threshold and logic settings on these devices.

SECTION 10: DOCUMENTATION

The Contractor systems will be supplied with sufficient supplemental documentation as required by NIST SP 800-82 latest to allow the end user to modify, repair, replace, upgrade, and expand the system without dependence on and specific manufactory. The following list represents a typical documentation set:

- Functional Design Specifications (FDSs)
- Electric system one-line diagram
- Communications architecture diagrams
- Data flow diagram
- I/O points list
- Communications design
- Reliability analysis
- AC and dc schematics
- Simulator drawings
- Bills of materials (BOMs)
- Model option tables (MOTs) and data sheets
- Spare parts lists
- User and maintenance manuals
- Cybersecurity assessment
- Electromagnetic Transients Program (EMTP) modeling validation report
- EMTP-based system stability report
- Factory acceptance test (FAT) agenda
- FAT results
- Training materials
- Commissioning and outage schedule
- Installation, startup, and commissioning plan
- Commissioning closeout checklist

- Signed and approved site acceptance test (SAT) results
- Signed and approved SAT action log
- SAT closeout checklist

SECTION 11: PROJECT EXECUTION

OT Intelligent Control Systems projects require attention to quality and detail, discipline, technical skill, and a proven set of project execution procedures.

SCHEDULING

The Contractor project managers will create plans for resource allocation, panel and part production, testing schedules, and site commissioning services based on OT Intelligent Control Systems requirements. The Contractor project manager is responsible for proper planning and providing qualified skilled workers to provide consistency throughout the technical and commercial solution.

QUALITY CONTROL

The Contractor will be ISO 9001-compliant. The Contractor will provide products that have a history by owner, by serial number and tracks MTBF, mean time between removal (MTBR), maintenance indicator (MI), and initial quality (IQ) information. The observed MTBF—not calculated or estimated based on component counts—will be at a minimum of 300 years or greater for manufactory products that are key components for resilience and security.

MODELING

The Contractor will provide simulations for proper understanding of system transients and dynamics for conceptual design of protection and controls. The Contractor OT Intelligent Control Systems will provide models based on first principles for microgrid assets such as flywheel storage, wind generators, battery storage, turbine and reciprocating driven (conventional) generation, solar generators, dump loads, dispatchable loads, battery storage, and power electronic devices.

VALIDATION TESTING

OT Intelligent Control Systems will be delivered after having undergone closed-loop factory testing of all completed control, protection, monitoring, and engineering subsystems. Validated EMTP models are connected to real controls and protection systems for these tests. Thousands of test cases are run in real time, allowing confidence that all systems will react as expected in the field. This testing method minimizes commissioning time for the OT Intelligent Control Systems. Users are requested to attend this testing as part of an FAT.

SIMULATION SYSTEMS

The Contractor will provide a simulators used during user field training and scenario testing of an offline control system. The contractor simulator options may range from simple to complex. Simple simulators play back live power system disturbances, will include breaker openings and power flow changes. The Complex real-time, EMTP-based simulators model will all transient reactions of the electric power system.

OFFLINE CONTROL SYSTEMS

The Contractor will provide offline copies of in-service protection and control systems. The Contractor OT Intelligent Control systems are typically connected to the Contractor supplied simulation systems and are commonly used to train users and perform system simulations in the field.

FACTORY ACCEPTANCE TESTING

The Contractor will provide the personnel, equipment, instrumentation, and supplies necessary to perform FATs. FAT procedures will define the tests required to ensure that the system meets technical, operational, and performance specifications. The Contractor procedures will define the location of the tests and the milestones for the tests. These procedures also identify simulation programs, equipment, personnel, facilities, and required supplies.

COMMISSIONING SUPPORT

The Contractor will supply personnel for onsite installation, commissioning, and SATs. For this work, product competent engineers will work under the direction of the user's engineer in charge and assists with technical issues that arise regarding devices and the OT Intelligent Control Systems during commissioning.

TRAINING

The Contractor will provide instructors and course materials to train personnel in the maintenance, service, and operation of the OT Intelligent Control Systems.

SECTION 12: CYBERSECURITY

All OT Intelligent Control Systems are designed with a defense-in-depth cybersecurity architecture that ensures resiliency of the network while keeping out malicious and unauthorized communications. The applicable criteria for this effort include: the Intelligence Community Directive (ICD) 503; DoD Instructions 8500.01 Cybersecurity and 8510.01 Risk Management Framework; and UFC 4-010-06. The high-level security features of an OT Intelligent Control Systems include the following:

- An electronic security perimeter (ESP) that is maintained at all outside system interfaces
- Separate business and operational communications systems
- Encryption for all access point connections
- Strong password capability requiring uppercase and lowercase letters, numbers, symbols, and 15-character passwords using a 90-character alphabet
- Multilevel access control that gives personnel access only to the functions they require
- Port timeouts that slow and/or eliminate automated or manual password guessing attacks
- A communications channel that disconnects after three bad attempts
- Real-time access monitoring that notifies about access attempts