TCF-20-20213: Advanced Power Distribution Sensing and Communications through the Cable TV Broadband Network

Final Report

Period of Performance: June 2020 to June 2022

Michael Ingram,[1] Scott Caruso,[2] and Robert Cruickshank[2]

1 National Renewable Energy Laboratory
2 CableLabs

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

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Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-5D00-83624
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NOTICE

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Cover Photos by Dennis Schroeder: (clockwise, left to right) NREL 51934, NREL 45897, NREL 42160, NREL 45891, NREL 48097, NREL 46526.

Executive Summary

To commercialize the rapid widespread commercial availability of secondary distribution grid voltage and phase angle data, the DOE OE Technology Commercialization Fund (TCF) project:[1] 1) created a new American National Standard for next-generation grid power quality sensing and communications, 2) created a new prototype broadband-based standard-compliant grid power sensing system for use by utilities and others, and 3) improved by several orders of magnitude the spatiotemporal scale of the in-progress DOE CESER CEDS project: *Situational Awareness of Grid Anomalies (SAGA) for Visual Analytics: Near Real-Time Cyber-Physical Resiliency through Machine Learning.*

The widespread adoption of consumer solar, battery storage, and smart-load distributed energy resources (DERs) creates many new challenges for power system operations and provides opportunities for next-generation grid sensors to enable distribution system state estimation; cyber event detection; physical fault location, isolation, and service restoration(FLISR); optimal power flow; and the provision of bulk system ancillary services from distributed resources. While DERs have the potential to revolutionize power system operations, an often-overlooked aspect is the need for scalable, low-cost grid power sensors and sensor communications to fully manage and utilize DERs in near real-time. Presently, the distribution system is sensor-starved and as such is ill-equipped to handle many new DER challenges. What is needed are robust and secure communications which rapidly propagate action-worthy information and provide utilities with real-time data from millions of new power sensors on distribution circuits to provide enhanced coordination and control. Fortunately, the cable television (CATV) broadband network already provides high bandwidth low-latency access to nearly 700,000 first-generation sensors of secondary distribution grid voltage and passes within 1,000 feet of over 95% of all U.S. properties. The first-generation CATV voltage sensors operated by cable companies today provide approximately one measurement location per 200 households, which represents a near order of magnitude increase in system visibility over the existing utility distribution point typically serving 2000 customers. Extending functionality beyond first generation broadband-based voltage sensing to include next-generation power quality sensing will provide additional spatiotemporal visibility for harmonics and anomalous transients. Standardizing low-cost broadband next-generation sensor functionality and creating prototype sensors are disruptive innovations that will accelerate sensor commercialization and smart grid technology adoption to increase the impact of DERs.

Major Deliverables of the TCF Project:

- Phase 1 – A new standard for broadband-based next-generation grid power sensors issued by the American National Standards Institute (ANSI) and the Society of Cable Telecommunications Engineers (SCTE).
- Phase 2 – Six prototype broadband-based next-generation (v2) grid power sensors for use by the National Renewable Energy Laboratory (NREL) plus six additional sensors for use by utility project partner members of the TCF project Technology Review Committee (TRC)[2].

[1] The TCF Project was funded by the U.S. Department of Energy (DOE), Office of Electricity (OE).
[2] The six additional sensors double the sensor count in the original project scope.

- Phase 3 – Improved spatiotemporal scale of the in-progress DOE CESER CEDS Situational Awareness of Grid Anomalies (SAGA) project award M619000162.

Summary of Scope, Objectives, and Impact:

- Widespread commercial availability of high-fidelity grid sensing via a synergistic combination of the evolving power and broadband communications infrastructures.
- Technical advancements that rapidly modernize situational awareness of the distribution grid and enable breakthroughs in the near real-time management of DER operations.

Budget & Tasks: The project is 100% spent from the baseline plan. The project completed on schedule and included a no-cost time extension from 3/1/2022 to 6/30/2022.

- **Task 1.1: Summarize limitations of existing standards-based sensors.** Comprehensive compilation of the limitations in the existing population of broadband-based voltage sensors in terms of variables and timing.
    - *Milestone Completed (Q1 FY21)* and was detailed in the quarterly report, meeting minutes, and the resulting consensus document. In summary, NREL, broadband, and utility stakeholders routinely met in the first several months of the TCF project to develop sensing requirements, review the strengths and limitations of existing sensors and sensing standards, and to ensure no conflict with existing standards and conformance with other ANSI and IEEE standards.
- **Task 1.2: Develop Use Cases and requirements.** Integration of physical modeling and simulation of synthetic power systems, including spatiotemporal dynamics concerning intra-area, boundary, and multi-region interactions.
    - *Milestone Completed (Q1 FY22)* and was detailed in the quarterly report. In summary, this milestone was originally scheduled to be completed in Q2 FY2020 but was delayed because our commercial partner, CommScope (though very helpful in Tasks 1.1 and 2.1) was unable to execute on delivering prototype sensors due to COVID-19 impact on their business. In lieu of CommScope's developing prototype sensors, CableLabs assumed responsibility for designing and building three revisions of prototype sensors. To ensure success, the CableLabs prototypes delivered a range of capabilities beyond the minimum requirements and specifications detailed in the new standard and encapsulated by our "Conceptualized Architecture" – that was tested and refined at CableLabs and is being validated at NREL and utility TRC partners.
- **Task 1.3: Draft a next-generation American National Standard for broadband-based grid sensing.** Create a new ANSI standard for variables observed, their resolution, timing, and transport, along with security requirements[3].
    - **Q2 Progress:** *Milestone Completed (Q3 FY21)* and was detailed in the quarterly report. In summary, this milestone was officially complete upon the Society of Cable Telecommunications Engineers (SCTE) and American National Standards Institute (ANSI) vote for acceptance of the standard. In the ANSI-accredited

[3] Completing the ANSI standard is in addition to the original project scope which only called for creating a draft SCTE standard. The SCTE standard setting process went smoothly allowing us to go beyond the draft stage, on to balloting and passing the ANSI standard.

standards setting process, after careful consideration of existing standards by the SCTE, broadband providers, broadband and utility vendors, and electric utility stakeholders, it was decided that the existing ANSI/SCTE 25-3 and 38-4 standards did not need to be updated--but that instead, a new standard should be created. As such, the TCF funds were used to create the new broadband-based grid power quality sensing standard, ANSI/SCTE 271 2021 *Requirements for power sensing in cable and utility networks*, which is attached as Appendix A.

- **Task 2.1: Summarize parameters to be observed and potential performance of observation engine (Part 1).**
    - *Milestone Completed (Q2 FY21).* The limitations of existing sensors and the variables that could be measured were summarized in the quarterly report.
- **Task 2.2: Summarize parameters to be observed and potential performance of observation engine (Part 2).**
    - *Milestone Completed (Q3 FY21).* The use cases and sensor requirements, parameters to be sensed, and communications for initiating and passing observations to a management system were implemented as summarized ANSI/SCTE 271.
- **Task 2.3: Deliver working prototypes.**
    - *Milestone Completed (Q2 FY22).* Prototype Sensors were delivered to NREL and utility TRC partners.

Funding Source:
The TCF Project was funded via an amended SAGA project Statement of Work. For details, see Scope of Work in document TCF_1M-Mod1-AppdxA-1(#SUB-2020-10140).pdf, which is attached as Appendix B.

Scope of Work:
The TCF project focused on three main topic areas:

- A U.S. draft standard for broadband-based next-generation grid power sensors
- Six prototype broadband-based next-generation grid power sensors
- Improved spatiotemporal scale of the in-progress SAGA project, i.e., this [TCF] project is focused primarily on the hardware components to the ongoing, parallel SAGA software project.

Intellectual Property:
The U.S. patent, HETEROGENEOUS NETWORK TOPOLOGY MANAGEMENT AND CONTROL was granted on January 12, 2021. Please see Appendix C for details.

Technical Review Committee:
We are thankful that the SAGA TRC also were stakeholders that guided the TCF project to success. A letter in support of follow-on SAGA and TCF work is included in Appendix D.

Table of Contents

1 Project Overview

1.1 Goals:

1. Leverage National Laboratory, utility, vendor, and university research experts to define the types, sampling rates, and resolutions of power measurements that would be helpful to utility Distribution System Operators (DSOs) in managing secondary distribution grids and DERs.
2. Leverage broadband industry engineering and operations experts to define additional broadband network measurement functionality that, along with grid measurements, could be built-in to broadband-based next-generation power sensors.
3. Combine the lessons learned in pursuing Goals (1) and (2) to revise the existing U.S. ANSI/SCTE standard or to create a new ANSI/SCTE draft standard for broadband-based next-generation power measurements.
4. Create prototype broadband-based next-generation grid power sensors suitable for use and evaluation by project partners.
5. Extend the prototype data collection system to securely aggregate and deliver data at higher data rates from the next-generation power sensors.
6. Improve the spatiotemporal scale of the in-progress DOE CESAR CEDS Situational Awareness of Grid Anomalies (SAGA) project.
7. Deliver a rapid, commercially viable quantum advancement in electrical grid secondary distribution sensor data without massive new capital expenditures.

1.2 Objectives:

1. Create commercially available high-fidelity sensing of the grid via a combination of the evolving power and broadband communications infrastructures.
2. Produce technical advancements that modernize situational awareness of the grid and enable breakthroughs in near real-time management of DER operations.

Progress with v1 sensors: An increasing number of CableLabs member companies continue to support commercial aggregation of first-generation (v1) sensors and data are being collected periodically every 1 to 5-minutes for approximately 300,000 sensors. Presently, half of the United States lives within 1 km of a v1 sensor and plans are in place to double the v1 sensor footprint. Tools and specifications were developed to standardize collection of v1 sensor data every five minutes or less and data are aggregated in a national (and soon to be international) data store.

Progress with v2 sensors: Next-generation sensors compliant with the new ANSI/SCTE 271 standard are being deployed. As part of an analytical and experimental proof of concept, analysis of v2 sensor data is underway in the laboratory and in the field to establish baselines and thresholds for power quality operational parameters. In addition, functionality is being developed and trialed to automatically provide alerts when thresholds are exceeded (e.g., voltage high, low, fluctuating, absent, etc.).

1.3 Motivation and Plan

Disrupting the status quo was necessary for innovation, and the next-generation standard revolutionizes and creates synergies between two enormous industries, cable and utilities. An appropriate marriage of technologies from two domains of nearly twinned topology, the electric distribution and cable television (CATV) broadband networks, helps enable rapid progress in grid modernization and yields a fresh take on the smart grid by leveraging the critical mass of existing v1 and new v2 sensors to accelerate the implementation of DERs. Making sensor data available is synonymous with expanding the grid's SCADA system down to the neighborhood level without massive new capital expenditures. Neighborhood-level sensor data is important to support location-specific creation of price- or supply-responsive information such that DERs in buildings can be orchestrated to have an aggregate influence and act as ancillary services to jointly optimize electricity supply, demand, and distribution networks over multiple timescales.

The project first examined the types, sampling rates, and resolutions of power measurements that would be helpful to DSOs in managing secondary distribution grids and DERs. This was important because the rapid growth of DERs raises new operational questions such as whether voltage or current are flowing into or out of a house, up or down a city block, or into or out of a neighborhood. Furthermore, the risk of a misbehaving DER, such as a faulty inverter on a household PV array causing spurious power oscillations that impact an entire neighborhood, increases dramatically as DERs flourish in number.

The sensor capabilities in existing CATV network power supplies were studied with the goal of determining missing functionality that is critical for DSOs. First-generation v1 sensors located in battery-backed uninterruptible power supplies currently monitor the state of the cable TV network on the level of 200 homes and represent a tremendous advancement in distribution grid sensing and visibility. However, additional orders of magnitude improvement become possible through the same CATV networks as the v1 broadband sensor population expands further into neighborhoods.

The project next examined possibilities for functionality additions and enhancements that would benefit DSOs and could be built-in to broadband-based next-generation power sensors. For example, from a hardware perspective, Commscope International, the world's largest manufacturer of broadband equipment, estimated that the Bill of Materials for high fidelity grid sensors embedded into the existing network equipment supporting CATV deployments could be less than $1000 at scale.

In addition, grid voltage measurements could be added to the bill of materials for a HFC cable modem for less than $1 per device and grid frequency measurements for less than $4 per device. New devices are routinely installed during capacity expansion efforts in the normal course of business, which would result in a rapid growth of the existing population of sensors.

In addition to backhaul for network power supplies, neighborhood Wi-Fi and 5G access points, cable modems with Ethernet and Wi-Fi interfaces already serve as gateways to utilities for DERs such as solar PV inverters, electric vehicles, and demand side management equipment. From the distribution grid perspective, new power sensors further enhance the ability to monitor and control DERs, and allow for integration with forecasting, planning, operations, and business support systems. The broadband network provides the massive next generation monitoring and communications necessary for the multiple geospatial and temporal data resolutions required for active DER market participation.

- **Task 1:** Revise the existing or create a new draft U.S. standard—One of the main limitations of most existing first-generation broadband voltage sensors is a 1.2 VAC input voltage precision which results in large quantization errors when sampling the continuously varying distribution secondary voltage. With the v2 sensor, higher resolution voltage readings combined with more accurate timestamps and high sample rates increase the operational value and accelerate the adoption of broadband sensor data and the recognition by both power utilities and cable broadband providers of the potential synergies of more closely intertwining their network operations. Therefore, we proposed to carefully develop a new standard based on the emerging needs of DSOs and the potential capabilities of next generation broadband power sensors. The team already had access to the existing v1 voltage sensor data necessary to conduct these studies. The successful completion of this task provided standardized specifications that bolster commercialization and market adoption of v2 power sensors. Table 2.1 summarizes Task 1.

Table 2.1: Task 1 Milestones, Outcomes & Goals Achieved, and Due Date

Milestone	Description:	Due Date:
1) Summarize limitations of existing standards-based sensors	Comprehensive compilation of the limitations in the existing population of broadband-based voltage sensors in terms of variables and timing.	Month 3 Completed
2) Develop Use Cases and requirements	Documented use cases and corresponding sensor requirements for one or more of: cybersecurity, distribution system state estimation, load shaping, fault location, isolation, system restoration(FLISR), Volt-Var optimization, conservation voltage reduction(CVR), distribution system optimal power flow, and the provision of bulk system ancillary services from distributed resources	Month 6 Completed
3) Draft a next-generation U.S. ANSI/SCTE standard	Draft submitted to create a new ANSI/SCTE standard for variables observed, resolution, timing, and protocol.	Month 9 Completed

- **Task 2:** Prototype Next-generation Sensors—An operational development environment was used to create prototype v2 broadband power sensors that can be used in network elements and, perhaps someday, customer premise equipment. Prototype sensors leverage capabilities such as an accurate clock reference from the GPS network to timestamp the high-speed analog to digital conversion of observations. Sensor design options for voltage, frequency, and phase angle were explored for cost viability and environmental longevity. Use cases were found to have differing data intensity requirements and practical limitations related to the specific variables being observed. Table 2.2 summarizes Task 2.

Table 2.2: Task 2 Milestones, Outcomes & Goals Achieved, and Due Date

Milestone	Description:	Due Date:
1) Summarize parameters to be observed and potential performance of observation engine	At the completion of the Task 1.1 milestone to summarize the limitations of existing sensors, the variables that could be measured by a cable modem and the performance of doing so were explored and summarized	Month 6 Completed
2) Summarize parameters to be observed and potential performance of observation engine	At the completion of the Task 1.2 milestone to document use cases and sensor requirements, the parameters to be sensed and an Application Programming Interface (API) for initiating and passing observations to a managementsystem were implemented	Month 9 Completed
3) Deliver working prototypes	Prototype sensors and data collection system shared with project partners	Month 15 (was Month 12)

2 Commercialization Plan

2.1 Target Markets

Target markets for commercialization of the technology include distribution system operators (DSOs), broadband service providers (BSPs), and vendors in each industry that make power quality sensors such as syncrophasors, advanced distribution management systems, and communications systems to backhaul sensor readings. It was anticipated that potential market barriers could include poor participation by DSOs, BSPs, and vendors; unsuccessfully integrating newly available standardized sensor data into DSO operations; and a potentially unfavorable cost-benefit analysis of next-generation sensors. Market barriers were anticipated and overcome through project involvement with the departments responsible for product development, standardization, testing, and technology transfer within DSOs, BSPs, National, academic, and industry laboratories, the SCTE ANSI-accredited standards body of the Cable TV (CATV) industry, and vendor product management functions. Over time, the business justification for purchasing, installing, and operating next-generation broadband-based power sensors will improve as BSPs create value by organically expanding their networks and adding commercial off-the-shelf broadband sensors.

2.2 Competing Technology

For the very same reasons that broadband-based distribution power sensors are attractive, the market for power sensors from companies like Sentient, Alcara and Landis+Gyr is experiencing significant growth, despite the high costs of $10k to $15k per sensor for a sophisticated power sensor such as a phasor measurement unit (PMU). Due to their high cost, mass PMU deployment has focused on transmission infrastructure. In contrast, we believe broadband-based power sensors that offer microPMU (uPMU) functionality costs significantly less and do a better job. A complicating factor with the PMUs is that the wave shape of voltages and currents in secondary distribution grids is incompatible with the sine-wave-based PMU measurement model. As such, measurements produced using PMUs during times of grid stress will be of questionable value. We believe that DSOs achieve ubiquitous distribution grid sensing and control much faster and cheaper when leveraging millions of existing and newly installed broadband-based power sensors.

NREL was awarded a U.S. patent on technology for managing the heterogeneous network topologies of DSOs and BSPs to leverage the existing broadband voltage sensors and communication networks. That said, we believe broadband power sensors will eventually co-exist (with some level of investment) in utility-owned and operated sensors. There were no privacy concerns in the scope of this project as all distribution grid sensors are physically located in the broadband access network (i.e., the last mile), not in homes or businesses. In the future, if power sensors are installed in buildings, privacy issues would be overcome by anonymization of measurements and by secure communications based on two-factor authentication and other identity protection schemes potentially including a secure blockchain implementation.

2.3 Related Intellectual Property

The roots of this research began with the DOE project: "GMLC 1.4.4: Buildings as Sensors". During the GMLC 1.4.4 project, the NREL team applied for the aforementioned U.S. patent,

HETEROGENEOUS NETWORK TOPOLOGY MANAGEMENT AND CONTROL. The patent was granted on January 12, 2021 and is included in this Final Report because of its relevance to our TCF project; please see Appendix C for details.

2.4 Commercialization End State

The commercialization end state of the project supports existing and new power sensor data being widely available to utilities, public service, and safety entities in various U.S. markets of BSPs. Pilot and commercialization agreements are in place for sharing sensor data from the BSPs. In addition, there are ongoing efforts to develop commercial agreements and obtain sensor readings from broadband networks worldwide.

2.5 Industry Transformation

CATV next-generation power sensors can radically transform existing approaches by removing the construction time and cost barriers for the installation of electric grid distribution network sensing and communications infrastructure. Stakeholder benefits are anticipated throughout the value chain. Energy providers can immediately benefit from increased distribution network visibility and reduced operational expense along with better, faster, and cheaper outage and disaster management. Energy providers' smart grids will also benefit from improved power quality and cybersecurity. The CATV sensors will complement and improve the cybersecurity of existing smart grid sensing and communications by aiding in detection, confirmation, and mitigation of cybersecurity events.

The CATV broadband access network is based on the Data Over Cable Service Interface Specifications (DOCSIS), international standards that have been routinely revised since their inception in 1998. DOCSIS networks have demonstrated resilient cybersecurity against hackers. Over 2 billion cable modems that meet the DOCSIS standards have been deployed and very few cybersecurity and denial of service incidents have been reported. In contrast, there are limited deployments of utility distribution network communication systems; most are a heterogeneous mix of slower speed proprietary and open solutions and, as such, are inherently more susceptible to cyber-attack as evidenced by frequent reports appearing in the press of the grid being hacked. BSPs can benefit and earn revenue by providing sensing as a service along with backhaul of intra-grid communications, for example, for distributed PV inverters.

There is increased awareness and concerns of the expanding volume of cyber-attack vectors. For example, attack vectors that are focused on disrupting the demand side of the grid could result in coordinated manipulations of the supply side. Such attacks may not involve the intrusion of the utility networks, but rather the 'smart devices' that modulate, time-shift, and control power consumption (EV chargers, HVAC and water heater thermostats, commercial and industrial loads, etc.). Increasing visibility to last mile distribution networks cyber "blind spots" helps improve the day-to-day operations of distribution utilities and retail electric providers.

2.6 How the Technology Represents an Innovative and Significant Improvement

CATV broadband-based sensors expose power quality and consistency of the secondary distribution grid by combining voltage (and in the future, current, and frequency) sensor data with the high-speed, low-latency, secure broadband communication network. Heretofore, utilities could not access this unique CATV broadband sensor dataset. Moreover, even where utilities have deployed automatic meter reading and advanced metering infrastructure, voltage sensing of all deployed smart meters is limited to 240-volt measurements. As such, utilities do not see the 'as-delivered' quality of 120-volt service and remain blind to hazardous life- threatening issues related to unbonded, open, or intermittent neutral and other grounding related issues.

The gigabit speeds and millisecond latencies provided by today's DOCSIS networks are unsurpassed by available utility distribution network communications solutions, and it is unclear whether any amount of new investment would allow utilities to quickly surpass the performance of CATV broadband networks.

Furthermore, broadband-based sensor data is available through a customizable commercial version of the application programming interface (API), accessed via a virtual private network that can provide visibility to the vast quantity of existing sensors throughout the distribution network. Hundreds of new sensors are added by BSPs every day in the normal organic growth of the broadband business that increases network capacity and reduces the size of serving areas. Conversely, modern approaches to deploying smart grid sensing take months to years to complete and require enormous capital commitments for installing sensors and erecting and commissioning communications networks. While the sensor reporting APIs and analytics are being refined by NREL and CableLabs, the data service itself is powered by mission-critical sensors maintained and operated by cable companies throughout the world.

3 Compilation of Relevant Material from Quarterly Updates

It is important to note that the material in this section came from working documents. As such, where differences or inconsistencies are noted, the ANSI/SCTE 271 standard is the defining document and supersedes this material.

3.1 Project Authorization Request Approved by SCTE/ISBE Standards

Appears on next page.

Project Authorization Request (PAR)

In order to propose a new standards or operational practice project, please fill out the following form and submitit to SCTE. If needed, Rights Management and Patent Declaration forms are available at http://www.scte.org/standards. This proposal will be reviewed by the SCTE Engineering Committee and you will be notified of the disposition.

Title of Proposed Standard or Project:
Standard for observing power quality on electric utility secondary distribution grids.

Abstract:
This project will bring up to date ANSI/SCTE 25-3 and 38-4 or will result in a development of a new standard.Both existing standards date back to (at least) the mid-1990s and, among other things, specify methods to remotely observe voltage on the 120/240 VAC power grid: 1) ANSI/SCTE 25-3, Hybrid Fiber/Coax (HFC) Outside Plant Status Monitoring – Power Supply to Transponder Interface Bus (PSTIB), and 2) ANSI/SCTE 38-4,Hybrid Fiber/Coax Outside Plant Status Monitoring SCTE-HMS-PS-MIB, Management Information Base (MIB) Definition.

Ongoing research at several U.S. Dept of Energy (DOE) National Laboratories and CableLabs shows that HFC-based grid voltage observations are unique and useful to electric grid operators, Homeland Security, FEMA, insurance companies, and local through national emergency responders. Use cases for grid power quality data have been developed and information on pilot deployments are available from CableLabs.

Broadband-based power quality sensing is already critically needed to detect and coordinate multi-agency recovery from outages—and will be increasing important as the grid evolves to a mesh of two-way energy flowsbetween central station generators and the ever-increasing number of connections between distributed energy resources (DERs) such as Internet-connected photovoltaic panels, battery walls, electric vehicles (EV).

Today, utilities' secondary distribution systems—the last mile of the grid—are sensor-starved and ill-equipped to handle the challenges introduced by new operational technologies such as DERs and digital automation fromIoT devices, smart cities, and homes. The introduction of DERs and the evolution to energy sharing between homes and businesses is accelerating exponentially with the growing commitments of cities, states and nations to rapidly transition to carbon-free energy and 100% renewable energy sources.

The widespread adoption of DERs creates challenges for power system operations, providing opportunities for broadband-based power quality measurements to provide data to advanced sensing and supervisory algorithms to enable distribution system: state estimation; fault location, isolation, and optimal power flow; and the provision of bulk system ancillary services from distributed resources. While DERs have the potential to revolutionize power system operations, an often-overlooked aspect is the need for scalable, low-cost sensors andcommunications to fully utilize DERs in near real-time. What is needed are robust and secure communications which propagate action-worthy information and provide utilities with real-time data from millions more sensors for coordination and control of distribution circuits.

The grid voltage observations already routinely collected from cable company HFC power supplies provide approximately one measurement per 200 customers; this represents a near order of magnitude increase in distribution system visibility over existing utility substation readings per 2,000 homes. Defining next-generation broadband power quality sensory capabilities will enable additional spatiotemporal visibility, with granularity approaching individual buildings (without involving any personally identifiable information, PII). Commercializing the availability of existing sensor data while standardizing next-generation functionality is a disruptive innovation that will accelerate smart grid technology adoption and increase DER impact.

In a world of increasing energy reliability and resiliency concerns, the cable television industry faces energy complexities, outages, and rising costs. Around the world, relationships between cable companies and energy utilities vary. Both industries work together every day to build out and ensure the reliability of the existing broadband infrastructure. However, utilities generally deploy their own communications infrastructure, whichprecludes the Cable industry from monetizing already existing and evolving broadband assets.

The challenges that utilities experience while evolving the grid to two-way flows of electricity are somewhat reminiscent of the challenges faced by the Cable industry transitioning from delivering one-way broadcasts to two-way services. As utilities deploy proprietary monitoring solutions, they lack the Cable industry's capabilityof monitoring the availability of grid power via broadband power supplies that communicate quickly and reliably using the world standard DOCSIS cable modem. Furthermore, the proprietary communications solutions deployed by utilities are proving to be slow and increasingly susceptible to cyber-attack. In contrast, broadband-based power quality sensing via DOCSIS-based power supplies has a proven track-record of providing cyber-secure communications and is an active research area within the DOE (see September 2019 NREL/CableLabs $3M, 3-year award for *"Situational Awareness of Grid Anomalies (SAGA)",* fourth from bottom: https://www.energy.gov/ceser/cybersecurity-energy-delivery-systems-2019-research-call-awardees).

In addition to SAGA, the DOE is also funding $250k for "*Advanced Power Distribution Sensing and Communications Through the Cable TV Broadband Network"* with project partners CableLabs, SCTE, Commscope, and utilities Holy Cross Energy in Glenwood Springs, CO and Northern Lights, Inc. in Sagle, ID.

Access network power quality sensing has a vital role in sustaining the viability of the broadband industry by creating opportunities in grid sensing, status monitoring, and proactive grid management. The default future of "business as usual" relationships with utilities can result in missed opportunities and fewer jobs for the Cable industry. Alternatively, monetizing HFC grid power quality observations can provide immediate and growing value to utilities for managing DERs and repair actions that improve the security & reliability of energy supply.

This project is intended to produce: ☒ Standard ☐ Operational Practice

Is there intellectual property associated with this PAR?

☒ No

☐ Copyright (Please provide a Rights Management form)

☐ Patent (Please provide a Patent Declaration form)

Submitter's Name and Title: Robert F Cruickshank III PhD, Consultant
Submitter's Organization: National Renewable Energy Laboratory / CableLabs
Date: 6/19/2020 Phone: 703-568-8379
E-mail address: rfciii@cruickshank.org

FOR STAFF USE ONLY	**EC-2020-016**	**Subcommittee: NOS**	**EC Approval Date: 07/13/2020**
EC Comments to subcommittee: None			

3.2 Meeting Minutes and Agendas from Nov. and Dec 2020, and Jan. 2021

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Network Operation Subcommittee, Working Group 4HFC Management

Jim Welch, Chair

Meeting Minutes

Teleconference, Nov 05, 2020

4:00 p.m. – 5:00 p.m. Eastern

1. The proposed agenda was reviewed. The agenda is included below. No modifications were made. There were 13 attendees.

2. The minutes from the last meeting were accepted with no edits.

3. A minute taker to help with preparing meeting minutes was requested. With no volunteers, the chair will take notes and requests the membership's additions and corrections. Your help for one or more future meetings would be appreciated!

4. Bob Cruickshank reviewed Requirements updates and reviewed papers on the following:

5. Clock Recovery on [DOCSIS and PON] networks
    a. PMU Tutorial
    b. High-Resolution, Time-Synchronized Grid Monitoring Devices

6. In meeting discussions, consensus was achieved that the following sample rates and accuracies should be specified: (Refer to the working Google spreadsheet for Definitions and other project information)

Sensor internal parameters in use prior to reporting a measurement
Voltage & Current, V & I : 0.1%, 30K samples per second, ~500/cycle good enough
Phase angle 10-50 millidegrees, 30K/sec
Frequency, Rate of Change of Frequency (ROCOF), "goodness of fit"
Observation Timestamp resolution of 10e-6 relative to UTC, clock accuracy of 500*10e-9
Include specification of all embedded post-processing required (such as averaging and peak hold) that are used in translation from internal parameters to external communication?
Consideration for associated meta-data required, e.g., 1) Lat/Long automatically via GPS or manual, 2) feeder circuit ID ...

7. Consensus was also reached that a Sensor Specification should be completed first. Command and Control structures would be out of scope for this document.

8. Another Specification covering Authorization, Configuration, and Reporting requirements but without specifying the specific protocols or details required for implementation was proposed. This was considered in noting that we want to avoid duplicating or competing with other SDO work, both existingand ongoing, such as those from the IETF such as RFCs 7326, 7461, 7460, and IEEE P2664.

9. The next WG4 teleconference will be November 19, 2020 at 4:00 p.m. Eastern for 1 hour and every 2 weeks following.

Network Operations Subcommittee, Working Group 4

Jim Welch Chair

Meeting Agenda

Teleconference, Nov 5, 2020
4 p.m. – 5:00 p.m. Eastern

Teleconference information:

https://global.gotomeeting.com/join/533729853

You can also dial in using your phone.
United States: +1 (571) 317-3129

Access Code: 533-729-853

1. Introductions/Roll Call/Identify minute taker
2. Review and approve the minutes from the last call
3. Bob Cruickshank:
    a. Review updates to Requirements
    b. Document overviews:
        i. Clock Recovery on [DOCSIS and PON] networks
        ii. PMU Tutorial
        iii. High-Resolution, Time-Synchronized Grid Monitoring Devices documents
4. Other business
5. Next WG4 Teleconference Nov 19, 2020 at 4 p.m. Eastern (and every 2 weeks following)
6. Adjourn

Network Operations Subcommittee, Working Group 4

Jim Welch Chair

Meeting Agenda

Teleconference, Dec 17, 2020

4 p.m. – 5:00 p.m. Eastern

Teleconference information:

https://global.gotomeeting.com/join/922117341

You can also dial in using your phone.

United States: +1 (224) 501-3412

Access Code: 922-117-341

1. Introductions/Roll Call/Identify minute taker
2. Review and approve the minutes from the last call
3. Bob Cruickshank: Review and discuss sensor form status
4. Bob Cruickshank: Do we have consensus on writing a new spec rather than revising an existing one?
5. Other business
6. Next WG4 Teleconference Dec 30, 2020 at 4 p.m. Eastern (and every 2 weeks following)
7. Adjourn

Network Operations Subcommittee, Working Group 4

Jim Welch Chair

Meeting Agenda

Teleconference, Jan 14, 2021

4 p.m. – 5:00 p.m. Eastern

Teleconference information:

https://global.gotomeeting.com/join/922117341

You can also dial in using your phone.

United States: +1 (224) 501-3412

Access Code: 922-117-341

1. Introductions/Roll Call/Identify minute taker
2. Review and approve the minutes from the last call
3. Bob Cruickshank: Review and discuss draft of new document
4. Other business
5. Next WG4 Teleconference Jan 28, 2021 at 4 p.m. Eastern (and every 2 weeks following)
6. Adjourn

3.3 Consensus among SCTE Standards Members

SCTE GridSenseCom Consensus Form - Completed during WG4 session 12/17/20

Purpose: Confirm consensus of broadband Ops & OSS staff on HFC Grid Sensing and Communications.

Overview: Meeting bi-weekly since August, the SCTE Network Ops Subcommittee Working Group 4 (WG4) is now finalizing requirements for sensing and communicating power quality observations on both the 90 VAC quasi-square wave HFC network and the 120/240 VAC supply from the electric power grid.

Use Cases:

1. Cable TV HFC power quality needs to be monitored for anomaly 'glitches' known to cause the reboot of newer digital HFC actives which interrupt voice, video, and data services for up to 15 minutes.
2. Utility secondary distribution grid power quality needs to be monitored for anomaly 'glitches' known to cause wildfires and shorten the lifespan of cable TV infrastructure elements, CPE, consumer appliances.
3. Future use cases may include other network access equipment including xPON, switched ethernet, Wi-Fi hotspots, small cells, etc.

Limitations of existing solutions:

Since 2002, day-to-day Cable TV grid power outage detection relies on voltage and inverter status readings retrieved from DOCSIS modems connected to neighborhood HFC power supplies. Limited voltage resolution,sampling rates, and transport over SNMP (Simple Network Management Protocol) are rudimentary for detecting critical anomalies that cause loss of life/property and disrupt service.

Proposed Sensing Requirements:

For network elements, Grid and HFC voltage will be sensed with a precision of 0.001 per-unit (0.1% of the nominal value), e.g., +-0.12 volts at 120 VAC. For devices that measure power, amperage and will be sensed with a precision of 0.001 per-unit. A continuous point on wave (CPOW) capture will be configurable, e.g., 10k samples/sec, to support the identification of loose seizure screws, life-threatening faults such as unbonded grounds and floating neutrals, high-impedance faults such as arcing grid conductors, and unintended behavior of distributed energy resources such as solar inverters and EV chargers feeding power into the grid when they shouldn't, e.g., during line maintenance. Requirements discussion is ongoing for sensing of frequency, rate of change of frequency, and sine-wave goodness of fit.

Observation Timestamp resolution <= 10e-6 secs relative to UTC w/ clock accuracy <=500*10e-9 seconds.

The timing signal will be driven by an onboard GPS/satellite timing subsystem, or possibly DOCSIS or GPONloop timing or other timing system.

Proposed Configuration Requirements:

1. A control plane will be used to configure sensor reporting: destination, rate, and stop time. This will allow sensors to be configured for: a) a 1-time poll reply, b) continuous replies or c) fixed interval replies.
2. An optional embedded downloadable event engine will enable network-efficient edge detection.

Proposed Communication Requirements:

1. A communication plane will use gRPC or other modern network transport using IETF/APSIS YANG model.
2. There will be no backward compatibility for SNMP; no retrofit is anticipated for existing SNMP sensors.

Why now? The evolution of the cyber-secure smart grid requires a concomitant growth in sensing technology. The resilience of the 5.5 million miles of distribution lines (96.5% of the grid) can be greatly enhanced with additional monitoring. SCADA and other telemetry systems will benefit. Migration from 1-way delivery of central power to dynamic 2-way flows of distributed renewable power creates an unlimited number of changing 'normal' states that thwart detection of anomalous states created by cyberattacks and failing infrastructure. Cable needs the grid to be reliable and is a most capable partner.

3.4 Grid and Broadband Network Use Cases

The goal of the grid and broadband network use cases is to capture uses and observational parameters as shown in Figure 1.

Cable-specific Use Cases 60/90 VAC	Shared Use Cases 120/240 VAC	Utility-specific Use Cases 120/240 VAC
	Business scenarios	
Sensors and all node devices working properly (HFC Outage)	Grid outage	Circuit reconfiguration
Power supply inverter status	Grid voltage sag	High-impedance / transient arc faults
Impact, spatiotemporal extent, and map of anomalies	Impact, spatiotemporal extent, and map of anomalies	Impact of distributed generation and storage
Individual battery: Voltage, SoC, minutes remaining, Temp, Sulfation, EOL	Config and read sensors	Impact of EVs
Generator required?	Detect cybersecurity attacks	Volt-Var Optimization (VVO)
Generator refuel required?	Alarms on events based on triggers, aka event capture & reporting	Conservation Voltage Reduction (CVR)
Node outage detection that rapidly updates all customer contact channels	Multi-protocol synchronous and asynchronous push & pull	Frequency deviation
Odd current draw indicating a short or fault in a network element	Edge detection with minimal compression	Congestion detection
	Sensed variables	
Voltage	Voltage	Frequency
Current	Current	Phase angle
Quasi-square waveform capture	Waveform capture including interuptions	Grid congestion?
Battery readiness (SoC, Voltage...)	Temperature & Environmental	
	Sensor internal parameters in use prior to reporting a measurement	
	Voltage & Current, V & I : 0.1%, 30K samples per second, ~500/cycle good enough	
	Phase angle 10-50 millidegrees, 30K/sec	
	Frequency, Rate of Change of Frequency (ROCOF), "goodness of fit"	
	Observation Timestamp resolution of 10e-6 relative to UTC, clock accuracy of 5*10e-9	
	Include specification of all embedded post-processing required (such as averaging and peak hold) that are used in translation from internal parameters to external communication?	
	Consideration for associated meta-data required, e.g., 1) Lat/Long automatically via GPS or manual, 2) feeder circuit ID ...	
	Sensor parameters used when externally communicating a measurement	
	TBD	
	Bachkhaul via IEEE-2664 (PAR in 2018) or other methods	

Figure 1: Use Cases and Observational Parameters

3.5 Conceptualized Architecture

The goal of the sensor system Conceptual Architecture is to create secure, independent, real-time instrumentation and communication planes to modernize the distribution power grid and deliver power insights to improve grid performance, security, and resilience as shown in Figure 2.

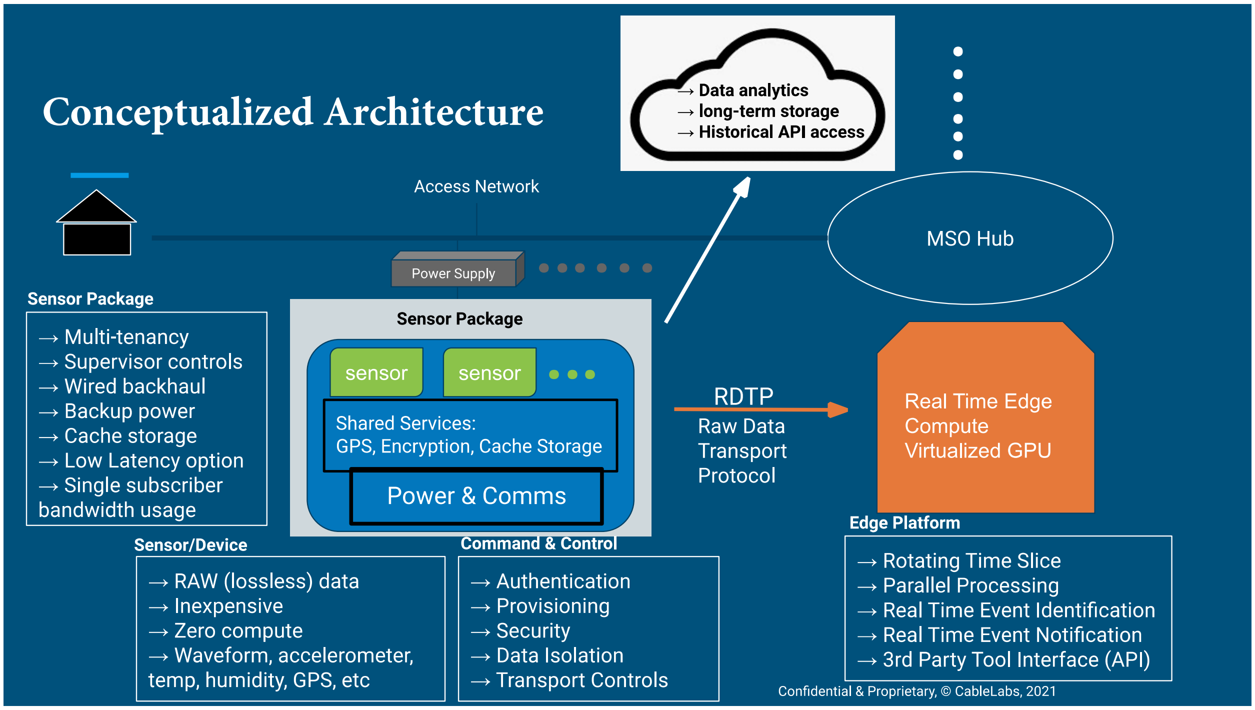

Figure 2: Conceptualized Architecture

The unique features of the sensor system include:

- Sensor location and density
    - Existing real-estate platform at the intersection of power and communications
    - Platform for extracting value from existing in-service sensor and communications assets
- Flexible sensor packages
    - Sensor packages configurations based on application needs and deployment density
- Unmatched data frequency
    - Real-time streaming data services
- Data form
    - Lossless, unfiltered, raw data aggregated at the Edge
- Unprecedented data processing and analysis
    - Leveraging the Edge's ability to analyze multiple raw data streams, GPS aligned

The Key takeaways of the sensor system include:

- Leverages existing broadband infrastructure assets
- No personally identifiable information - Broadband operators own all the sensors, data & distribution rights
- Opportunity to provide instrumentation necessary for modernizing the power grid

- Natural extension of grid cybersecurity effort funded by DOE for NREL's SAGA project (CESERCEDS)
- Compliant with emerging SCTE point-on-wave next-gen power sensing standard
- Existing sensors are Disruptive technology creating visibility to out-of-band grid monitoring
- Next-gen sensors and sensing system are transformative in creating an "instrumentation-as-a-service" platform

4 Appendices

A. ANSI/SCTE 271: Requirements for Power Sensing in Cable and Utility Networks

Begins on next page.

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Network Operations Subcommittee

AMERICAN NATIONAL STANDARD

ANSI/SCTE 271 2021

Requirements for Power Sensing in Cable and Utility Networks

NOTICE

140 Philips Road
Exton, PA 19341

Document Types and Tags

Document Type: Specification

Document Tags:

☒ Test or Measurement	☐ Checklist	☐ Facility
☐ Architecture or Framework	☐ Metric	☒ Access Network
☐ Procedure, Process or Method	☐ Cloud	☐ Customer Premises

Table of Contents

Title **Page Number**

1. Introduction

1.1. Executive Summary

This specification provides precision, sampling rate, and configuration requirements if vendors choose to measure and report voltage and/or current in hardware and software to enable advanced power sensing in cable and utility networks. Included are requirements for sensing and communicating power quality observations from both the 60/75/90 VAC quasi-square wave HFC network and the 120/240 VAC supply from the electric power grid. For systems that require remote communication of measurements, requirements for the control plane and communications security are specified. This specification does not *require* any particular measurements, but if supply voltage and/or current is measured, it specifies *how* those measurements must be made to realize the benefits described in section 1.3.

More details about the specified measurements and their precision, sampling rate, and reporting requirements usefulness and application are further detailed in the published paper "High-Resolution, Time-Synchronized Grid Monitoring Devices" referenced in section 3.3.

1.2. Scope

The scope of the standard covers two distinct use cases.

1. Cable TV Hybrid Fiber-Coax (HFC) power quality needs to be monitored for anomaly 'glitches' known to have caused the reboot of some newer digital HFC actives which interrupted voice, video, and data services for up to 15 minutes.
2. Utility secondary distribution grid power quality needs to be monitored for anomaly 'glitches' known to cause wildfires and shorten the lifespan of cable TV infrastructure elements, customer premises equipment (CPE), and consumer appliances.

1.3. Benefits

Since 2002, Cable TV providers have relied on voltage and inverter status readings retrieved from DOCSIS® modems connected to neighborhood HFC power supplies to detect grid power outages. Since the release of the Simple Network Management Protocol (SNMP) transport protocol and circa 2000 sensing technology, new technologies have become available for improved voltage resolution, sampling rates, and secured information transport to enable detecting critical anomalies that may ultimately lead to loss of life/property and disrupt service. Detecting anomalies will aid in early detection of potentially customer-affecting issues.

The increasing complexity of the grid requires a concomitant growth in sensing technology. The resilience of the 5.5 million miles (over 8 million kilometers) of distribution lines (96.5% of the grid) can be greatly enhanced with additional monitoring. Supervisory control and data acquisition (SCADA) systems and other telemetry systems will benefit. Migration from 1-way delivery of central power to dynamic 2-way flows of distributed renewable power creates an unlimited number of changing 'normal' states that thwart detection of anomalous states created by cyberattacks and failing infrastructure. Cable providers need the grid to be reliable to power millions of nodes. These nodes and other network elements can provide useful power quality and status information to utility providers.

1.4. Intended Audience

The intended audience of this specification includes power providers and broadband telecommunications providers including operations centers, product managers, designers, engineers, plant and field service technicians, and end users of equipment that is used to sense the quality of power delivered by the electric power secondary distribution network and broadband networks such as the HFC network.

1.5. Areas for Further Investigation or to be Added in Future Versions

Future versions of this specification may specify the measurement accuracy, sampling rate, communications, and security of non-customer premises devices on other networks including passive optical networks (xPON), switched Ethernet, powered Ethernet, Wi-Fi hotspots, small cells, etc.

2. Normative References

The following documents contain provisions, which, through reference in this text, constitute provisions of this document. At the time of Subcommittee approval, the editions indicated were valid. All documents are subject to revision; and while parties to any agreement based on this document are encouraged to investigate the possibility of applying the most recent editions of the documents listed below, they are reminded that newer editions of those documents might not be compatible with the referenced version.

2.1. SCTE References

- SCTE 216 2020, Adaptive Power System Interface Specification (APSIS™)

2.2. Standards from Other Organizations

- RFC 6101 The Secure Sockets Layer (SSL) Protocol Version 3.0
- RFC 8446 The Transport Layer Security (TLS) Protocol Version 1.3

2.3. Published Materials

- No normative references are applicable.

3. Informative References

The following documents might provide valuable information to the reader but are not required when complying with this document.

3.1. SCTE References

- No normative references are applicable.

3.2. Standards from Other Organizations

- IEEE P2888.1 - Specification of Sensor Interface for Cyber and Physical World
- IEEE P2888.2 - Standard for Actuator Interface for Cyber and Physical Worlds
- IEEE P2888.3 - Standard on Orchestration of Digital Synchronization between Cyber and Physical Worlds
- RFC 1157 Simple Network Management Protocol (SNMP)
- [YANG] – A description of the YANG modeling language is available at: http://www.yang-central.org/twiki/bin/view/Main/WebHome
- [YANGTOOLS] http://www.yang-central.org/twiki/bin/view/Main/YangTools

3.3. Published Materials

- North American Synchrophasor Initiative, Technical Report: High-Resolution, Time-Synchronized Grid Monitoring Devices, Alison Silverstein, Alison Silverstein Consulting, Dr. Jim Follum, PNNL, March 20, 2020.

4. Compliance Notation

Shall	This word or the adjective "***required***" means that the item is an absolute requirement of this document.
shall not	This phrase means that the item is an absolute prohibition of this document.
forbidden	This word means the value specified shall never be used.
should	This word or the adjective "*recommended*" means that there may exist valid reasons in particular circumstances to ignore this item, but the full implications should be understood and the case carefully weighted before choosing a different course.
should not	This phrase means that there may exist valid reasons in particular circumstances when the listed behavior is acceptable or even useful, but the full implications should be understood and the case carefully weighed before implementing any behavior described with this label.
may	This word or the adjective "*optional*" means that this item is truly optional. One vendor may choose to include the item because a particular marketplace requires it or because it enhances the product, for example, another vendor may omit the same item.
deprecated	Use is permissible for legacy purposes only. Deprecated features may be removed from future versions of this document. Implementations should avoid use of deprecated features.

5. Abbreviations and Definitions

5.1. Abbreviations

APSIS	Adaptive Power Systems Interface Specification
CPE	customer premises equipment
CPOW	continuous point on wave
DOCSIS	Data-over-Cable Service Interface Specifications
EV	electric vehicle
GPS	global positioning system
gRPC	Remote Procedure Call developed at Google
HFC	hybrid fiber-coax
IETF	Internet Engineering Task Force
OSS	operational support system
SCADA	supervisory control and data acquisition
SCTE	Society of Cable Telecommunications Engineers
SNMP	Simple Network Management Protocol
UTC	universal time coordinated
VAC	volts alternating current
xPON	X version of passive optical network

5.2. Definitions

continuous point on wave	Means of tracking performance of a sinusoidal power wave traditionally found on grid power, taken over very short intervals of time for extremely high resolution of observation.
YANG	A data modeling language used to model configuration, state data, and administrative actions manipulated by the NETCONF protocol
cyber-physical security	The superset of cybersecurity used in protecting cyber-physical systems.

6. Requirements

6.1. Sensing Requirements

For network elements, if HFC voltage and/or current is sensed grid and HFC voltage ***shall*** be measured with a precision of 0.002 per-unit (0.2% of the nominal value), e.g., +/- 0.24 volts at 120 VAC and current, ***shall*** be measured with the same precision of 0.002 per-unit.

If a continuous point on wave (CPOW) capture (see the "North American Synchrophasor Initiative, Technical Report") capability is provided, the sampling rate ***shall*** be a minimum of 10k samples/sec. This enables the identification of loose seizure screws, life-threatening faults such as unbonded grounds and floating neutrals, high-impedance faults such as arcing grid conductors, and unintended behavior of distributed energy resources such as solar inverters and EV chargers feeding power into the grid when undesirable or unsafe to do so, e.g., during line maintenance.

Higher sensing rates could provide specific benefits. If the rate of change of frequency and sine-wave goodness-of-fit (See "North American Synchrophasor Initiative, Technical Report") is provided, they *may* be calculated remotely from the measuring network element.

6.2. Timing Requirements

If a measurement observation timestamp capability is provided in the sensing network element, the observation timestamp resolution ***shall*** be <= 10e-6 seconds (1 microsecond). Clock accuracy ***shall*** be <=500*10e-9 seconds (500 nanoseconds) relative to Coordinated Universal Time (UTC). Reporting of values ***shall*** use UTC timestamps.

To meet the clock accuracy requirement, the system timing signal *should* be driven by either an onboard GNSS (Global Navigation Satellite System)-based timing subsystem such as GPS, DOCSIS or xPON loop timing, or other timing system with comparable stability and accuracy.

6.3. Configuration Requirements

If a configurable remote reporting capability is provided in the sensing network element, the control plane ***shall*** enable configuration for a) a 1-time poll reply, b) continuous replies and/or c) fixed interval replies.

6.4. Communication Requirements

If a communication plane is provided, it ***shall*** use the IETF/APSIS YANG model as defined in SCTE 216 Adaptive Power System Interface Specification.

Streaming oriented communications protocols such as gRPC are preferred.

7. Security Requirements

If a communication plane is used, it ***shall*** use SSL as defined in RFC 6101 The Secure Sockets Layer (SSL) Protocol Version 3.0 or TLS as defined in RFC 8446 The Transport Layer Security (TLS) Protocol Version 1.3, for authentication and encryption.

B. TCF Statement of Work TCF_1M-Mod1-AppdxA-1(#SUB-2020-10140)

Begins on next page.

APPENDIX A-1

STATEMENT OF WORK

"Situational Awareness of Grid Anomalies (SAGA) for Visual Analytics: Near Real-Time Cyber-Physical Resiliency through Machine Learning"

November 30, 2021

1.0 BACKGROUND

The National Renewable Energy Laboratory (NREL) is a national laboratory of the U.S. Department of Energy's (DOE) Office of Science and Office of Energy Efficiency and Renewable Energy. NREL is the only federal laboratory dedicated to research, development, commercialization, and deployment of renewable energy and energy efficiency technologies. NREL is managed and operated by The Alliance for Sustainable Energy (Alliance), the "M&O Contractor".

The National Renewable Energy Laboratory (NREL) was awarded via the U.S. Department of Energy (DOE) Research Call (RC) Number: RC-CEDS-2019, Cybersecurity for Energy Delivery Systems (CEDS) 2019 Research Call ***and TCF-20-20213***. Through ***these*** RC***'s***, the DOE seeks to:

1. research, develop, integrate and demonstrate technology or techniques to provide a situational awareness interface based on geospatial data;
2. including but is not limited to: US energy sector assets, utility operational boundaries, communications channels, and other relevant energy sector information; and
3. must also have a standard Application Programming Interface (API) to allow for the flexibility of additional data ingestion by DOE as it becomes available.
4. ***create an open hardware standard relevant to the Cable Television (CATV) and electric grid (industry) interface.***
5. ***identify the use cases pertinent to various stakeholders***
6. ***prototype (6) sensors for next generation monitoring of the aforementioned interface.***

NREL's solution is described below:

We propose the Situational Awareness of Grid Anomalies (SAGA) visual analytics platform for near real-time cyber-physical resiliency through machine learning. To facilitate rapid commercialization, SAGA will build on foundational tools developed at NREL, integrate these tools with geospatial data, and demonstrate a disruptive technology that builds on existing infrastructure. In particular, SAGA leverages voltage observations from CATV networks' broadband power supplies for out-of-band monitoring and communications over a secure, high-speed, low-latency backhaul network; furthermore, broadband cable networks topologically overlay the electric grid, mapping to 95% of residential and commercial utility customers. The project's high-level objective is to develop and field-validate an extensibleAPI and Graphical User Interface (GUI) for enhanced grid visibility and situational awareness. Three research thrusts, also corresponding to three years (i.e. phases) for DOE, support the overarching goal:

1. *Visual Analytics*: Geospatial data visualization and alerting to support analysts' operational decision-making and standardize a new algorithm-agnostic interface for machine learning;*Power Flow Simulation*: Integration of semi-automated physical

modeling and simulationfor leveraging geospatial data and the power system's spatiotemporal dynamics concerning intra-area, boundary, and multi-region interactions; and

2. *Cyber-Physical Emulation*: Detection and classification of anomalous behavior on power systems by utilizing the two previous items in conjunction with a field-validated demonstration of cyber events.

2.0 OBJECTIVE

The objective of this work effort is to integrate CATV data and software, communication methods, and functional coupling to any electric grid with prototypical power system operational requirements; and to demonstrate situational awareness, including considerations for cyber-physical modeling and visualization tools, such that a more reliable and resilient power system is possible as assessed by geospatial and power system variables and metrics.

3.0 SCOPE OF WORK

The scope of work, to be performed by the Subcontractor consists of work in following ***six*** (***6***) main topic areas:

1. Software development for visual analytics whereby CATV data and communications are functionally coupled to power flow requirements and machine learning is possible to enhance electric grid reliability, resiliency, and overall situational awareness.
2. Verification, validation, and review of power flow simulations, their interaction with the CATV network, and engineering development required to functionally couple them to the requirements of the electric grid.
3. Cyber-physical emulation of electric grid cyberattacks using CATV data, including development of use cases and review of associated documentation.
4. ***A U.S. draft standard for broadband-based next-generation grid power sensors***
5. ***Six prototype broadband-based next-generation grid power sensors***
6. ***Improved spatiotemporal scale of the in-progress DOE CESER CEDS Situational Awareness of Grid Anomalies (SAGA) project, i.e., this project is focused primarily on the hardware components to an ongoing, parallel SAGA software project.***

These topic areas investigated by the Subcontractor align with NREL's SAGA project objective and the aforementioned ***six*** (***6***) research thrusts to be accomplished duringthe three-year project. The below paragraphs describe the data the Subcontractor shall deliverto NREL, including the processes needed to accomplish delivery, and provides a high-level summary of the Subcontractor's responsibilities as part of the SAGA project.

Define the data type and structure to be delivered for SAGA APIs, i.e., processes may include derivative data

It is critical to initiate the project with a clear understanding of the data structure that the Subcontractor will be providing SAGA. The raw data is well structured, but not necessarily normalized across the various suppliers. Tasks will require the team to come to a common understanding of the data type (e.g., input voltage, inverter status, timestamp, and location), their accompanying resolution, and temporal interval. In addition, derivative data required such as "islanding" and "brown out" flags should be characterized and noted in the data supplied. These are expected to evolve over the course of the project.

Ensure the data's integrity delivered to SAGA via the APIs

Not all data are equal. It is imperative that SAGA is able to rely on the integrity of the data supplied. Tasks should ensure that the data delivered meets an expectation of data confidence.

The Subcontractor's team shall qualify the data relative to expected and deviant values. For instance, a sensor that shows its inverter is on and yet reports 120v is suspect. Ensuring data integrity will help reduce potential false positives generated by the SAGA analytics engine.

Ensure security compliance as required in the Data Agreements

The data supplied are under strict security requirements for collection, storage, transmission, access, and use. As such, it is required that the SAGA project team adhere to the security compliances outlined in the supplier data agreement between the Subcontractor and NREL. The process will be ongoing throughout the project to ensure compliance. Regular reminders, reviews, and audits will be standard practice during this project.

Coordinate the sensor selection set that adhere to the Data commitments

The scope of the data will include access to at least 50k sensors in year 1, 75k sensors in year 2, and 100k sensors in year 3. The team should collectively assess and strategically select the sensors to be included for this project. Tasks will include (to be completed at least annually, as detailed below in Section 4) an identified "set" of sensors for use in SAGA, inclusive of the previous years when applicable.

Define the APIs to be created

Application Programming Interfaces (APIs) are systematic methods for accessing, transporting and delivering data, securely and reliably. The APIs may take many forms and will evolve over the course of the project. Conceptually, it is envisioned there will be three distinct SAGA APIs: Historical, Monitoring, and Event. The Historical SAGA API provides a dataset from a selected set of sensors encompassing a date range. The SAGA Monitoring API provides a full dataset from a selected set of sensors every 5 minutes. The SAGA Event API provides a dataset of qualified events (e.g., Power goes on or off, Voltage reading exceed a defined threshold, etc.) from a selected set of sensors every 5 minutes. The SAGA APIs will evolve over the course of the project, and additional SAGA APIs may be developed. The SAGA API development follows a well understood process from prototype to alpha, beta, and finally production ready (commercialized).

Tasks will develop the prototype SAGA APIs, which will likely be manual and hard-coded, and prove the ability to extract, encapsulate, transport, and deliver a dataset. Tasks will then focus on developing the alpha SAGA API, which will still be manually invoked, and perform a specified query, encapsulate, transport, and deliver the data to a defined end-point. Further tasks will develop the beta SAGA API, which will be semi-automated, and offer more flexibility in terms of data ranges and sensor selections. Finally, the terminal task is to develop a production-ready version of the SAGA API which will be fully automated and offer customized selection criteria, including date ranges, sensor selections, and data types.

Define the UIs to be created for the APIs

The SAGA APIs provide the mechanism to extract and transport data. The SAGA UIs (user interfaces) will be developed for the accompanying APIs and provides the user the ability to specify the query and ensure the proper application of constraints associated with the access controls, permissions, and roles for the datasets. The development of the SAGA UIs map one-to-one with the SAGA APIs and will evolve over the course of the project. Tasks will develop the prototype SAGA UI, which will be manual, non-interactive, and hard-coded. The prototype will not account for users or permissions. Tasks will then develop the alpha SAGA UI, which will provide a selection of pre-defined queries and account for a single user profile. Tasks then will then develop the beta SAGA UI, which will be semi-automated and incorporate multiple user profiles, basic access controls, as well as flexible query parameter selection. Tasks will then develop a production ready (commercialized) SAGA UI, which enables customized query selections and multiple user profiles with comprehensive access controls.

4.0 TASKS

The SAGA project is planned such that the APIs and UIs are a sequenced development: prototype and alpha (refined) are expected in Year 1 / Phase 1, the beta (robustized) in Year 2 / Phase 2, and production ready (commercialized) in Year 3 / Phase 3. The SAGA project end dates for each year are as follows: Year 1 is 09/30/20, Year 2 is 09/30/21, and Year 3 is 09/30/22; the start of the U.S. government's financial quarters (i.e., Q1, Q2, Q3, and Q4) are specified as October 1, January 1, April 1, and July 1, respectively.

The tasks (discussed below) are therefore additive and build on each other; the deliverables associated with these tasks are explicitly stated in section 6.0. All software requirements rest on a comprehensive dataset, provided to NREL by the Subcontractor, with expectations described in sections 1.0 – 3.0 and implicit to SAGA's success. The Subcontractor shall complete the following tasks:

YEAR 1 (Date of execution through 09/30/2020)

- **4.1 Attend project kick-off meeting.** The Subcontractor shall attend and participate in the project kickoff meeting to be held for one day at NREL's facilities in Golden, CO.
- **4.2 Document the data structure used for the API development.** The data structure should be mapped yearly to the requirements for the SAGA project and include defining a unique sensor ID, the time stamp format, the geolocation of sensors and data associated with each sensor.
- **4.3 Develop prototype APIs for batch and streaming delivery of real-world sensor data.** API should allow for different "start-to-stop date" ranges (i.e., timespans) and selection of various geographic areas (i.e., geographies). Individual data records should be time stamped and include distribution grid secondary input voltage reading, inverter status, latitude, longitude, and a unique location identifier. *The APIs will evolve over the course of this project, beginning with prototypes and maturing into commercial-grade services. This fact is noted to ensure that it is clear that during the SAGA project's evolution, specifically over years 2 and 3, deliverables may not be separate deliverables but continuation deliverables – like an API that is refined as necessary in years 1, 2, and 3.*
- **4.4 Develop the prototype UIs necessary to access the prototype APIs.** Develop the UI to enable qualified NREL users to select, automate, log and ingest power quality and presence data structures needed to support visualization in years 1, 2, and 3. Demonstrate the API UIs with actual broadband sensor data selections. *The APIs UI will evolve over the course of this project, beginning with prototypes and maturing into commercial grade services. NOTE: there is a significant implication of security compliance in this effort.*
- **4.5 Develop Alpha level APIs for batch and streaming delivery of real-world sensor data.** Demonstrate the Alpha version with actual broadband sensor data.
- **4.6 Develop Alpha UIs necessary to access the Alpha APIs.** Demonstrate the Alpha versions with actual broadband sensor data
- **4.7 Critique power simulation visual analytics provided by NREL.** Based on synthetic grid infrastructure and operations data
- **4.8 Development of distribution grid models.** Review distribution grid models provided by NREL based on synthetic sources.
- **4.9 Grid simulations to produce training data.** Identify variances observed in broadband sensor data.

YEAR 2 (10/01/2020 through 09/30/2021)

- **4.10** **Develop Beta level APIs for batch and streaming delivery of real-world sensor data.** Demonstrate the Beta version with actual broadband sensor data.
- **4.11** **Develop Beta UIs necessary to access the Beta APIs.** Demonstrate the Beta versions with actual broadband sensor data.
- **4.12** **Potential use cases identified.** Assist in identifying, critiquing, and prioritizing use cases concerning cyber-physical emulation
- **4.13** **Data Assimilation:** Review empirical data generated.
- **4.14** **Develop data-informed physical simulation models.** Review layers proposed by NREL.
- **4.15** **Baseline calibration of distribution grid models.** Review NREL-provided baseline calibration of distribution grid.
- **4.16** **Near real-time prediction engine.** Review NREL-provided near real-time prediction engine.
- **4.17** **Cybersecurity Layer.** Critique NREL-provided cybersecurity layer
- **4.18** **Synthetic cyber event threat detection**. Review detection of NREL-provided synthetic cyber events
- **4.19** ***Co-Develop and Finalize ANSI/SCTE standard.***
  - *Facilitate the development of an ANSI/SCTE standard containing Requirements for Power Sensing in Cable and Utility Networks with consensus from Stakeholders.*
- **4.20** ***Co-Develop and Finalize six (6) Prototype Power Sensors.***
  - *Based on consensus from the previous task, facilitate development, including design, build and performance, of sensor hardware, embedded software, real-time data transport protocol, and sensor command and control functions.*
  - *Conduct tests to verify sensor capabilities, including basic behavior and calibration of prototype sensors, with the sensors terminal application being within the complementary and parallel SAGA project for in situ testing of the next-generation hardware.*
- **4.21** ***Contribute to quarterly reports for DOE.*** *During the project, the Subcontractor shall prepare quarterly written summaries including progress updates, issues and challenges, and a summary of upcoming work, which NREL will incorporate into quarterly reports it will provide to DOE.*
- **4.22** ***CO-Prepare a final technical report.*** *The Subcontractor shall prepare a final report, in draft and final versions, and should include work completed to-date, issues experienced, and upcoming work.*

YEAR 3 (10/01/2021 through 09/30/2022)

- **4.23** **Develop Commercial level APIs for batch and streaming delivery of real-world sensor data.** Demonstrate the Commercial versions with actual broadband sensor data.
- **4.24** **Develop Commercial UIs necessary to access the Commercial APIs.** Demonstrate the Beta versions with actual broadband sensor data.
- **4.25** **Data Assimilation.** Visualizing cybersecurity with emulation: Review visualization of actual infrastructure (NREL-provided) and operational data (Subcontractor-provided).
- **4.26** **Visualizing cyber-physical resilience with emulation**. Review visualization of cyber-physical resilience with emulation.
- **4.27** **Performance metrics developed.** Review NREL-provided power flow emulation

performance metrics.

4.28 **Near real-time grid prediction**. Review NREL-provided near real-time grid prediction.

4.29 **SAGA Demonstrations 1-4.** Review emulation of NREL-provided cyber-compromised scenarios.

5.0 REVIEW MEETINGS AND TRAVEL REQUIREMENTS (if required)

5.1 Participate and attend project kick-off meeting at NREL in Golden, CO. This meeting will be a one (1) day meeting. ***While on-site the subcontractor must comply with NREL's COVID-19 requirements, as provided by the technical monitor.***

5.2 Participate in project status meeting, via conference or video calls, as scheduled and arranged by the NREL technical monitor, as stated in the table below:

Year	Approx. Date	Purpose	Location	Duration
1	Quarterly	Project Review Meetings: To keep informed of project progress and to provide timely review and feedback of the project team.	Web-meeting	2 hours
2	Quarterly	Project Review Meetings: To keep informed of project progress and to provide timely review and feedback of the project team.	Web-meeting	2 hours
Year	**Approx. Date**	**Purpose**	**Location**	**Duration**
3	Quarterly	Project Review Meetings: To keep informed of project progress and to provide timely review and feedback of the project team.	Web-meeting	2 hours

6.0 DELIVERABLES

DELIVERY OF COMPUTER SOFTWARE CODE (AS APPLICABLE)

All object, source, or other code (including all applicable data sets) developed under this subcontract effort shall be provided to the technical monitor as a condition of final payment, in accordance with the subcontract. It is expected that all delivered source code shall be original and the subcontractor shall provide a written certification to the subcontract associate that all source, or other code developed and delivered under this subcontract does not contain any open source code - as a condition of final payment in accordance with the subcontract. The subcontractor's (including all lower tier subcontractors, as applicable) certification shall specify that "All source, or other software code developed and/or delivered under this Subcontract No.__________is original and does not contain any 3rd party or other open source software."

DELIVERY OF OPEN SOURCE SOFTWARE

All object, source, or other code (including all applicable data sets) developed under this subcontract effort shall be provided to the technical monitor (TM) as a condition of final payment, in accordance with the subcontract.

The Subcontractor shall provide the following deliverables by the due dates indicated in the table below:

Deliverable No.	Deliverable	Description	Due Date
Year 1 Deliverables (From Execution through 9/30/20)			
6.1	Report	Document the data structure for the API development with respect to Task 4.2	9/30/20
6.2	Report	Document that shows messages and responses across API, accomplished with respect to Task 4.3 to meet the prototype requirements	9/30/20
6.3	Report	Document that provides the UI access to the APIs accomplished with respect to Task 4.4 meeting the prototype requirements	9/30/20
6.4	Report	Screenshots and documentation of Alpha APIs for power quality and power presence detection; accomplished with respect to Task 4.5	9/30/20
6.5	Report	Screenshots and documentation of Alpha UI access to the Alpha APIs for power quality and power presence detection, accomplished with respect to Task 4.6	9/30/20
6.6	Report	A written critique based on sharing NREL-provided material with the Subcontractor's internal staff and one or more of the Subcontractor's member companies; accomplished with respect to Task 4.7	9/30/20
6.7	Report	A document reviewing NREL-provided power flow simulations, accomplished with respect to Task 4.8	9/30/20
6.8	Report	Documentation of variances observed in broadband sensor data, accomplished with respect to Task 4.9	9/30/20
6.9	Quarterly Project Review Reports	Prepare quarterly written summaries including progress updates, issues and challenges, and a summary of upcoming work, which NREL will incorporate into quarterly reports it will provide to DOE	Q3, Q4
6.10	Annual Report	Prepare an annual report, in draft and final versions. This report shall include work completed to date, issues experienced, and upcoming work.	9/30/20
6.11	Annual Project Meeting	Attend and participate in annual project meetings at NREL in Golden, CO	9/30/20
Year 2 Deliverables (From 10/01/20 through 9/30/21)			
6.12	Report	Document that shows messages and responses across API, accomplished with respect to Task 4.10 to meet the Beta requirements	9/30/21
6.13	Report	Document that provides the UI access to the APIs accomplished with respect to Task 4.11 meeting the Beta requirements	9/30/21
6.14	Report	Document reviewing the Subcontractor's-originated Use Cases and NREL-provided Use Cases, accomplished with respect to Task 4.12	9/30/21

Deliverable No.	Deliverable	Description	Due Date
6.15	Report	Document reviewing layers proposed by NREL concerning data-informed physical simulation models, accomplished with respect to Task 4.13	9/30/21
6.16	Report	Document reviewing layers proposed by NREL concerning API & UI, accomplished with respect to Task 4.14	9/30/21
6.17	Report	Document reviewing NREL-provided baseline calibration of distribution grid, accomplished with respect to Task 4.15	9/30/21
6.18	Report	Document reviewing near real-time prediction engine, accomplished with respect to Task 4.16	9/30/21
6.19	Report	Document reviewing NREL-provided cybersecurity layer, accomplished with respect to Task 4.17	9/30/21
6.20	Report	Document reviewing detection of synthetic cyber event, accomplished with respect to Task 4.18	9/30/21
6.21	***Report***	***An open hardware standard and its submittal to ANSI/SCTE standard processes***	***03/31/2022***
6.22	***Report***	***Documentation showing data, messages, and responses across API/UI developments associated with the six (6) co-developed, prototype power sensors – including considerations for NREL's open-source, event detection algorithms***	***03/31/2022***
6.23	***Report***	***Documentation of the tests conducted to verify the sensor capabilities and performance.***	***03/31/2022***
6.***24***	Quarterly Project Review Reports	Prepare quarterly written summaries including progress updates, issues and challenges, and a summary of upcoming work, which NREL will incorporate into quarterly reports it will provide to DOE	Q1, Q2, Q3, Q4
6.***25***	Annual Report	Prepare an annual report, in draft and final versions. This report shall include work completed to date, issues experienced, and upcoming work.	9/30/21
6.***26***	Annual Project Meeting	Attend and participate in annual project meetings at NREL in Golden, CO	9/30/21
Year 3 Deliverables (From 10/01/21 through 9/30/22)			
6.***27***	Report	Document that shows messages and responses across API, accomplished with respect to Task 4.***23*** to meet the commercialization requirements	9/30/22
6.***28***	Report	Document that provides the UI access to the APIs accomplished with respect to Task 4.***24*** meeting the commercialization requirements.	9/30/22

Deliverable No.	Deliverable	Description	Due Date
6.***29***	Report	Document reviewing visualization of actual infrastructure and operational data; accomplished with respect to Task 4.***25***	9/30/22
6.***30***	Report	Document reviewing visualization of cyber-physical resilience with emulation; accomplished with respect to Task 4.***26***	9/30/22
6.***31***	Report	Document reviewing NREL-provided power flow emulation performance metrics; accomplished with respect to Task 4.***27***	9/30/22
6.***32***	Report	Document reviewing near real-time grid prediction; accomplished with respect to Task 4.***28***	9/30/22
6.***33***	Report	Document reviewing cyber-compromised scenarios; accomplished with respect to Task 4.***29***	9/30/22
6.***34***	Quarterly Project Review Reports	Prepare quarterly written summaries including progress updates, issues and challenges, and a summary of upcoming work, which NREL will incorporate into quarterly reports it will provide to DOE	Q1, Q2, Q3, Q4
6.***35***	Annual Report	Prepare an annual report***, in draft, due 15 days prior to project end date. Final report will incorporate any revisions, due by project end date.*** This report shall include work completed to date, issues experienced, and upcoming work.	9/30/22
6.***36***	Annual Project Meeting	Attend and participate in annual project meetings at NREL in Golden, CO.	9/30/22

7.0 ELECTRONIC REPORTING REQUIREMENTS FOR SUBCONTRACT REPORT DELIVERABLES

It is NREL's intention to publish subcontract report deliverables containing publicly available information (e.g. non-confidential, non-protected, non-proprietary information) for distribution on the internet. The subcontractor shall provide the final approved version of report deliverables inaccordance with the electronic reporting requirements described below.

The technical monitor may specifically direct the subcontractor to provide reports in one or more of the file format standards provided below.

a. The subcontractor shall submit all report deliverables (including status, annual, or final reports) as electronic files in Adobe .pdf format, preferably with all graphics and images embedded within the document.

b. All final approved version submissions shall be delivered to NREL via e-mail to the 1) NREL Technical Monitor, 2) the NREL Subcontract Administrator or Associate (as specified in the Deliverable Addresses below).

c. If it is not possible to include all of the graphics and images (figures, illustrations, and photographs) in the same file as the text, NREL will accept the text in Adobe .pdf formats and the graphics and images as separate electronic graphic or image files*.

The accepted standard for page layout and graphics is the Adobe Creative Suite of programs.

*The acceptable graphic or image file formats are: .eps, .tif, .gif, .jpg, .wmf, .emf, .pct, .png, .bmp, .psd, .ai, .fh, .qif, .fpx, cdr. The preferred resolution for graphics or images is 300 dpi. Include all fonts used in creating the file.

d. For animation, video, or multi-media elements, CD-ROM, DVR and thumb drive are acceptable technical deliverable media.

e. For all calculations in support of subcontract reports that are conducted, an electronic copy must be submitted with all reports. Additionally, if costing or sizing calculations are conducted in a spreadsheet [no process calculations (heat and material balances) in spreadsheet format are permitted], a copy of the fully documented MS Excel file shall be supplied.

f. A fully executed model release shall be supplied to NREL with all photographs and images, regardless of whether such photographs or images are delivered to NREL electronically or in hard copy. Such model release shall certify that the Alliance for Sustainable Energy, LLC, Management and Operating Contractor for the National Renewable Energy Laboratory for the U.S. Department of Energy is granted a non-exclusive, paid-up, irrevocable, worldwide license to publish such photographs in any medium or reproduce such photographs or allow others to do so for United States Government purposes. Model releases are required in all situations in which a reasonable person would respond in the affirmative to the question – could someone, other than the model himself/herself, recognize the person in this photograph or image? All model releases shall be provided to the subcontract associate as a condition of final payment, in accordance with the subcontract. To obtain a Subcontractor Model Release form, please contact images@nrel.gov.

8.0 ACKNOWLEDGEMENTS IN SUBCONTRACTOR PUBLICATIONS

In any scientific or technical report or article, conference paper, journal article, etc. based on or containing data first produced in the performance of this subcontract and published in academic, technical, or professional journals, symposia proceedings or similar works, the subcontractor shall use this acknowledgement stating, “This [article, conference paper, journal article, etc.] was developed based upon funding from the Alliance for Sustainable Energy, LLC, Managing and Operating Contractor for the National Renewable Energy Laboratory for the U.S. Department of Energy.”

9.0 COPYRIGHT PERMISSION/AUTHORIZATIONS

The subcontractor is responsible for obtaining copyright permissions and/or authorizations for all information and/or data, as applicable that is incorporated into all final technical reports. Electronic copies of these copyright permissions and/or authorizations shall be provided to the subcontract associate at the email address provided below. The subcontractor shall also provide a written certification to the subcontract associate as to such permissions and/or authorizations as a condition of final payment. The subcontractor’s (including all lower tier subcontractors, as applicable) certification shall specify that “I have obtained all necessary and legally required copyright permissions and/or authorizations for any and all information, data, graphs, images, etc., as applicable, that is incorporated into the final Technical Report titled __________________________, delivered under this Subcontract No.__________. Copies of these permissions and/or authorizations are attached.”

Deliverable Addresses:

The subcontractor shall clearly label all deliverables to include:

- The subcontractor's name
- NREL's subcontract number
- NREL Technical Monitor's name
- Deliverable date, and
- Deliverable description.

Electronic deliverables shall be sent via email to the Technical Monitor as follows:

1) Michael Ingram, Technical Monitor
   National Renewable Energy Laboratory
   15013 Denver West Parkway
   Golden, CO 80401

   e-mail: Michael.Ingram@nrel.gov

   One (1) master electronic version, including graphics

C. U.S. Patent 10,892,838: Heterogeneous Network Topology Management and Control

Begins on next page.

US010892838B2

(12) **United States Patent**
Cruickshank, III et al.

(10) **Patent No.: US 10,892,838 B2**
(45) **Date of Patent: Jan. 12, 2021**

(54) **HETEROGENEOUS NETWORK TOPOLOGY MANAGEMENT AND CONTROL**

(71) Applicants: **Alliance for Sustainable Energy, LLC**, Golden, CO (US); **The Regents of the University of Colorado, a body corporate**, Denver, CO (US)

(72) Inventors: **Robert Fraser Cruickshank, III**, Big Indian, NY (US); **Bri-Mathias Scott Hodge**, Golden, CO (US); **Anthony Reed Florita**, Broomfield, CO (US)

(73) Assignees: **Alliance for Sustainable Energy, LLC**, Golden, CO (US); **The Regents of the University of Colorado, a body corporate**, Denver, CO (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 37 days.

(21) Appl. No.: **16/185,903**

(22) Filed: **Nov. 9, 2018**

(65) **Prior Publication Data**

US 2019/0140756 A1 May 9, 2019

Related U.S. Application Data

(60) Provisional application No. 62/583,847, filed on Nov. 9, 2017.

(51) **Int. Cl.**
H04H 60/96 (2008.01)
H04H 60/78 (2008.01)
(Continued)

(52) **U.S. Cl.**
CPC ***H04H 60/96*** (2013.01); ***H04H 20/12*** (2013.01); ***H04H 60/70*** (2013.01); ***H04H 60/78*** (2013.01);
(Continued)

(58) **Field of Classification Search**
None
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,008,843 A * 4/1991 Poelsler G01D 3/022 702/104
2008/0046387 A1* 2/2008 Gopal G01D 4/004 705/412

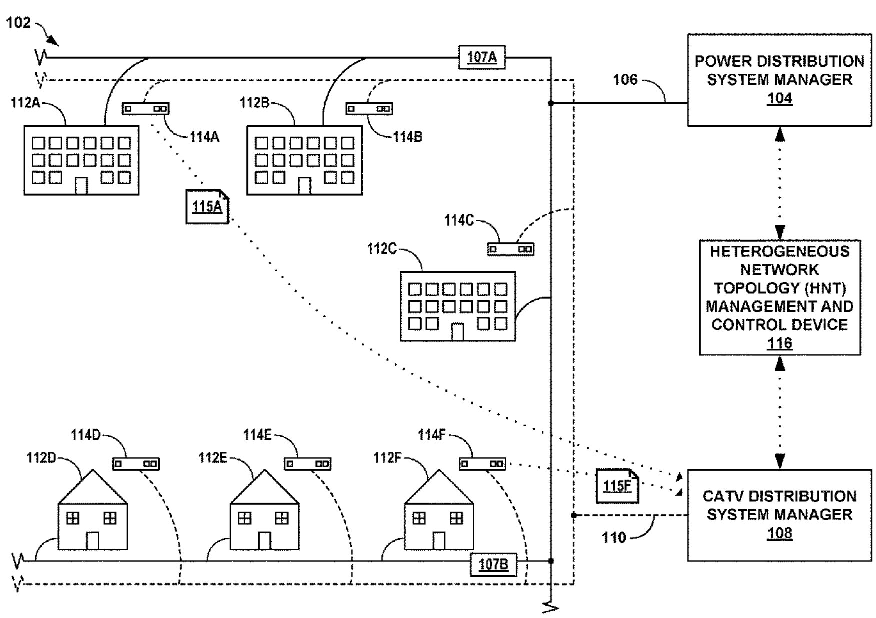
(Continued)

Primary Examiner — Pankaj Kumar
Assistant Examiner — Timothy R Newlin
(74) *Attorney, Agent, or Firm* — Robert G. Pittelkow

(57) **ABSTRACT**

In one aspect, the present disclosure may provide devices or systems configured to receive indications of geographic areas, each corresponding to distribution networks, and determine whether the distribution networks overlap. The processor(s) may also be configured to receive parameter value(s) obtained by a device within one distribution network at a location within an overlapping area, and cause device(s) within another distribution network to modify operation based on the parameter value(s). In another aspect, the present disclosure may provide devices that include a voltage sensor to measure a voltage of a power distribution network at a power consumption location that corresponds to the device. The device may be configured to provide at least one cable service to the power consumption location via a cable television (CATV) distribution network and output an indication the measured voltage value.

12 Claims, 6 Drawing Sheets



(51) **Int. Cl.**

H04H 60/70	(2008.01)
H04H 20/12	(2008.01)
H04H 60/97	(2008.01)
G06Q 50/06	(2012.01)
H04H 60/51	(2008.01)

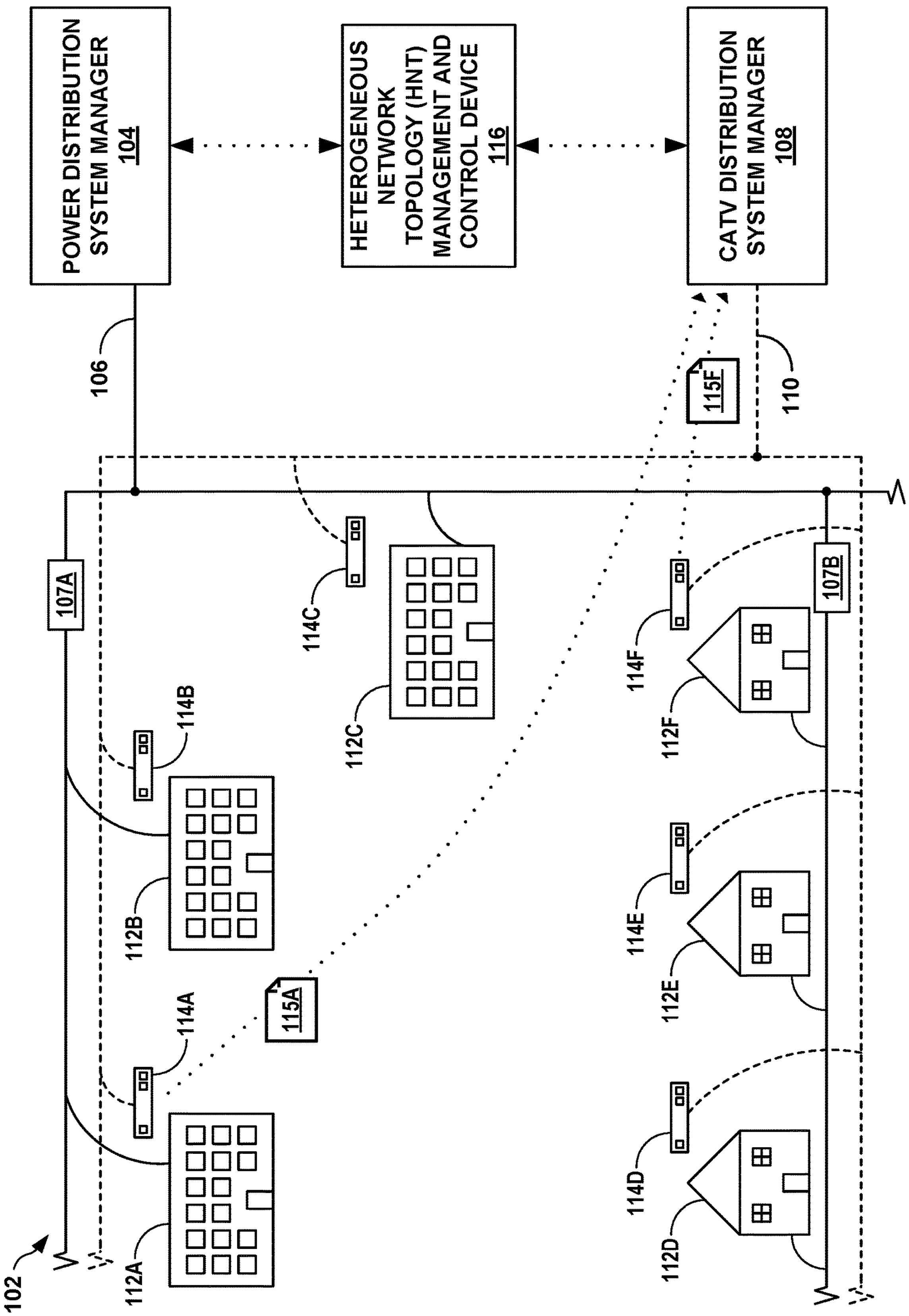
(52) **U.S. Cl.**
CPC ***H04H 60/97*** (2013.01); *G06Q 50/06* (2013.01); *H04H 60/51* (2013.01)

(56) **References Cited**

U.S. PATENT DOCUMENTS

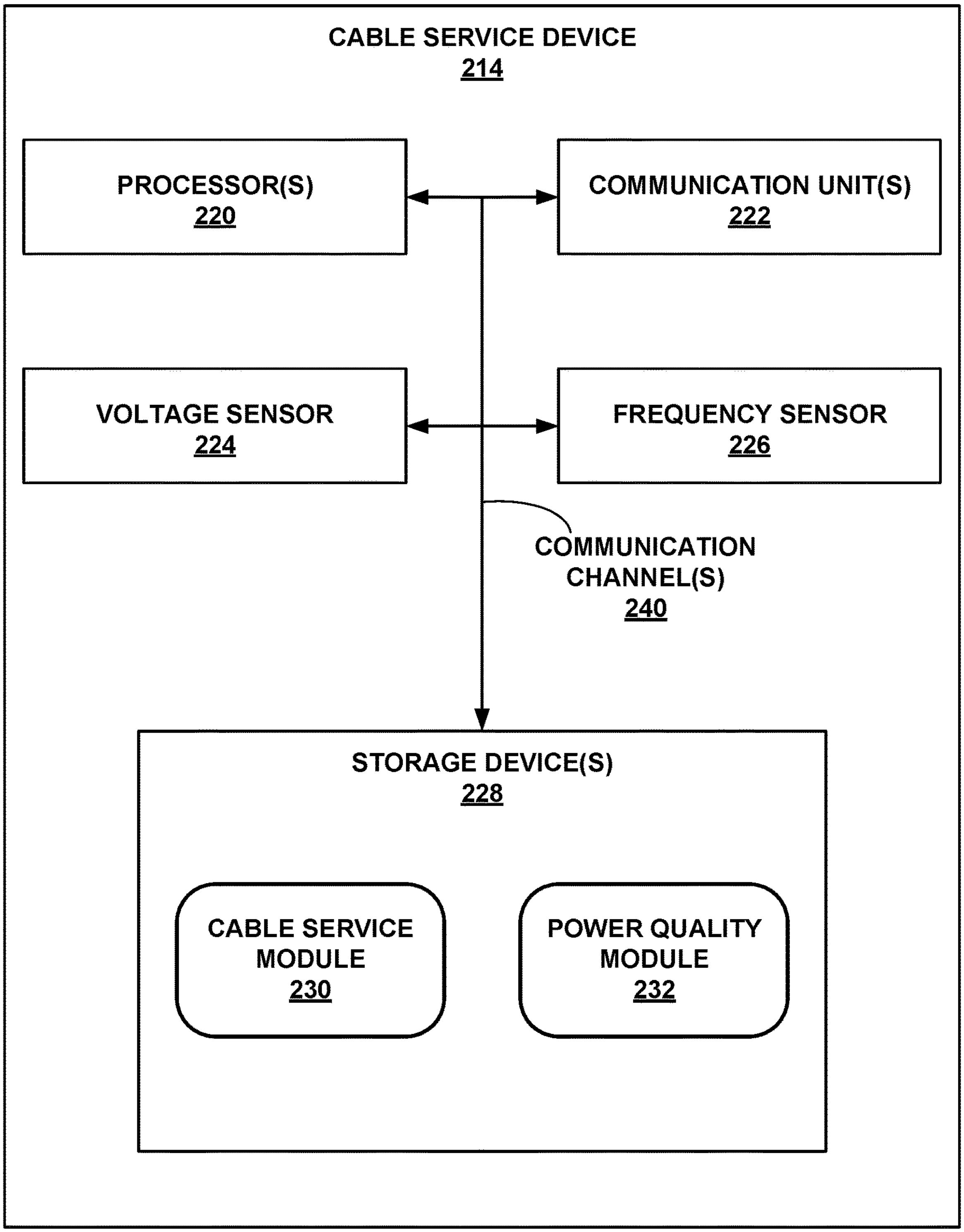
2009/0079632	A1*	3/2009	Ochi	H01Q 3/242 342/372
2009/0089854	A1*	4/2009	Le	H04N 21/6582 725/139
2010/0094479	A1*	4/2010	Keefe	H02J 3/1878 700/298
2012/0123602	A1*	5/2012	Sun	H02J 3/14 700/292
2014/0070756	A1*	3/2014	Kearns	H02J 7/007 320/101
2015/0112501	A1*	4/2015	Rombouts	H02J 3/14 700/295
2017/0045904	A1*	2/2017	Nishita	G05F 1/66
2017/0098937	A1*	4/2017	Huomo	H02J 3/383

* cited by examiner



POWER DISTRIBUTION SYSTEM MANAGER 104
HETEROGENEOUS NETWORK TOPOLOGY (HNT) MANAGEMENT AND CONTROL DEVICE 116
CATV DISTRIBUTION SYSTEM MANAGER 108
106
110
115F
107A
107B
114A
114B
114C
114D
114E
114F
112A
112B
112C
112D
112E
112F
115A
102

FIG. 1


CABLE SERVICE DEVICE
214
PROCESSOR(S)
220
COMMUNICATION UNIT(S)
222
VOLTAGE SENSOR
224
FREQUENCY SENSOR
226
COMMUNICATION
CHANNEL(S)
240
STORAGE DEVICE(S)
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CABLE SERVICE
MODULE
230
POWER QUALITY
MODULE
232

FIG. 2

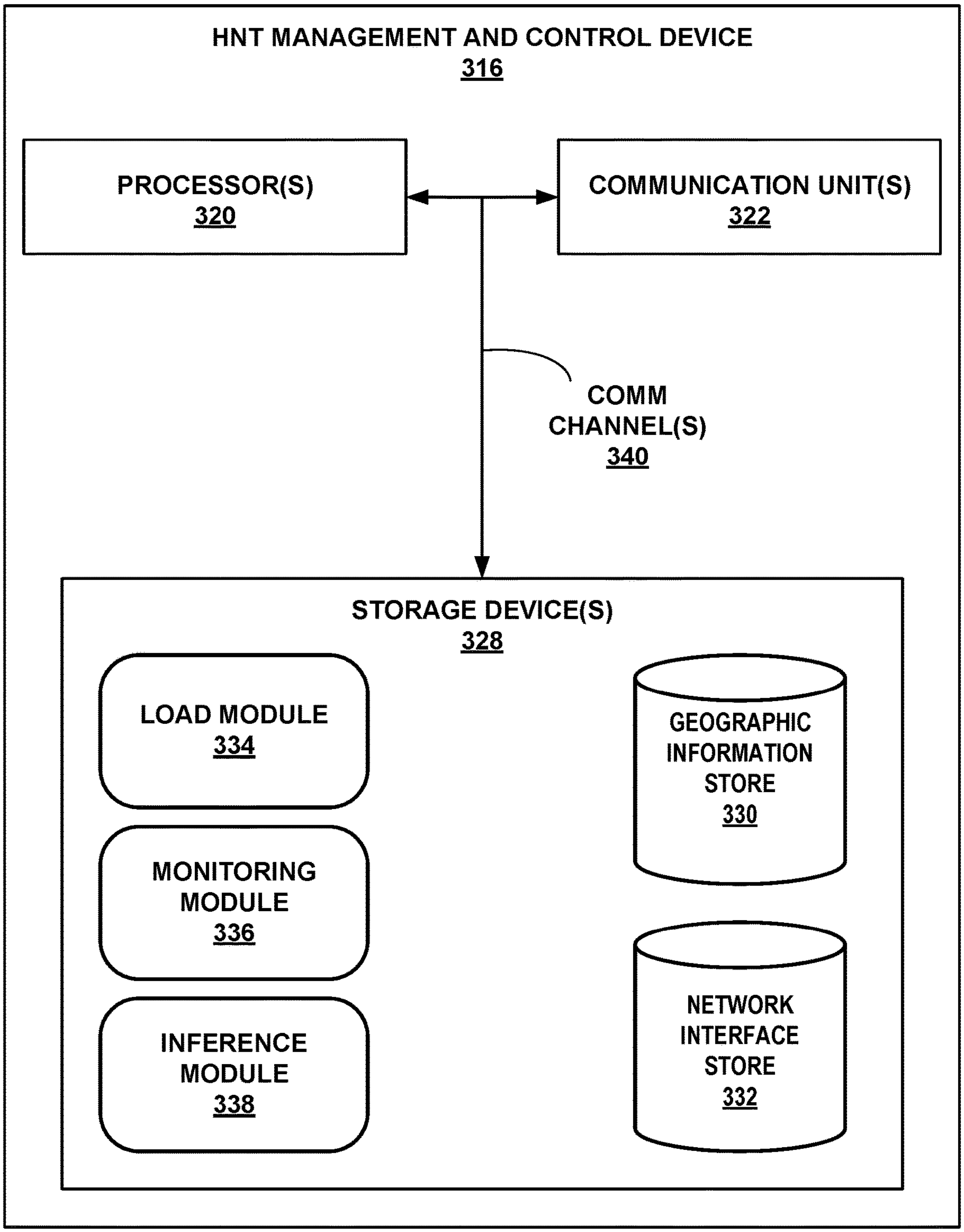
HNT MANAGEMENT AND CONTROL DEVICE
316
PROCESSOR(S)
320
COMMUNICATION UNIT(S)
322
COMM
CHANNEL(S)
340
STORAGE DEVICE(S)
328
LOAD MODULE
334
MONITORING
MODULE
336
INFERENCE
MODULE
338
GEOGRAPHIC
INFORMATION
STORE
330
NETWORK
INTERFACE
STORE
332

FIG. 3

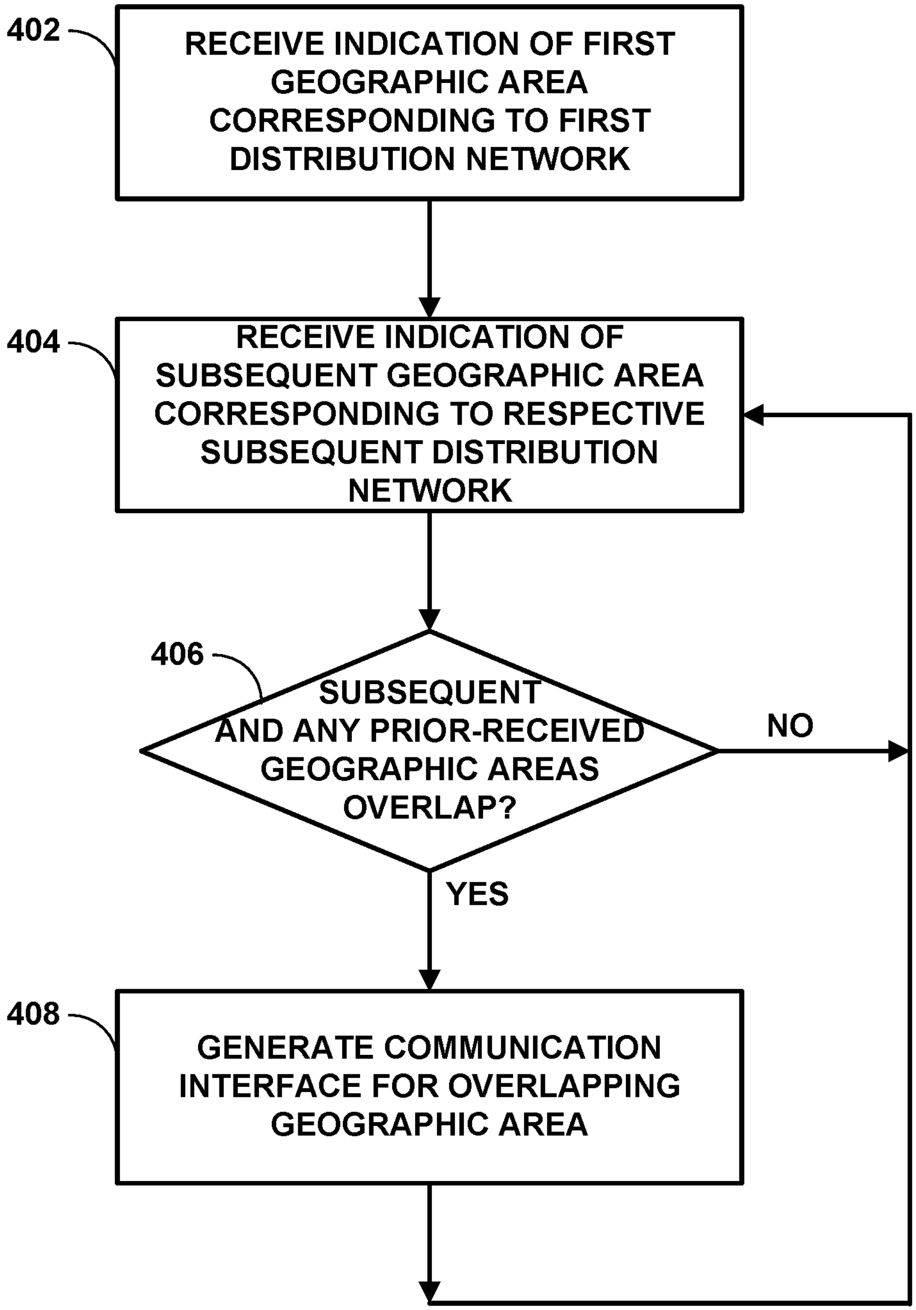
402
RECEIVE INDICATION OF FIRST GEOGRAPHIC AREA CORRESPONDING TO FIRST DISTRIBUTION NETWORK
404
RECEIVE INDICATION OF SUBSEQUENT GEOGRAPHIC AREA CORRESPONDING TO RESPECTIVE SUBSEQUENT DISTRIBUTION NETWORK
406
SUBSEQUENT AND ANY PRIOR-RECEIVED GEOGRAPHIC AREAS OVERLAP?
NO
YES
408
GENERATE COMMUNICATION INTERFACE FOR OVERLAPPING GEOGRAPHIC AREA

FIG. 4

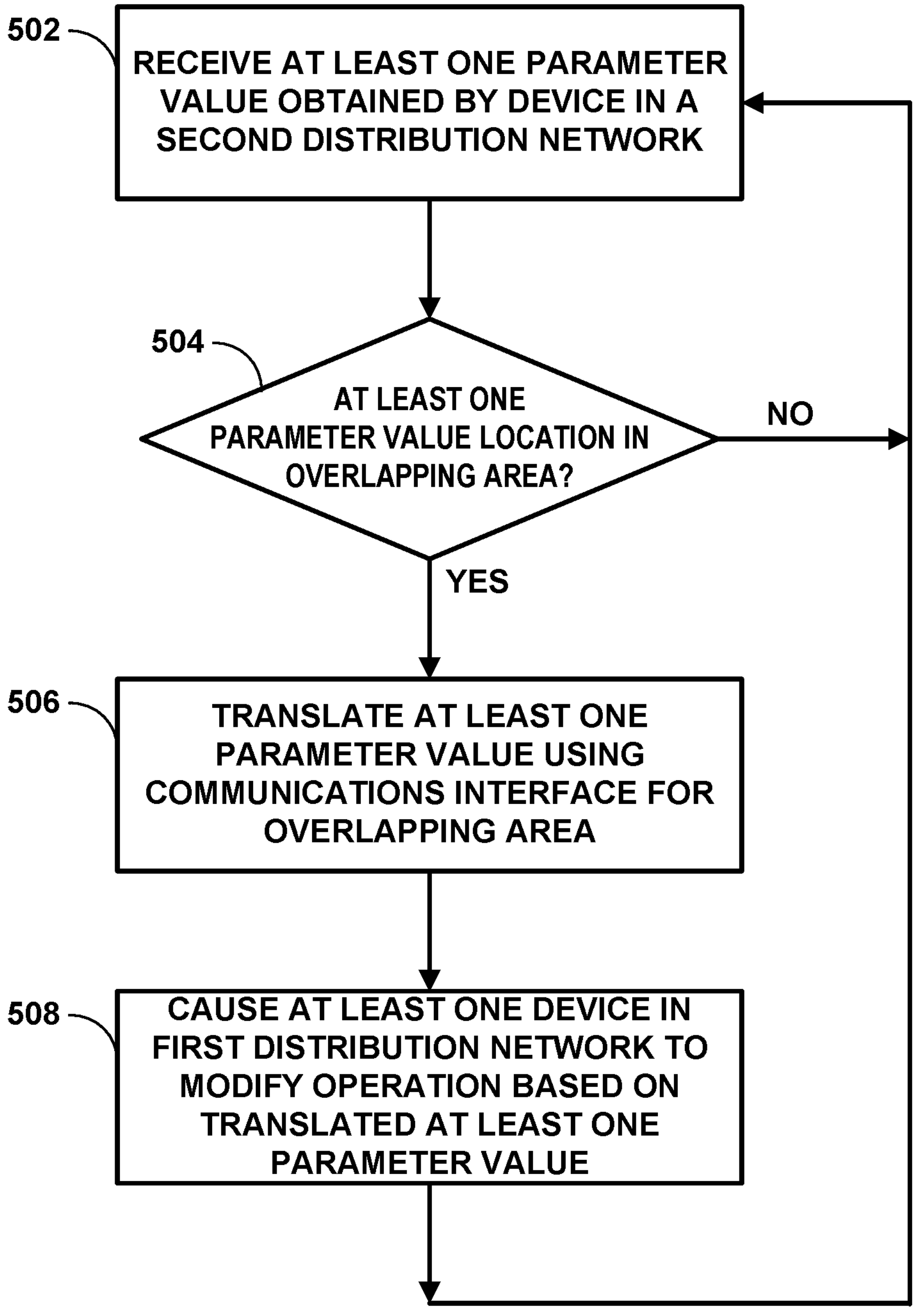
502
RECEIVE AT LEAST ONE PARAMETER VALUE OBTAINED BY DEVICE IN A SECOND DISTRIBUTION NETWORK
504
AT LEAST ONE PARAMETER VALUE LOCATION IN OVERLAPPING AREA?
NO
YES
506
TRANSLATE AT LEAST ONE PARAMETER VALUE USING COMMUNICATIONS INTERFACE FOR OVERLAPPING AREA
508
CAUSE AT LEAST ONE DEVICE IN FIRST DISTRIBUTION NETWORK TO MODIFY OPERATION BASED ON TRANSLATED AT LEAST ONE PARAMETER VALUE

FIG. 5

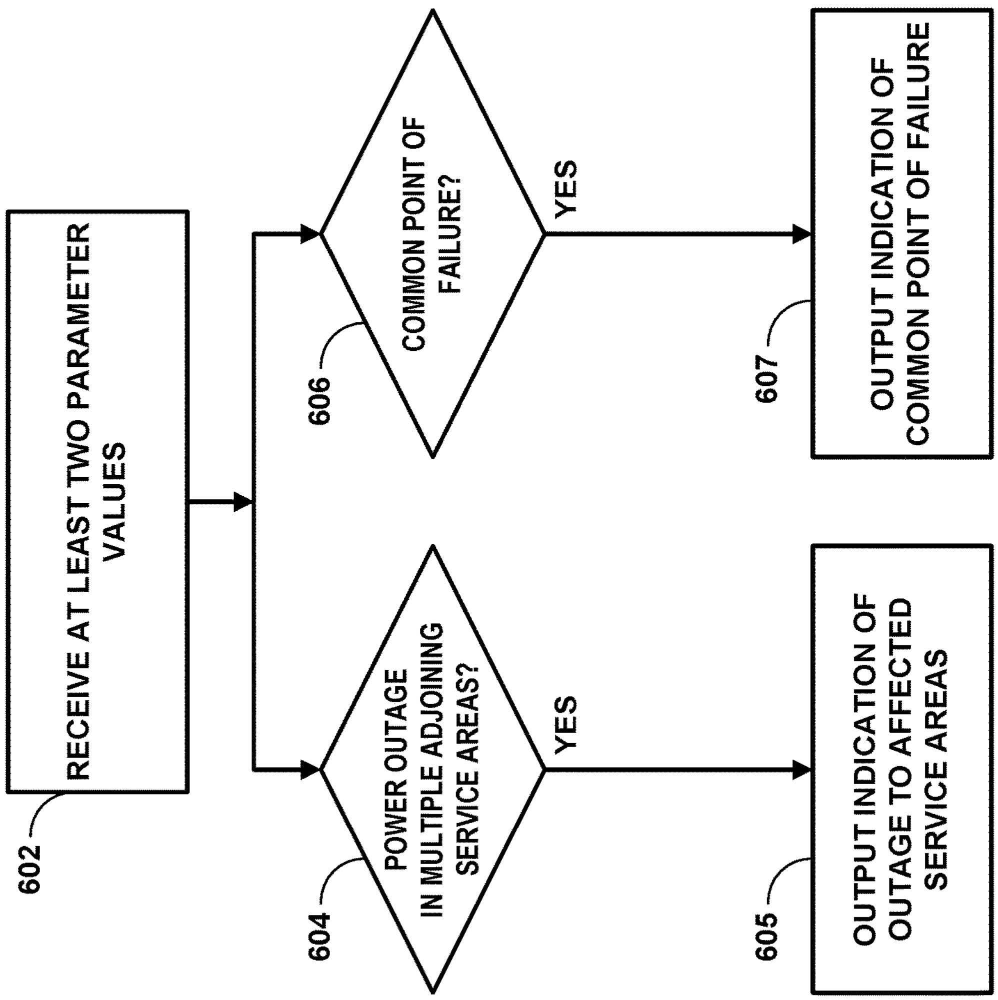
RECEIVE AT LEAST TWO PARAMETER VALUES
602
POWER OUTAGE IN MULTIPLE ADJOINING SERVICE AREAS?
604
YES
OUTPUT INDICATION OF OUTAGE TO AFFECTED SERVICE AREAS
605
COMMON POINT OF FAILURE?
606
YES
OUTPUT INDICATION OF COMMON POINT OF FAILURE
607

FIG. 6

HETEROGENEOUS NETWORK TOPOLOGY MANAGEMENT AND CONTROL

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application No. 62/583,847, titled "HETEROGENEOUS NETWORK TOPOLOGY MANAGER" and filed Nov. 9, 2017, the entire content of which is incorporated herein by reference.

CONTRACTUAL ORIGIN

The United States Government has rights in this invention under Contract No. DE-AC36-08GO28308 between the United States Department of Energy and Alliance for Sustainable Energy, LLC, the Manager and Operator of the National Renewable Energy Laboratory.

BACKGROUND

Electric power distribution networks deliver electric power to consumers. Power quality can vary spatiotemporally across such networks with the ebb and flow of power supply and demand. Distribution system operators (DSOs) may utilize aggregate power quality information from locations in the power distribution network to account for such ebb and flow and to provision power in an efficient and reliable manner. Increasing penetration of distributed energy resources (DERs), such as photovoltaics (PV), on-site generators, battery systems, demand response systems, and others may lead to increasingly larger and potentially harmful variations in power quality across power distribution networks. Cable television (CATV) distribution networks deliver cable services, such as television programming, internet, and others, to many of the same consumers. CATV distribution networks have sensors that measure performance of power distribution networks at more granular, but still aggregate, levels.

SUMMARY

In one example, a system includes at least one cable service device having a processor and a voltage sensor. The at least one cable service device corresponds to a respective at least one power consumption location that is connected to a power distribution network, and the at least one cable service device is configured to: provide at least one cable service to the power consumption location via a cable television (CATV) distribution network, determine a voltage value representing a voltage of the power distribution network at the at least one power consumption location, and output the voltage value. The system also includes a heterogenous network topology management and control (HNTMC) device comprising a processor and configured to receive an indication of the voltage value and cause at least one device within the power distribution network to modify operation based on the voltage value.

In another example, a device includes a voltage sensor configured to measure a voltage value that represents a voltage of a power distribution network at a power consumption location that corresponds to the device and at least one processor communicatively coupled to the voltage sensor. The at least one processor is configured to provide at least one cable service to the power consumption location via a cable television (CATV) distribution network and output an indication the voltage value.

In another example, a device includes at least one processor configured to receive an indication of a first geographic area corresponding to a first distribution network, receive an indication of a second geographic area corresponding to a second distribution network, and determine, based on the first geographic area and the second geographic area, that at least a portion of the first distribution network and at least a portion of the second distribution network overlap in an overlapping geographic area. The at least one processor is further configured to receive at least one parameter value obtained by a device within the second distribution network, the at least one parameter value corresponding to a location within the overlapping geographic area, and cause at least one device within the first distribution network to modify operation based on the at least one parameter value of the second distribution network.

The details of one or more examples are set forth in the accompanying drawings and the description below. Other features, objects, and advantages will be apparent from the description and drawings, and from the claims.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a conceptual diagram illustrating an example heterogeneous network topology (HNT) management and control system, in accordance with one or more aspects of the present disclosure.

FIG. **2** is a block diagram illustrating an example cable service device configured to measure and provide power distribution network information for HNT management and control, in accordance with one or more aspects of the present disclosure.

FIG. **3** is a block diagram illustrating an example HNT management and control device configured to manage and control two or more networks having heterogenous topology, in accordance with one or more aspects of the present disclosure.

FIG. **4** is a flow diagram illustrating example operations of a HNT management and control device, in accordance with one or more aspects of the present disclosure.

FIG. **5** is a flow diagram illustrating example operations of a HNT management and control device, in accordance with one or more aspects of the present disclosure.

FIG. **6** is a flow diagram illustrating example operations of a HNT management and control device, in accordance with one or more aspects of the present disclosure.

DETAILED DESCRIPTION

The present disclosure provides systems, devices, and methods that may be used to improve management and control of two or more networks having heterogeneous topology. In one aspect, the techniques described herein provide cable service devices, for use within a cable television (CATV) distribution network, that can monitor and report electric power quality. For example, in addition to providing services (e.g., television programming, internet service, internet-based telephone services, etc.) to a consumer, a cable modem, CATV set-top box, or other cable service device may be configured to determine values of voltage, frequency, or other attributes of a power distribution network, at the consumer's location, and provide those values to the CATV distribution system manager.

In another aspect, the techniques of the present disclosure may allow information obtained from a first network, such as a CATV distribution network, to be used for management and control of a geographically overlapping second distribution network, such as a power distribution network, and vice versa. For example, a heterogenous network topology (HNT) management and control device may receive power quality information obtained by devices in a CATV distribution network and by devices in a power distribution network. The HNT management and control device may correlate the two distribution networks and associate received information from each of the networks with the other. The HNT management and control device may also utilize the combined information to manage and control the power distribution network and/or the CATV distribution network.

Power distribution networks are designed and built such that power quality delivered to consumers is within acceptable ranges. For example, in the United States, these ranges are specified by the American National Standards Institute (ANSI C84.1-2016). Power distribution system operators (DSOs) may use telemetry systems to remotely monitor power quality (e.g., measured voltage values, frequency values, and/or others) at aggregations of approximately 1,000 consumers and use this information as input signals to control the power distribution network. Finer resolution power quality information, for smaller groups of homes, is typically not available to DSOs. For example, voltages between phases and neutral are not available even in service areas where DSOs have deployed advanced metering infrastructure,

CATV distribution networks often geographically overlay power distribution networks and CATV multiple system operators (MSOs) routinely obtain power quality information throughout the day from outside plant power supplies that serve groups of approximately 125 consumers. In fact, an international standards-based CATV power supply collection method (ANSI/SCTE 112 2005) is employed around the world by domestic MSO broadband providers as well as by international MSO broadband providers.

Analysis of recent studies of CATV power supply input voltage and frequency information shows that many groups of approximately 125 homes receive power quality well outside acceptable ANSI limits. That is, many ~125-home areas have high, low, and fluctuating voltages and frequencies. The observability limitations of the power distribution infrastructure leave utilities blind to end-of-line and last-mile power quality issues. Such issues may, however, be visible (or may be more easily visible) to CATV broadband providers.

Via straightforward, well established methods of Internet Protocol (IP) communication with servers at these MSOs, ongoing power quality information for the majority of the worldwide distribution grid could be aggregated via a high-speed messaging bus and routinely shared with DSOs for the purpose of improving network operations such as power quality monitoring, outage prediction, and service restoration, as well as improving overall system-level end-to-end efficiency of the grid.

The inverse question, "How may DSOs systematically share voltage and frequency measurements with CATV broadband (and other) providers?", is also of great interest. Power distribution network power quality telemetry readings obtained by DSOs, particularly operational vs. outage status, are valuable to widely dispersed large and small entities with a critical need to know of grid power failures such as MSOs, and other water, gas and/or emergency service providers.

By enabling common capture, storage, analysis, and forwarding of information between two or more networks having heterogenous topology, the techniques described herein may open up significantly more information, both geographically and temporally, about the status of the networks for management and control by distribution system operators. In addition, by enabling cable service devices to determine and transmit information about power quality at a consumer's location, the techniques of the present disclosure may provide an efficient, low-cost, and easy-to-implement alternative to related-art techniques hoping to provide DSOs with timely, granularized information about the power distribution network.

FIG. **1** is a conceptual diagram illustrating an example heterogeneous network topology (HNT) management and control system (e.g., system **102**), in accordance with one or more aspects of the present disclosure. In the example of FIG. **1**, system **102** includes power distribution system manager **104**, power distribution network **106**, CATV distribution system manager **108**, and CATV distribution network **110**. Power distribution network **106** includes telemetry devices **107**A and **107**B (collectively "telemetry devices **107**"). System **102** also includes consumers **112**A-**112**F (collectively "consumers **112**"), cable service devices **114**A-**114**F (collectively "cable service devices **114**"), and heterogenous network topology (HNT) management and control device **116**.

The example of FIG. **1** is for illustration only and system **102** represents only one example of a HNT management and control system. Various other systems, including more, fewer, or different devices and components may be used in accordance with the techniques of the present disclosure. For example, system **102** includes six of consumers **112**. In some examples, HNT management and control systems may include any number of consumers.

In the example of FIG. **1**, power distribution system manager **104** represents the infrastructure of a DSO. Power distribution system manager **104** may receive power from a transmission network or other source (not shown) and provision power to consumers **112**. Power distribution system manager **104** may generally include hardware and software platforms that integrate numerous utility systems, provide automated outage restoration and optimization of distribution grid performance, and otherwise generally manage a power distribution network. Power distribution system manager **104** provides power to consumers **112** via power distribution network **106**.

Power distribution network **106**, in the example of FIG. **1**, represents a physical network configured to distribute power to consumers **112**. For example, power distribution network **106** may include wire conductors, insulators, switches, transformers, capacitors, load tap changers and/or other components. In other words, power distribution network **106** may represent the hardware necessary to distribute electrical power to consumers **112**.

Power distribution network **106** includes telemetry devices **107**. Examples of telemetry devices **107** may include supervisory control and data acquisition (SCADA) units, phasor measurement units (PMUs), and/or other devices. In other words, each of telemetry devices **107** may represent any device within power distribution network **106** that is configured to determine and provide values of power quality attributes to power distribution system manager **104**. While only two telemetry devices are shown in the example of FIG. **1**, power distribution networks may, in various examples, include any number of telemetry devices.

In the example of FIG. **1**, telemetry devices **107** may determine values of power quality attributes, such as voltage, frequency, and/or others. Typically, telemetry devices may be located at aggregation points throughout a power distribution network, and thus power quality information provided by the telemetry devices may correspond to (often large) aggregations of consumers, instead of at the per-consumer level. In the example of FIG. **1**, for instance, determinations by telemetry device **107**A correspond to an aggregation of one third of power distribution network **106** (two of consumers **112**), and determinations by telemetry device **107**B correspond to an aggregation of one half of power distribution network **106** (three of consumers **112**).

Telemetry devices **107** may output the determined power quality attribute values to power distribution system manager **104** for management and control of power distribution network **106**. Typical power distribution network telemetry devices may determine and/or output such power quality information on a relatively slow timescale, such as once every 5 minutes, once every 15 minutes, or even slower. In the example of FIG. **1**, telemetry devices **107** may only determine and transmit such power quality information once every 15 minutes.

In the example of FIG. **1**, CATV distribution system manager **108** represents the infrastructure of a MSO. CATV distribution system manager **108** may provision cable services such as television programming, internet connectivity, voice over IP (VoIP) services, and others, to cable service devices **114** for use by consumers **112**. CATV distribution system manager **108** may generally include network and element management systems and/or any other devices commonly used to manage a CATV distribution network. CATV distribution system manager **108** provides cable services via CATV distribution network **110**.

CATV distribution network **110**, in the example of FIG. **1**, represents a physical and/or logical network configured to provide cable services to cable service devices **114** for use by consumers **112**. For example, CATV distribution network **110** may include fiber optic and coax cable for carrying signals, neighborhood fiber nodes that provide optical to electrical conversion, network power supplies, various types of amplifiers for extending signals, and/or other components. In other words, CATV distribution network **110** may represent the hardware necessary to distribute cable services to consumers **112**.

In the example of FIG. **1**, consumers **112** represent homes, businesses, and/or any other power consumption locations within power distribution network **106**. Consumers **112** are each associated with one of cable service devices **114**. While each of cable service devices **114** is associated with a single respective consumer **112** in the example of FIG. **1**, cable service devices may, in some examples, be associated with multiple consumers (e.g., when providing cable services to an apartment building). Additionally, in some examples, consumers may have two or more associated cable service devices (e.g., a cable modem and a set-top box). In some examples, certain consumers may not have any associated cable service devices.

Cable service devices **114**, in the example of FIG. **1**, represent cable modems, cable set-top boxes, VoIP provisioning devices, or any other devices capable of providing one or more cable services to consumers **112**. In addition, cable service devices **114** are configured to determine values of power quality attributes (e.g., voltage values, frequency values, outages, and harmful deviations from ANSI limits or other specified limits, etc.) for power distribution network **106** at the location of the respective one of consumers **112**. For example, cable service device **114**A may be configured to determine a voltage value representing the voltage of power distribution network **106** at consumer **112**A, cable service device **114**B may be configured to determine a voltage value at consumer **112**B, and so on.

Cable service devices **114** are also configured to output the determined power quality attribute values. For example, cable service device **114**A may output quality information **115**A. Cable service device **114**F may output power quality information **115**F. Power quality information **115**A and **115**F are collectively referred to herein as "power quality information **115**". Cable services devices **114**B-**114**E may also output respective power quality information but this is not shown in FIG. **1**, for brevity. Power quality information **115** may be transmitted (e.g., via existing CATV distribution network infrastructure) to CATV distribution system manager **108**.

Power quality information **115** may include a location identifier and information about the power quality at that location. In some examples, the location identifier may be information specifying a geographic location (e.g., coordinates or an address). In some examples, the location identifier may be information specifying a logical location, such as an IP address, a consumer identifier, a CATV distribution network position indicator, or any other information that may provide CATV distribution system manager **108** with a way to determine where in CATV distribution network **110** the information came from.

In some examples, power quality information **115** may include actual measurements made by cable service devices **114**, such as voltage values, frequency values, and the like. In some examples, power quality information **115** may additionally or alternatively include inferred data that is generated based on the measurements. In some examples, power quality information **115** may not include voltage values. In other words, in various examples, power quality information **115** may include various measured and/or inferred information about power quality. Further details of an example cable service device are provided below with respect to FIG. **2**.

System **102** includes HNT management and control device **116**. HNT management and control device **116** may be configured to provide common capture, storage, analysis, and forwarding of power distribution network information and CATV distribution network information in order to enable improved management and control of power distribution network **106** and/or CATV distribution network **110**. HNT management and control device **116** may be a computing device, such as a server computer, a desktop computer, or any other device capable of implementing some or all of the techniques described herein.

In some examples, HNT management and control device **116** may represent a cloud computing environment. That is, while shown as a single box and described as a "device" herein, HNT management and control device **116** may, in some examples, be a group of distributed computing resources that communicate with one another to perform at least some of the techniques described herein. In some examples, HNT management and control device **116** may be the same as or be physically collocated with power distribution system manager **104** or CATV distribution system manager **108**. In other words, HNT management and control device **116** may, in some examples, be a part of power distribution system manager **104** or CATV distribution system manager **108**. In some examples, such as the example shown in FIG. **1**, power distribution system manager **104**, CATV distribution system manager **108**, and HNT management and control device **116** may be physically separated.

In accordance with the techniques of the present disclosure, HNT management and control device **116** may receive an indication of a first geographic area corresponding to a first distribution network. In the example of FIG. **1**, for instance, HNT management and control device **116** may receive information from power distribution system manager **104** indicating a geographic area corresponding to power distribution network **106**. HNT management and control device **116** may also receive an indication of a second geographic area corresponding to a second distribution network. In the example of FIG. **1**, for instance, HNT management and control device **116** may receive information from CATV distribution system manager **108** indicating a geographic area of CATV distribution network **110**.

Based on the first geographic area and the second geographic area, HNT management and control device **116** may determine that at least a portion of the first distribution network and at least a portion of the second distribution network overlap in an overlapping geographic area. For instance, HNT management and control device **116** may determine that power distribution network **106** an CATV distribution network **110** overlap in the geographic area covering consumers **112**. Consequently, HNT management and control device **116** may generate one or more interfaces for translating data received from each distribution system manager into data usable by the other distribution manager.

HNT management and control device **116** may receive at least one parameter value of the second distribution network, the at least one parameter value corresponding to a location within the overlapping geographic area. For example, HNT management and control device **116** may receive, from CATV distribution system manager **108**, voltage and/or frequency values that were included in power quality information **115** as received from consumers **112**. HNT management and control device **116** may utilize the generated interface(s) to translate this data into data understandable and usable by power distribution system manager **104**.

HNT management and control device **116** may cause at least one device within the first distribution network to modify operation based on the at least one parameter value of the second distribution network. That is, HNT management and control device **116** may cause at least one device within power distribution network **106** to modify operation based on the voltage and/or frequency values determined by devices within CATV distribution network **110**. As one example, HNT management and control device **116** may cause a switch within power distribution network **106** to open, thus cutting off the flow of power through the switch and protecting at least a portion of the network. As another example, HNT management and control device **116** may cause a load tap changer within power distribution network **106** to change to a different tap to provide voltage support. As another example, HNT management and control device **116** may cause a DER within power distribution network **106** to add or shed load. As another example, HNT management and control device **116** may cause a DER inverter within power distribution network **106** to modify the proportions of active and/or reserve power provided to power distribution network **106**.

In some examples, HNT management and control device **116** may determine appropriate changes to be made in power distribution network **106** and issue instructions to cause such changes. That is, in some examples HNT management and control device **116** may directly cause devices within power distribution network **106** to modify operation. In some examples, HNT management and control device **116** may cause devices within power distribution network **106** to modify operation by converting the voltage and/or frequency values into data understandable by power distribution system manager **104** and outputting that data to power distribution system manager **104**, which in turn may cause devices within power distribution network **106** to modify operation. In some examples, HNT management and control device **116** may be configured both to directly cause devices to modify operation and to indirectly cause devices to modify operation.

In some examples, HNT management and control device **116** may additionally or alternatively cause at least one device within CATV distribution network **108** to modify operation based on parameter values from within power distribution network **106**. That is, HNT management and control device **116** may be used for improved control of both distribution networks. In some examples, HNT management and control device **116** may be configured to receive information from more than two networks for use by multiple networks. One example of HNT management and control device **116** is further described with respect to FIGS. **3-5** below.

In accordance with the techniques of the present disclosure, cable service devices **114** provide the ability to obtain power quality information for a power distribution network at the per-consumer level. Furthermore, because cable service devices **114** may utilize preexisting CATV distribution network infrastructure, this granular power quality information may be easily transmitted to a CATV distribution system manager, allowing for information collection at a much faster frequency. Cable service devices as disclosed herein may allow for more accurate management and control of CATV distribution networks, power distribution networks, and/or other systems.

HNT management and control device **116**, in accordance with the techniques described herein, may provide an Internet-based geographic information system (GIS) that can offer DSOs & MSOs common capture, storage, analysis and forwarding of power quality information from spatially overlapping serving areas. HNT management and control device **116** contains a Heterogeneous Network Topology Manager that performs the function of a go-between between DSOs and MSOs, who each voluntarily populate the common GIS database with named geographic polygons that reflect their respective serving areas. The geographic go-between function translates power quality information from DSO parlance to MSO parlance and vice versa. In this way, for example, degraded power quality at the corner of 5th Avenue and Main Street observed by the MSO power supply, which may be known as “31A124-PS1”, can be communicated to the local DSO in an automated fashion using network identifiers and verbiage familiar to the DSO, such as “Power Pole: Golden_126_Distrib-Phase A”.

The nature of GIS systems in use today by DSOs and MSOs is such that exhaustive details on millions of miles of conductor lengths, diameters and attachment points are recorded in great detail. In contrast, by design, HNT management and control device **116** may require only a limited amount of GIS information from DSOs and MSOs, such as the names and the geographic boundaries of their respective individual serving areas.

While described in the example of FIG. **1** as being provided by CATV distribution system manager **108** to HNT management and control device **116**, power quality information **115** may additionally or alternatively be used by

CATV distribution system manager **108**. That is, the cable service devices disclosed herein may be used in conjunction with the HNT management and control devices disclosed herein, or may be used in current CATV distribution networks, without a HNT management and control device. Additionally, while described in the example of FIG. **1** as receiving power quality information **115** from cable service devices **114**, HNT management and control device **116** may additionally or alternatively receive such information from other devices within CATV distribution network **110**. That is, the HNT management and control devices disclosed herein may be used in conjunction with the cable service devices disclosed herein or may be used with other devices already in use in current CATV distribution networks.

FIG. **2** is a block diagram illustrating an example cable service device (cable service device **214**) configured to measure and provide power distribution network information for HNT management and control, in accordance with one or more aspects of the present disclosure. The example of FIG. **2** is described below within the context of FIG. **1**. For instance, Cable service device **214** may represent one or more of cable service devices **114** described with respect to FIG. **1**.

FIG. **2** illustrates only one particular example of a cable service device configured in accordance with the techniques described herein. Other examples of a cable service device may be used in other instances. In some examples, cable service devices may include fewer components than shown in the example of FIG. **2** or may include additional or different components not shown in the example of FIG. **2**.

In the example of FIG. **2**, cable service device **214** includes one or more processors (processors **220**), one or more communications units (communications units **222**) and one or more storage devices (storage devices **228**). Cable service device **214** also includes voltage sensor **224** and frequency sensor **226**. Storage devices **228** of cable service device **214** include cable service module **230** and power quality module **232**. Communications channels **240** may interconnect each of components **220**, **222**, **224**, **226**, **228**, **230**, and **232** for inter-component communications (physically, communicatively, and/or operatively). In some examples, communication channels **240** may include a system bus, a network connection, an inter-process communication data structure, or any other method for communicating data.

Communication units **222** may allow cable service device **214** to communicate with external devices via one or more networks by transmitting and/or receiving network signals on the one or more networks. For example, cable service device **214** may use communication units **222** to transmit and/or receive radio frequency signals carrying cable television programming, internet data, VoIP data, or other data via CATV distribution network **110**. In some examples, communication units **222** may be configured to communicate via a wired network (e.g., using coaxial cable common to CATV distribution networks). In some examples, communications units **222** may be configured to communicate via one or more wireless networks. Examples of communication units **222** include a tuner, a modulator/demodulator (modem), a diplex filter, a communications processor, buffer memory, a network interface controller (e.g., an Ethernet card), an optical transceiver, a radio frequency transceiver, a GPS receiver, or any other type of device that can send and/or receive information. Additional examples of communication units **222** may include Bluetooth®, GPS, 3G, 4G, and Wi-Fi® radios, or Universal Serial Bus (USB) controllers.

Voltage sensor **224** and frequency sensor **226** may be devices configured to measure electrical voltage and alternating current electrical frequency, respectively. As one example, voltage sensor **224** and frequency sensor **226** may be connected to a power source (not shown) for cable service device **214**. Thus, voltage sensor **224** and frequency sensor **226** may measure the voltage and frequency of the power received by cable service device **214**, which may be representative of power distribution network **106** at the location of the consumer or consumers with whom cable service device **214** is associated.

While illustrated as internal components of cable service device **214**, voltage sensor **224**, frequency sensor **226**, and or other components may, in some examples, represent external components that share a data path with other components of cable service device **214**. For instance, in one example, voltage sensor **224** and frequency sensor **226** may be an external component located outside of and physically separated from a packaging of cable service device **214** but connected to cable service device **214** via wired or wireless communication means. In such example, voltage sensor **224** and frequency sensor **226** may be configured to measure voltage and frequency at another location corresponding to the consumer, such as where power distribution network **106** connects to the consumer's physical location.

Storage devices **228** may store information for processing during operation of cable service device **214**. In some examples, storage devices **228** represent temporary memory, meaning that a primary purpose of storage devices **228** is not long-term storage. In some examples, storage devices **228** may be configured for short-term storage of information as volatile memory and therefore may not retain stored contents when powered off. Examples of volatile memories include random access memories (RAM), dynamic random access memories (DRAM), static random access memories (SRAM), and other forms of volatile memories known in the art.

In some examples, storage devices **228** may include one or more computer-readable storage media. That is, storage devices **228** may, in some examples, be configured to store larger amounts of information than volatile memory. Storage devices **228** may further be configured for long-term storage of information as non-volatile memory space and thus may retain information even when powered off. Examples of non-volatile memories include magnetic hard discs, optical discs, floppy discs, flash memories, or forms of electrically programmable memories (EPROM) or electrically erasable and programmable (EEPROM) memories. Storage devices **228** may store program instructions and/or data associated with cable service module **230** and/or power quality module **232**.

One or more of processors **220** may implement functionality and/or execute instructions within cable service device **214**. For example, processors **220** of cable service device **214** may receive and execute instructions stored by storage devices **228**, thereby enabling the functionality of cable service module **230** and/or power quality module **232**. In some examples, the execution of these instructions, by processors **220**, may cause cable service device **214** to store information within storage devices **228** during program execution. Cable service module **230** and power quality module **232** may be operable by processors **220** to perform various actions, including providing cable service(s) and determining values of power quality attributes.

In accordance with aspects of the present disclosure, cable service module **230** may include instructions that are executable by processors **220** to cause cable service device **214** to provide one or more cable services to a consumer. Cable services may include internet connectivity, delivery of television programming, VoIP services, or any other cable services.

Power quality module **232** may include instructions that are executable by processors **220** to cause cable service device **214** to determine one or more values for power quality attributes. For example, processors **220** may obtain information from voltage sensor **224** to determine a voltage value. Processors **220** may also obtain information from frequency sensor **226** to determine a frequency value. Power quality module **232** may further include instructions that, when executed, cause cable service device **214** to output the determined power quality information. That is, cable service device **214** may output the determined voltage value and determined frequency value (e.g., using communication units **222**). In the example of FIG. **1**, cable service device **214** may output the determined voltage value and determined frequency value, using the existing infrastructure of CATV distribution network **210**, to CATV distribution system manager **208** as part of power quality information **115**.

In some examples, cable service device **214** may be configured to determine and output voltage values, frequency values, and/or other power quality attribute values on a periodic basis. For instance, cable service device **214** may determine and output such information every 30 seconds, every minute, every 5 minutes, or at any other frequency. In some examples, cable service device **214** may determine power quality attribute values on a periodic basis but only output such information when various criteria have been met. For instance, power quality module **232** may include instructions that, when executed, cause cable service device **214** to compare determined values to certain threshold values to ascertain whether the determined values are "acceptable." Such threshold values may be static (e.g., preprogrammed into cable service device **214**), controlled (e.g., periodically programmed into cable service device **214** directly or remotely), and/or dynamic (e.g., rolling average values or otherwise learned based on historical determined values).

In some examples, cable service device **214** may be configured to generate inferred information based on the determined voltage values, frequency values, and/or other power quality attribute values. For instance, power quality module **232** may include instructions that, when executed, cause cable service device **214** to monitor the determined voltage and frequency value over time and determine, based on the determined voltage and frequency values, whether the values indicate that a fault has occurred. The instructions may further cause cable service device **214** to output such inferred information in addition to or alternative to the "raw" or measured values.

In some examples, cable service device **214** may be configured to determine and/or output power quality parameter values and/or inferred information in response to receiving instructions to do so. In some examples, cable service device **214** may be configured additionally or alternatively to determine and/or output power quality parameter values and/or inferred information on its own. In other words, cable service device **214** may be configured to provide poll data (e.g., when polled by a CATV distribution system manager or other device or entity) and/or trap data (e.g., generated at regular intervals and/or when specified criteria are met).

By determining and outputting voltage values, frequency values, and/or other power quality attribute values, cable service device **214** may allow CATV distribution system managers to better understand and account for variabilities in a geographically overlapping power distribution network. As further described herein, cable service devices as disclosed herein may also allow power distribution system managers to have significantly more insight into power distribution network operation (e.g., via a HNT management and control device) and thus may improve management and control of such power distribution networks, as well. In addition, cable service devices such as cable service device **214** may allow for such improved management and control with only a small increase in device cost and without the need for additional distribution network infrastructure.

FIG. **3** is a block diagram illustrating an example HNT management and control device (HNT management and control device **316**) configured to manage and control two or more networks having heterogenous topology, in accordance with one or more aspects of the present disclosure. The example of FIG. **3** is described below within the context of FIG. **1**. For instance, HNT management and control device **316** may represent HNT management and control device **116** described with respect to FIG. **1**.

FIG. **3** illustrates only one particular example of a HNT management and control device configured in accordance with the techniques described herein. Other examples of a HNT management and control device may be used in other instances. In some examples, HNT management and control devices may include fewer components than shown in the example of FIG. **3** or may include additional or different components not shown in the example of FIG. **3**.

In the example of FIG. **3**, HNT management and control device **316** includes one or more processors (processors **320**), one or more communications units (communications units **322**) and one or more storage devices (storage devices **328**). Storage devices **328** of HNT management and control device **316** include geographic information store **330**, network interface store **332**, load module **334**, monitoring module **336**, and inference module **338**. Communications channels **340** may interconnect each of components **320**, **322**, **328**, **330**, **332**, **334**, **336**, and **338** for inter-component communications (physically, communicatively, and/or operatively). In some examples, communication channels **340** may include a system bus, a network connection, an inter-process communication data structure, or any other method for communicating data.

While illustrated as internal components of HNT management and control device **316**, one or more components may, in some examples, represent external components that share a data path with other components of HNT management and control device **316**. For instance, in one example, modules **334**, **336**, and/or **338** may be external components stored in storage devices **328** that are located outside of and physically separated from a packaging of HNT management and control device **316** but connected to HNT management and control device **316** and to one another via wired or wireless communication means, such as in a cloud computing environment.

Communication units **322** may allow HNT management and control device **316** to communicate with external devices via one or more networks by transmitting and/or receiving network signals on the one or more networks. For example, HNT management and control device **316** may use communication units **322** to transmit and/or receive digital data via a physical network, such as Ethernet. As another example, HNT management and control device **316** may use communication units **322** to transmit and/or receive radio signals on a radio network such as a cellular radio network. Likewise, communication units **322** may transmit and/or receive satellite signals on a satellite network such as a GPS network. Examples of communication units **322** include a network interface controller (e.g., an Ethernet card), an optical transceiver, a radio frequency transceiver, a GPS receiver, or any other type of device that can send and/or receive information. Other examples of communication units **42** may include Bluetooth®, GPS, 3G, 4G, and Wi-Fi® radios, as well as Universal Serial Bus (USB) controllers.

Storage devices **328** may store information for processing during operation of HNT management and control device **316**. In some examples, storage devices **328** represent temporary memory, meaning that a primary purpose of storage devices **328** is not long-term storage. In some examples, storage devices **328** may be configured for short-term storage of information as volatile memory and therefore may not retain stored contents when powered off. Examples of volatile memories include random access memories (RAM), dynamic random access memories (DRAM), static random access memories (SRAM), and other forms of volatile memories known in the art.

In some examples, storage devices **328** may include one or more computer-readable storage media. That is, storage devices **328** may, in some examples, be configured to store larger amounts of information than volatile memory. Storage devices **328** may further be configured for long-term storage of information as non-volatile memory space and thus may retain information even when powered off. Examples of non-volatile memories include magnetic hard discs, optical discs, floppy discs, flash memories, or forms of electrically programmable memories (EPROM) or electrically erasable and programmable (EEPROM) memories. Storage devices **328** may store program instructions and/or data associated with geographic information store **330**, network interface store **332**, load module **334**, monitoring module **336**, and/or inference module **338**.

One or more of processors **320** may implement functionality and/or execute instructions within HNT management and control device **316**. For example, processors **320** of HNT management and control device **316** may receive and execute instructions stored by storage devices **328**, thereby enabling the functionality of load module **334**, monitoring module **336**, and/or inference module **338**. In some examples, the execution of these instructions, by processors **320**, may cause HNT management and control device **316** to store information within storage devices **328** during program execution. load module **334**, monitoring module **336**, and/or inference module **338** may be operable by processors **320** to perform various actions, including determining geographic overlap between distribution networks having heterogenous topology, and allowing such distribution networks to be managed and/or controlled based additionally on information from overlapping distribution networks.

In accordance with aspects of the present disclosure, load module **334** may contain instructions executable by processors **320** to allow HNT management and control device **316** to receive indications of geographic areas of multiple distribution networks. Indications of geographic areas may include a unique name, and latitude/longitude coordinates of a land shape polygons (e.g., specifying a serving area). In some examples, the indications of geographic areas may also include names of network elements providing services to polygon serving areas. Load module **334** may also be executable to determine, using geographic information store **330**, whether or not the distribution networks geographically overlap. For any overlapping areas, load module **334** may be executable to generate communication interfaces for such overlapping areas. Communication interfaces may be stored in network interface store **332**.

As one specific example, communications units **324** of HNT management and control device **316** may receive (e.g., from power distribution system manager **104**) an indication of a first geographic area corresponding to the portion of power distribution network **106** that includes consumers **112**. Load module **334** may be executable by processors **320** to receive the indication and store the geographic information in geographic information store **330**. The indication of the first geographic area may be latitude and longitude coordinates indicating a center point and length of a radius around that center point, polygons described with northing and easting values, coordinates of hexagonal polygons, boundaries of regularly and irregularly shaped polygons, or another other way of indicating a geographic area. Load module **334** may also be executable by processors **320** to receive (e.g., from CATV distribution system manager **108**) an indication of a second geographic area corresponding to the portion of CATV distribution network that includes consumers **112**.

Load module **334** may be executable to compare the indicated second geographic area to other geographic areas in geographic information store **330** to determine whether the second geographic area overlaps with any other geographic areas. For example, load module **334** may determine a number of points around the defined edge of the second geographic area. In various examples, load module **334** may determine 3 points, 5 points, 10 points, or any other number of points that sufficiently approximates the boundary of the second geographic area. In some examples, such as when a geographic area is received as a set of geographic coordinates defining vertices of a polygon, load module may not need to determine such points and may instead use the provided points. Regardless, load module **334** may mathematically determine whether any of these points fall within any of the previously received geographic areas to determine whether the second geographic area overlaps with any other geographic area.

In some examples, load module **334** may be executable by processors **320** to receive one or more schemas corresponding to each geographic area. Each schema may define a logical/syntactical structure for sending data to and/or receiving data from the distribution system manager for the geographic area. That is, the schema may define how the distribution system manager's data is structured, so that HNT management and control device **316** can properly interpret data received from the distribution system manager and structure data (e.g., data received from other distribution system managers and/or data generated by HNT management and control device **316**) to be sent to the distribution system manager.

Load module **334** may be executable to determine that the first geographic area and the second geographic area overlap and consequently generate a communication interface for power distribution network **106** and CATV distribution network **110** in the overlapping geographic area (e.g., the area including consumers **112**).

A communication interface may be any logical architecture usable to translate data received from one distribution network to data interpretable by another distribution network. One example of a communication interface may be an application programming interface (API). The API may be created using software routines and communications protocols that are understood by DSO and MSO GIS systems. For example, load module **334** may utilize received schemas to create the communication interface. In some examples, an operator or manager of HNT management and control device **316** may assist in the creation of the communications interface. In others, load module **334** may generate the communication interface on its own (e.g., using provided information to link schema elements, etc.). The function of the API would be to present a uniform communications interface for translating the observed attribute values in one domain, such as the MSO, to the other domain, such as the DSO. Load module **334** may store generated communication interfaces in network interface store **332**.

Load module **334** may receive new and/or updated indications of geographic areas corresponding to power distribution network **106** and CATV distribution network **110** and create and modify communication interfaces between the two as necessary. In some examples, Load module **334** may also be executable by processors to remove communication interfaces, such as when an indication of an updated geographic area means there is no longer an overlap, or when a distribution system manager requests such removal.

In accordance with aspects of the present disclosure, monitoring module **336** may contain instructions executable by processors **320** to allow HNT management and control device **316** to receive information from a first network and determine whether the information is relevant to a second distribution network. If the information is relevant to a second network, monitoring module **336** may also be executable to translate the information into a format interpretable by a manager of the second network. The translated information may then be used for management and control of the second network.

As one specific example, communications units **324** of HNT management and control device **316** may receive (e.g., from CATV distribution system manager **108**) one or more power quality parameter values (e.g., included in power quality information **115**). Monitoring module **336** may be executable by processors **320** to receive the power quality parameter values and determine whether or not the power quality parameter values are relevant to another distribution network, such as power distribution network **106**. Monitoring module **336** may determine whether the values are relevant by checking whether a communication interface exists in network interface store **332** for the location from which the values were obtained.

If a communication interface exists in network interface store **332** for the location to which a power quality parameter value pertains, then monitoring module **336** may be executable to translate, using the communication interface, the received power quality parameter value into a translated parameter value that is interpretable by power distribution system manager **104**. If no such communication interface exists in network interface store **332**, then monitoring module **336** may take no action or perform other operations.

Monitoring module **336** may be executable to output translated parameter values to the manager for which the parameter values were translated. For instance, monitoring module **336** may transmit (e.g., via communication units **322**) translated power quality attribute values to power distribution system manager **104**. Power distribution system manager **104** may utilize the translated power quality attribute values to adjust operations of power distribution network **106**, such as by causing devices within power distribution network **106** to modify operation. In this way, HNT management and control device **316** may cause at least one device within power distribution network **106** to modify operation based on parameter values obtained by a device within CATV distribution network **110**.

In some examples, monitoring module **336** may also be executable to receive parameter values from devices within power distribution network **106**, determine whether such parameter values are relevant to CATV distribution network **110**, and, if so, translate such values using the applicable communication interface and output such translated parameter values to CATV distribution system manager **108**. That is, monitoring module **336** may be executable to provide two-way or even multi-way translation between any number of distribution networks.

In accordance with aspects of the present disclosure, inference module **338** may contain instructions executable by processors **320** to allow HNT management and control device **316** to monitor received parameter values and make inferences about distribution network problems. For example, inference module **338** may receive parameter values from contiguous devices indicating a drop in power quality. Consequently, inference module **338** may determine that the region is having power quality issues. Inference module **338** may output such inferences to various distribution system managers as necessary.

As one specific example, communications units **324** of HNT management and control device **316** may receive (e.g., from CATV distribution system manager **108**) power quality parameter values (e.g., included in power quality information **115** received from cable service devices **114**A, **114**B, and **114**C). The power quality parameter values may all indicate a similar problem with power quality at consumers **112**A, **112**B, an **112**C. Inference module **338** may be executable by processors **320** to receive these power quality parameter values.

Inference module **338** may be executable to determine, based on the geographic locations to which the parameter values pertain and the similarity between the parameter values, that a power outage is affecting a portion of power distribution network **106**. Consequently, inference module **338** may output an indication of the power outage to managers of potential affected distribution systems. For example, inference module **338** may output (e.g., via communication units **322**) an alert message about the inferred power outage to power distribution system manager **104** because power distribution system manager **104** manages power distribution network **106**. Inference module **338** may also output an alert message about the inferred power outage to CATV distribution system manager **108**, since the CATV distribution system relies on power distribution system **106**. In some examples, inference module **338** may also output an alert message to the manager of another power distribution network that is adjacent to power distribution network **106**, as the power outage in power distribution network **106** may affect the adjacent power distribution network.

By making inferences based on information from multiple distribution networks, inference module **338** may provide more proactive information to distribution network managers. This may, in turn, allow managers to more appropriately address network problems and prevent additional problems.

An important aspect of HNT management and control devices, as described herein is privacy and security. HNT management and control device **316**, for example, may enforce specific privacy-focused rules of engagement (ROE) to dramatically limit and restrict disclosure of power quality readings and other distribution network information, and to protect the confidentiality of distribution managers' GIS information.

The following is one example method for maintaining the privacy and/or security of various distribution system operators using HNT management and control:

1) Upon login to the HNT management and control device, any contributing entity (e.g., MSO, DSO, or other private or public facility or service operator, such

as a natural gas or water distributor or a municipal or emergency service operator) can only access (i.e., can only see) (a) what they themselves have submitted as their own land shapes (a.k.a. serving areas) in the GIS system and (b) those matches that exist with land shapes (serving areas) previously submitted by other entities, and

2) Upon any other entity submitting a newly overlapping land shape (serving area), the geographic go-between (i.e., a communication interface) is established, and contributing entities (a) are notified of the match, and (b) automatically start receiving forwarded telemetry readings.

Additional details and description of a HNT management and control device configured in accordance with the techniques of the present disclosure are provided below with respect to FIGS. **3**-**5**.

FIG. **4** is a flow diagram illustrating example operations of a HNT management and control device, in accordance with one or more aspects of the present disclosure. For purposes of illustration only, the example operations of FIG. **4** are described below within the context of FIG. **1**. For instance, the example operations of FIG. **4** may be performed by HNT management and control device **116**. The example operations of FIG. **4** may represent a "load mode" that HNT management and control device **116** may continuously execute to receive information about service areas from various stakeholders and integrate those service areas for common data capture and network management.

In the example of FIG. **4**, HNT management and control device **116** may receive an indication of a first geographic area that corresponds to a first distribution network (**402**). For instance, HNT management and control device **116** may receive information from power distribution system manager **104** identifying an area of power distribution network **106** (e.g., the area including consumers **112**A and **112**B and telemetry device **107**A). HNT management and control device **116** may also receive an indication of a subsequent geographic area that corresponds to a respective subsequent distribution network (**402**). For instance, HNT management and control device **116** may receive information from CATV distribution system manager **108** identifying the area of CATV distribution network **110** (e.g., the area of cable service device **114**A).

In the example of FIG. **4**, HNT management and control device **116** may determine whether the subsequent geographic area overlaps with any prior-received geographic areas (**406**). For instance, HNT management and control device **116** may determine whether the first geographic area and the subsequent geographic area overlap.

In the example of FIG. **4**, if HNT management and control device **116** determines that the subsequent geographic area does not overlap with any prior-received geographic areas ("NO" branch of operation **406**), HNT management and control device **116** may store the received subsequent geographic area and wait to receive another indication of a respective geographic area. In some examples, (such as when HNT management and control device **116** determines that the second geographic area overlaps with another geographic area) HNT management and control device **116** may perform one or more other operations or not perform any further operations.

In the example of FIG. **4**, if HNT management and control device **116** determines that the subsequent geographic area does overlap with a prior-received geographic area ("YES" branch of operation **406**), HNT management and control device **116** may generate a communication interface for the overlapping geographic area (**408**). For instance, because the area received from CATV distribution system manager **108** overlaps with the geographic area received from power distribution system manager **104**, HNT management and control device **116** may generate an API usable to translate power quality parameter values determined by cable service device **114**A and received from CATV distribution system manager **108** into power quality parameter values interpretable by power distribution system manager **104** and vice versa. In other words, communication interfaces generated by HNT management and control device **116** may translate data from the schema of a first distribution system manager to the schema of a second distribution system manager, thereby facilitating the easy exchange and collation of information between systems.

As shown in the example of FIG. **4**, HNT management and control device **116** may continuously wait to receive additional indications of respective geographic areas. As each new geographic area is received, HNT management and control device **116** may determine whether the newly-received geographic area overlaps with any previously received geographic areas and, if so, create communications interfaces accordingly.

The example operations of FIG. **4** may additionally or alternatively be described by the following example pseudo-code:

```
Start Load Mode
In the presence of a newly entered polygon for a DSO or MSO
serving area:
    a) If an overlap is identified with an existing polygon in GIS
    database,
        i) Notify all entities (e.g., DSO, MSO, etc.) of the
        match, and
        ii) Create a going forward "always active" application
        programming interface (API) for 2-way communication of:
            1) Telemetry Readings,
            2) Telemetry Queries,
            3) Telemetry Responses, and
            4) Spontaneous Messages (e.g., inference of power
            quality issue),
    b) Else
        i) Save the new serving area in GIS database and confirm
        submission
        ii) In anticipation of the arrival of a serving area
        match in the future, arm a notification trigger that will
        fire as soon as overlapping areas are detected.
End Load Mode
```

FIG. **5** is a flow diagram illustrating example operations of a HNT management and control device, in accordance with one or more aspects of the present disclosure. For purposes of illustration only, the example operations of FIG. **5** are described below within the context of FIG. **1**. For instance, the example operations of FIG. **5** may be performed by HNT management and control device **116**. The example operations of FIG. **5** may represent a "run1 mode" that HNT management and control device **116** may continuously execute to receive network information (e.g., power quality parameter values) from various stakeholders and provide such information to other relevant parties.

In the example of FIG. **5**, HNT management and control device **116** may receive at least one parameter value obtained by a device in a second distribution network (**502**). For instance, HNT management and control device **116** may receive power quality parameter values, determined by cable service device **112**A, from CATV distribution system manager **108**. The received power quality parameter values may be structured and formatted according to a schema used by CATV distribution system manager **108**.

In the example of FIG. **5**, HNT management and control device **116** may determine whether the at least one parameter value is from a geographic area that overlaps with other geographic areas received by HNT management and control device **116** (**504**). For instance, HNT management and control device **116** may determine whether the geographic location of cable service device **114**A overlaps with any other geographic areas received (including the geographic area received from power distribution system manager **104**). In some examples, HNT management and control device **116** may determine this based on geographic information received in conjunction with the at least one parameter value.

In the example of FIG. **5**, if HNT management and control device **116** determines that the at least one parameter value is not from a geographic area that overlaps with other received geographic areas ("NO" branch of operation **504**), HNT management and control device **116** may take no action or perform one or more other actions. If HNT management and control device **116** determines that the at least one parameter value is from a geographic area that overlaps with other received geographic areas ("YES" branch of operation **504**), HNT management and control device **116** may translate the at least one parameter value using a communications interface for the overlapping area (**506**). For instance, HNT management and control device **116** may use the API to convert the power quality parameter values from the schema used by CATV distribution system manager **108** to the schema used by power distribution system manager **104**.

In the example of FIG. **5**, HNT management and control device **116** may cause at least one device in the first distribution network to modify operation based on the translated at least one parameter value (**508**). For instance, HNT management and control device **116** may output the converted power quality parameter values to power distribution system manager **104** and power distribution system manager **104** may modify operation of devices within power distribution network **106** based on the received power quality parameter values.

In various examples, HNT management and control device **116** may convert and/or output different amounts and/or types of information in run1 mode. For instance, in some examples HNT management and control device **116** may always convert and output the literal received parameter values to managers of any overlapping area. In some examples, HNT management and control device **116** may determine a difference between the received parameter value and a previously received parameter value and output a difference value to managers of any overlapping area. This may be useful when there are limited communication means or in order to reduce the amount of data transferred. In some examples, HNT management and control device **116** may determine whether the received parameter value surpasses a particular threshold and may only convert and output the parameter value if it surpasses the threshold. This may be useful to reduce the amount of data transferred, as managers only get information if there is a problem.

The example operations of FIG. **5** may additionally or alternatively be described by the following example pseudocode:

```
Start Run1 Mode
In the presence of a new telemetry message on either side of an
existing API between DSO and MSO serving areas:
    a) Forward the message via an API from the DSO to the MSO,
    or vice-versa, in appropriate parlance using either,
        i) Verbose submode: containing all observations in their
        entirety,
        ii) Delta submode: containing only the delta value of the
        current or observation minus the prior observation, or
        iii) Exception submode: containing only observations
        determined to be out of tolerance, such as, for example,
            1) Percentage change > +-5% from prior
            observation(s), or
            2) Observation is outside fixed lower and upper
            limits of 114 VAC and 126 VAC.
End Run1 Mode
```

FIG. **6** is a flow diagram illustrating example operations of a HNT management and control device, in accordance with one or more aspects of the present disclosure. For purposes of illustration only, the example operations of FIG. **6** are described below within the context of FIG. **1**. For instance, the example operations of FIG. **5** may be performed by HNT management and control device **116**. The example operations of FIG. **5** may represent a "run2 mode" that HNT management and control device **116** may continuously execute to predictively generate inferences based on received network information (e.g., power quality parameter values) and provide such inferences to relevant parties.

In the example of FIG. **6**, HNT management and control device **116** may receive at least two parameter values (**602**). The received parameter values may be from the same distribution system manager or from different distribution system managers. The received parameter values may be about the same network or may be about different networks.

HNT management and control device **116** may, in the example of FIG. **6**, determine, based on the at least two parameter values, whether there is a power outage in multiple adjoining service areas (**604**). For instance, if two or more parameter values indicate a power outage, HNT management and control device **116** may compare the geographic locations corresponding to the received parameter values. The more parameter values received in a particular location that indicate a power outage, the more likely it is that there is a power outage in that area. Thus, HNT management and control device **116** may determine whether or not there is a power outage, as well as a confidence level for the power outage inference, based on the the geographic locations and power quality parameter values received.

In the example of FIG. **6**, responsive to determining there is a power outage in multiple adjoining service areas ("YES" branch of operation **604**), HNT management and control device **116** may output an indication of outage to affected service areas (**605**). For instance, HNT management and control device **116** may output indications to each manager having a geographic area overlapping with at least one of the locations from which parameter values were received and used to generate the inference. In some examples, the outputted indications may include confidence level information based on the certainty of the inferred power outage. For example, if only two locations caused the inference, then the confidence level may be relatively lower. If five to ten locations caused the inference, then the confidence level may be relatively moderate. If over ten locations caused the inference, then the confidence level may be relatively high.

In the example of FIG. **6**, HNT management and control device **116** may determine, based on the at least two parameter values, whether there is a common point of failure

(**606**). For example, when two or more received parameter values indicate a power outage or other issue, HNT management and control device **116** may use the locations corresponding to the two parameter values to infer whether there is a likely connection between them.

In the example of FIG. **6**, responsive to determining that there is a common point of failure ("YES" branch of operation **606**), HNT management and control device **116** may output an indication of the common point of failure (**607**). For instance, HNT management and control device **116** may output the indication to managers having areas that overlap with each of the locations corresponding to the two parameter values, as well as to managers having areas that overlap with the inferred common point of failure.

In the example of FIG. **6**, HNT management and control device **116** may, based on the at least two parameter values, determine other important inferences, such as ______. If such inferences are determined, HNT management and control device **116** may output information to relevant managers accordingly.

The example operations of FIG. **6** may additionally or alternatively be described by the following example pseudocode:

```
Start Run2 Mode
While performing continuous review of power quality issues within
overlapping shapes (serving areas):
    a) If an inference can be made as to contiguous failures, for
    example, multiple adjoining service areas have a power outage
    or have power quality issue (s),
        i) Create and send a spontaneous message to overlapping
        entities listing all affected service areas using a
        parlance suitable for each, or
    b) If an inference can be made as to common point of failure
    (including but not limited to customer triplex drop, DSO
    transformer, DSO Capacitor Bank, MSO power supply, etc.),
        i) Create and send a spontaneous message to overlapping
        entities listing suspected common point of failure,
        summary and raw supporting telemetry readings, or
    c) If any other valuable inference can be made,
        i) Create and send a spontaneous message to overlapping
        entities listing appropriate information.
End Run2 Mode
```

By allowing for common capture and distribution of distribution network information, the operations described in FIGS. **4**-**6** may enable distribution system managers to greatly increase the amount of information available for management and control of their networks. Furthermore, by providing spontaneous inferences, the operations of FIG. **6** may allow for more intelligent control of all distribution networks involved.

The techniques of the present disclosure may additionally or alternatively be described by one or more of the following examples:

Example 1

A system comprising: at least one cable service device comprising a processor and a voltage sensor, wherein: the at least one cable service device corresponds to a respective at least one power consumption location that is connected to a power distribution network, and the at least one cable service device is configured to: provide at least one cable service to the power consumption location via a cable television (CATV) distribution network; determine a voltage value representing a voltage of the power distribution network at the at least one power consumption location; and output the voltage value; a heterogenous network topology management and control (HNTMC) device comprising a processor and configured to: receive an indication of the voltage value; and cause at least one device within the power distribution network to modify operation based on the voltage value.

Example 2

The system of example 1, wherein: the at least one cable service device is further configured to: determine a frequency value representing a frequency of the power distribution network at the at least one power consumption location; and output the frequency value, and the HNTMC device is further configured to: receive an indication of the frequency value; and cause the at least one device within the power distribution network to modify operation based further on the frequency value.

Example 3

The system of any of examples 1-2, wherein: the cable service device comprises one of: a cable modem, a cable set-top box, or multimedia terminal adapter (MTA), and the at least one cable service comprises at least one of television programming, internet connectivity, or voice over IP (VoIP) services.

Example 4

The system of any of example 1-3, wherein the HNTMC device is further configured to: receive at least one of a second voltage value representing a voltage of the power distribution network at a second location, the second location being different from the at least one power consumption location or a frequency value representing a frequency of the power distribution network at the second location from a power distribution device; and cause the at least one device within the power distribution network to modify operation based further on the at least one of the second voltage value or the frequency value.

Example 5

The system of any of example 1-4, wherein: the HNTMC device is further configured to: receive an indication of a first geographic area corresponding to a first distribution network; receive an indication of a second geographic area corresponding to a second distribution network; and determine, based on the first geographic area and the second geographic area, that at least a portion of the first distribution network and at least a portion of the second distribution network overlap in an overlapping geographic area; and causing the at least one device within the power distribution network to modify operation comprises: determining whether the at least one power consumption location is within the overlapping geographic area; and responsive to determining that the at least one power consumption location is within the overlapping geographic area: converting the voltage value to a converted voltage value that is understandable by a power distribution network management system; and outputting the converted voltage value.

Example 6

The system of example 5, wherein: the HNTMC device is further configured to generate, responsive to determining that at least a portion of the first distribution network and at least a portion of the second distribution network overlap, a communication interface that converts power quality parameter information between a first schema that is interpretable by a manager of the first distribution network and a second schema that is interpretable by a manager of the second distribution network, and converting the voltage value comprises converting the voltage value using the communication interface.

Example 7

The system of any of example 1-6, wherein causing the at least one device within the power distribution network to modify operation comprises: determining a difference between the voltage value and a previously received voltage value, and outputting an indication of the difference.

Example 8

A device comprising: a voltage sensor configured to measure a voltage value that represents a voltage of a power distribution network at a power consumption location that corresponds to the device; at least one processor communicatively coupled to the voltage sensor, the at least one processor configured to: provide at least one cable service to the power consumption location via a cable television (CATV) distribution network; and output an indication the voltage value.

Example 9

The device of example 8, further comprising: a frequency sensor configured to measure a frequency value that represents a frequency of the power distribution network at the power consumption location, wherein the at least one processor is further configured to output the frequency value.

Example 10

The device of any of examples 8-9, wherein the at least one processor is configured to output the indication of the voltage value via the CATV distribution network.

Example 11

The device of example 8, wherein outputting an indication of the voltage value comprises: determining whether the voltage value exceeds a threshold value that represents either a specified minimum voltage or a specified maximum voltage; and responsive to determining that the voltage value exceeds the threshold value, outputting the indication of the voltage value.

Example 12

A device comprising: at least one processor configured to: receive an indication of a first geographic area corresponding to a first distribution network; receive an indication of a second geographic area corresponding to a second distribution network; determine, based on the first geographic area and the second geographic area, that at least a portion of the first distribution network and at least a portion of the second distribution network overlap in an overlapping geographic area; receive at least one parameter value obtained by a device within the second distribution network, the at least one parameter value corresponding to a location within the overlapping geographic area; and cause at least one device within the first distribution network to modify operation based on the at least one parameter value of the second distribution network.

Example 13

The device of example 12, wherein the first distribution network comprises a power distribution network and wherein the second distribution network comprises a cable television (CATV) distribution network.

Example 14

The device of any of examples 12-13, wherein the at least one parameter value comprises at least one second network parameter value and wherein the at least one processor is further configured to: receive at least one first network parameter value of the first distribution network, the at least one first network parameter value corresponding to a location within the overlapping geographic area; and cause at least one device within the second distribution network to modify operation based on the at least one first network parameter value of the first distribution network.

Example 15

The device of any of examples 12-14, wherein the at least one processor is further configured to: responsive to determining that the at least a portion of the first distribution network and the at least a portion of the second distribution network overlap, generate a communication interface for the overlapping geographic area, wherein the communication interface translates parameter values received from the second network into translated parameter values that are interpretable by a distribution network management system of the first distribution network.

Example 16

The device of example 15, wherein causing the at least one device within the first distribution network to modify operation comprises: translating, using the communication interface for the overlapping geographic area, the at least one parameter value into at least one translated parameter value; and outputting, to the distribution network management system, the at least one translated parameter value.

Example 17

The device of any of examples 15-16, wherein causing the at least one device within the first network to modify operation comprises: determining whether or not the at least one parameter value exceeds a threshold; responsive to determining that the at least one parameter value exceeds the threshold, translating, using the communication interface for the overlapping geographic area, the at least one parameter value into at least one translated parameter value; and outputting, to the distribution network management system, the at least one translated parameter value

Example 18

The device of example 17, wherein the threshold comprises at least one of: a value representing a maximum allowable limit; a value representing a minimum allowable limit; or a value representing a maximum deviation from a previous parameter value.

Example 19

The device of any of examples 15-18, wherein: the first distribution network comprises a power distribution network, the at least one parameter value comprises a first at least one parameter value, the location comprises a first location, and the at least one processor is further configured to: receive a second at least one parameter value, the second at least one parameter value corresponding to a second location that is different from the first location; determine, based on the first location, the second location, the first at least one parameter value, and the second at least one parameter value, a predicted common point of failure in the power distribution network; and output an indication of the common point of failure.

In one or more examples, the techniques described herein may be implemented in hardware, software, firmware, or any combination thereof. If implemented in software, the functions may be stored on or transmitted over, as one or more instructions or code, a computer-readable medium and executed by a hardware-based processing unit. Computer-readable media may include computer-readable storage media, which corresponds to a tangible medium such as data storage media, or communication media, which includes any medium that facilitates transfer of a computer program from one place to another, e.g., according to a communication protocol. In this manner, computer-readable media generally may correspond to (1) tangible computer-readable storage media, which is non-transitory or (2) a communication medium such as a signal or carrier wave. Data storage media may be any available media that can be accessed by one or more computers or one or more processors to retrieve instructions, code and/or data structures for implementation of the techniques described in this disclosure. A computer program product may include a computer-readable storage medium.

By way of example, and not limitation, such computer-readable storage media can comprise RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage, or other magnetic storage devices, flash memory, or any other medium that can be used to store desired program code in the form of instructions or data structures and that can be accessed by a computer. Also, any connection is properly termed a computer-readable medium. For example, if instructions are transmitted from a website, server, or other remote source using a coaxial cable, fiber optic cable, twisted pair, digital subscriber line (DSL), or wireless technologies such as infrared, radio, and microwave, then the coaxial cable, fiber optic cable, twisted pair, DSL, or wireless technologies such as infrared, radio, and microwave are included in the definition of medium. It should be understood, however, that computer-readable storage media and data storage media do not include connections, carrier waves, signals, or other transient media, but are instead directed to non-transient, tangible storage media. Disk and disc, as used herein, includes compact disc (CD), laser disc, optical disc, digital versatile disc (DVD), floppy disk and Blu-ray disc, where disks usually reproduce data magnetically, while discs reproduce data optically with lasers. Combinations of the above should also be included within the scope of computer-readable media.

Instructions may be executed by one or more processors, such as one or more digital signal processors (DSPs), general purpose microprocessors, application specific integrated circuits (ASICs), field programmable logic arrays (FPGAs), or other equivalent integrated or discrete logic circuitry. Accordingly, the term "processor," as used herein may refer to any of the foregoing structure or any other structure suitable for implementation of the techniques described herein. In addition, in some aspects, the functionality described herein may be provided within dedicated hardware and/or software modules. Also, the techniques could be fully implemented in one or more circuits or logic elements.

The techniques of this disclosure may be implemented in a wide variety of devices or apparatuses, including a wireless handset, an integrated circuit (IC) or a set of ICs (e.g., a chip set). Various components, modules, or units are described in this disclosure to emphasize functional aspects of devices configured to perform the disclosed techniques, but do not necessarily require realization by different hardware units. Rather, as described above, various units may be combined in a hardware unit or provided by a collection of inter-operative hardware units, including one or more processors as described above, in conjunction with suitable software and/or firmware.

The foregoing disclosure includes various examples set forth merely as illustration. The disclosed examples are not intended to be limiting. Modifications incorporating the spirit and substance of the described examples may occur to persons skilled in the art. These and other examples are within the scope of this disclosure and the following claims.

What is claimed is:

1. A system comprising:
at least one cable service device comprising a processor and a voltage sensor, wherein:
the at least one cable service device corresponds to a respective at least one power consumption location that is connected to a power distribution network, and
the at least one cable service device is configured to:
provide at least one cable service to the power consumption location via a cable television (CATV) distribution network;
determine a voltage value representing a voltage of the power distribution network at the at least one power consumption location; and
output the voltage value;
a heterogenous network topology management and control (HNTMC) device comprising a processor and configured to:
receive an indication of the voltage value; and
cause at least one device within the power distribution network to modify operation based on the voltage value, wherein:
the HNTMC device is further configured to:
receive an indication of a first geographic area corresponding to a first distribution network;
receive an indication of a second geographic area corresponding to a second distribution network; and
determine, based on the first geographic area and the second geographic area, that at least a portion of the first distribution network and at least a portion of the second distribution network overlap in an overlapping geographic area; and
causing the at least one device within the power distribution network to modify operation comprises:
determining whether the at least one power consumption location is within the overlapping geographic area; and
responsive to determining that the at least one power consumption location is within the overlapping geographic area:

converting the voltage value to a converted voltage value that is understandable by a power distribution network management system; and

outputting the converted voltage value.

2. The system of claim 1, wherein:

the at least one cable service device is further configured to:

determine a frequency value representing a frequency of the power distribution network at the at least one power consumption location; and

output the frequency value, and

the HNTMC device is further configured to:

receive an indication of the frequency value; and

cause the at least one device within the power distribution network to modify operation based further on the frequency value.

3. The system of claim 1, wherein:

the cable service device comprises one of: a cable modem, a cable set-top box, or multimedia terminal adapter (MTA), and

the at least one cable service comprises at least one of television programming, internet connectivity, or voice over IP (VoIP) services.

4. The system of claim 1, wherein the HNTMC device is further configured to:

receive at least one of a second voltage value representing a voltage of the power distribution network at a second location, the second location being different from the at least one power consumption location or a frequency value representing a frequency of the power distribution network at the second location from a power distribution device; and

cause the at least one device within the power distribution network to modify operation based further on the at least one of the second voltage value or the frequency value.

5. The system of claim 1, wherein:

the HNTMC device is further configured to generate, responsive to determining that at least a portion of the first distribution network and at least a portion of the second distribution network overlap, a communication interface that converts power quality parameter information between a first schema that is interpretable by a manager of the first distribution network and a second schema that is interpretable by a manager of the second distribution network, and

converting the voltage value comprises converting the voltage value using the communication interface.

6. A device comprising:

at least one processor configured to:

receive an indication of a first geographic area corresponding to a first distribution network;

receive an indication of a second geographic area corresponding to a second distribution network;

determine, based on the first geographic area and the second geographic area, that at least a portion of the first distribution network and at least a portion of the second distribution network overlap in an overlapping geographic area;

receive at least one parameter value obtained by a device within the second distribution network, the at least one parameter value corresponding to a location within the overlapping geographic area; and

cause at least one device within the first distribution network to modify operation based on the at least one parameter value of the second distribution network, wherein the at least one processor is further configured to:

responsive to determining that the at least a portion of the first distribution network and the at least a portion of the second distribution network overlap, generate a communication interface for the overlapping geographic area, wherein the communication interface translates parameter values received from the second network into translated parameter values that are interpretable by a distribution network management system of the first distribution network.

7. The device of claim 6, wherein the first distribution network comprises a power distribution network and wherein the second distribution network comprises a cable television (CATV) distribution network.

8. The device of claim 6, wherein the at least one parameter value comprises at least one second network parameter value and wherein the at least one processor is further configured to:

receive at least one first network parameter value of the first distribution network, the at least one first network parameter value corresponding to a location within the overlapping geographic area; and

cause at least one device within the second distribution network to modify operation based on the at least one first network parameter value of the first distribution network.

9. The device of claim 6, wherein causing the at least one device within the first distribution network to modify operation comprises:

translating, using the communication interface for the overlapping geographic area, the at least one parameter value into at least one translated parameter value; and

outputting, to the distribution network management system, the at least one translated parameter value.

10. The device of claim 6, wherein causing the at least one device within the first network to modify operation comprises:

determining whether or not the at least one parameter value exceeds a threshold;

responsive to determining that the at least one parameter value exceeds the threshold, translating, using the communication interface for the overlapping geographic area, the at least one parameter value into at least one translated parameter value; and

outputting, to the distribution network management system, the at least one translated parameter value.

11. The device of claim 10, wherein the threshold comprises at least one of: a value representing a maximum allowable limit; a value representing a minimum allowable limit; or a value representing a maximum deviation from a previous parameter value.

12. The device of claim 6, wherein:

the first distribution network comprises a power distribution network,

the at least one parameter value comprises a first at least one parameter value,

the location comprises a first location, and

the at least one processor is further configured to:

receive a second at least one parameter value, the second at least one parameter value corresponding to a second location that is different from the first location;

determine, based on the first location, the second location, the first at least one parameter value, and the second at least one parameter value, a predicted common point of failure in the power distribution network; and

output an indication of the common point of failure.

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D. Letter of Support from TRC Partner Holy Cross Energy for Continuing TCF follow-on work

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DATE: June 28, 2022

Principal Investigator Michael Ingram
National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401

SUBJECT: Continued commercialization of NREL Situational Awareness of Grid Anomalies

Dear Mr. Ingram:

Holy Cross Energy supports continued commercialization NREL's DOE CEDS project "Situational Awareness of Grid Anomalies (SAGA) for Visual Analytics: Near Real-Time Cyber-Physical Resiliency through Machine Learning". With the completion of the DOE TCF-funded ANSI/SCTE 271 standard and the availability of the next-generation sensors, the project is proceeding well. We recognize the value in developing and field-validating visual analytics that integrate cyber-physical data from Cable TV broadband power supplies with utility information systems to enhance electric distribution grid visibility and operational situational awareness, detecting patterns of operation indicative of cyber incidents. This work accelerates our efforts that align with the DOE goal to advance cyber resilient energy delivery systems that are designed, installed, operated and maintained to survive a cyber-incident while sustaining critical functions.

Holy Cross Energy is a member-owned electric cooperative serving 59,000 meters in rural Colorado.

As we transition SAGA and TCF project responsibilities within Holy Cross Energy, we continue supporting these exciting efforts by:

- Participating as a member of the Technical Review Committee (TRC) for the projects,
- Providing industry experience-based guidance, directional support, and strategic direction to the projects.

Holy Cross Energy understands the value of this work and related follow-on projects, and looks forward to continued collaboration with the project team.

Sincerely,

Bob Farmer
Vice President, Information Technology
Holy Cross Energy