NIST SPECIAL PUBLICATION 1800-32

Securing the Industrial Internet of Things:

Cybersecurity for Distributed Energy Resources

Includes Executive Summary (A); Approach, Architecture, and Security Characteristics (B); and How-To Guides (C)

Jim McCarthy
Eileen Division
Don Faatz
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John Wiltberger
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DRAFT

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National Institute of Standards and Technology
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McLean, Virginia

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September 2021

U.S. Department of Commerce
Gina M. Raimondo, Secretary

National Institute of Standards and Technology
James K. Olthoff, Performing the Non-Exclusive Functions and Duties of the Under Secretary of Commerce for Standards and Technology & Director, National Institute of Standards and Technology

NIST SPECIAL PUBLICATION 1800-32A

Securing the Industrial Internet of Things:

Cybersecurity for Distributed Energy Resources

Volume A:
Executive Summary

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Executive Summary

Protecting Industrial Internet of Things (IIoT) devices at the grid edge is arguably one of the more difficult tasks in cybersecurity. There is a wide variety of devices, many of which are deployed and operate in a highly specific manner. Their connectivity, the conduit through which they can become vulnerable, represents a growing cyber threat to the distribution grid. In this practice guide, the National Cybersecurity Center of Excellence (NCCoE) applies standards, best practices, and commercially available technology to protect the digital communication, data, and control of cyber-physical grid-edge devices. We demonstrate how to monitor and detect unusual behavior of connected IIoT devices and build a comprehensive audit trail of trusted IIoT data flows.

CHALLENGE

The use of small-scale distributed energy resources (DERs)—grid-edge devices such as solar photovoltaics—is growing rapidly and transforming the traditional power grid. As the use of DERs expands, the distribution grid is becoming a multisource grid of interconnected devices and systems driven by two-way data communication and power flows. These data and power flows often rely on IIoT technologies that are connected to wireless networks, given a level of digital intelligence that allows them to be monitored and tracked, and to share data on their status and communicate with other devices.

A distribution utility may need to remotely communicate with thousands of DERs, some of which may not even be owned or configured by the utility, to monitor the status of these devices and control the operating points. Many companies are not equipped to offer secure access to DERs and to monitor and trust the rapidly growing amount of data coming from them. Securing DER communications will be critical to maintaining the reliability of the distribution grid. Any attack that can deny, disrupt, or tamper with DER communications could prevent a utility from performing necessary control actions and could diminish grid resiliency.

This practice guide can help your organization:

- **develop a risk-based approach for connecting and managing** DERs and other grid-edge devices that is built on National Institute of Standards and Technology (NIST) and industry standards
- **protect data and communications traffic** of grid-edge devices and networks
- **support secure edge-to-cloud data flows,** visualization, and continuous intelligence
- **remotely monitor and control** utility and nonutility DERs
- **capture an immutable record of control commands** across DERs that can be shared with DER management systems, aggregators, regulators, auditors, financiers, or grid operators
- **advance the cybersecurity workforce skills needed** to support DER and smart grid growth
- **build the business case,** functional requirements, and test plan for a similar solution within your own environment

SOLUTION

The NCCoE collaborated with stakeholders in the electricity sector, the University of Maryland, and cybersecurity technology providers to build an environment that represents a distribution utility interconnected with a campus DER microgrid. Within this ecosystem, we are exploring several scenarios in which information exchanges among DERs and electric distribution grid operations can be protected from certain cybersecurity compromises. The example solution demonstrates the following capabilities:

- **authentication and access control** to ensure that only known, authorized systems can exchange information
- **communications and data integrity** to ensure that information is not modified in transit
- **malware detection** to monitor information exchanges and processing to identify potential malware infections
- **command register** that maintains an independent, immutable record of information exchanges between distribution and DER operators
- **behavioral monitoring** to detect deviations from operational norms
- **analysis and visualization** processes to monitor data, identify anomalies, and alert operators

The example solution documented in the practice guide uses technologies and security capabilities (shown below) from our project collaborators. The solution is mapped to security standards and guidelines of the NIST Cybersecurity Framework; *NIST Interagency or Internal Report 7628 Rev 1: Guidelines for Smart Grid Cybersecurity*; and *NIST SP 1108r4, Framework and Roadmap for Smart Grid Interoperability Standards, Release 4.0*.

Collaborator	Security Capability or Component
Anterix	Offers long-term evolution infrastructure and communications on wireless broadband for campus DER microgrid communications
Cisco	Detects process anomalies or unwanted IIoT device modifications; provides identity and access management capabilities; controls access to resources
Dots and Bridges	Serves in an advisory role in smart grid and critical infrastructure cyber-physical security
Radiflow	Provides operational technology network monitoring to detect malicious activity
Spherical Analytics	Affords data integrity and maintains a distributed ledger that gives an immutable audit trail for all data exchanges between the utility and the microgrid

Collaborator	Security Capability or Component
sumo logic	Offers cloud-based DER device log management and metrics that leverage big data analytics to produce real-time insights and actionable intelligence
tdi technologies	Manages privileged user permissions and access
University of Maryland	Delivers live data feed from on-campus solar arrays
xage security	Allows multiparty, fine-grained policy creation, authentication, and secure access control and data sharing for human, machine, and application interactions across utility and DER operations

While the NCCoE used a suite of commercial products to address this challenge, this guide does not endorse these particular products, nor does it guarantee compliance with any regulatory initiatives. Your organization's information security experts should identify the products that will best integrate with your existing tools and IT or operational technology (OT) system infrastructure. Your organization can adopt this solution or one that adheres to these guidelines in whole, or you can use this guide as a starting point for tailoring and implementing parts of a solution.

HOW TO USE THIS GUIDE

Depending on your role in your organization, you might use this guide in different ways:

Business decision makers, including chief information security, risk, compliance, and technology officers can use this part of the guide, *NIST SP 1800-32a: Executive Summary*, to understand the drivers for the guide, the cybersecurity challenge we address, our approach to solving this challenge, and how the solution could benefit your organization.

Technology, security, and privacy program managers who are concerned with how to identify, understand, assess, and mitigate risk can use *NIST SP 1800-32b: Approach, Architecture, and Security Characteristics,* which describes what we built and why, including the risk analysis performed and the security control mappings.

Information technology (IT) or operational technology (OT) professionals who want to implement an approach like this can use *NIST SP 1800-32c: How-To Guides*, which provide specific product installation, configuration, and integration instructions for building the example implementation, allowing you to replicate all or parts of this project.

SHARE YOUR FEEDBACK

You can view or download the guide at https://www.nccoe.nist.gov/iiot. Help the NCCoE make this guide better by sharing your thoughts with us as you read the guide. If you adopt this solution for your own organization, please share your experience and advice with us. We recognize that technical solutions alone will not fully enable the benefits of our solution, so we encourage organizations to share lessons learned and best practices for transforming the processes associated with implementing this guide.

To provide comments or to learn more by arranging a demonstration of this example implementation, contact the NCCoE at energy_nccoe@nist.gov.

COLLABORATORS

Collaborators participating in this project submitted their capabilities in response to an open call in the Federal Register for all sources of relevant security capabilities from academia and industry (vendors and integrators). Those respondents with relevant capabilities or product components signed a Cooperative Research and Development Agreement (CRADA) to collaborate with NIST in a consortium to build this example solution.

Certain commercial entities, equipment, products, or materials may be identified by name or company logo or other insignia in order to acknowledge their participation in this collaboration or to describe an experimental procedure or concept adequately. Such identification is not intended to imply special status or relationship with NIST or recommendation or endorsement by NIST or NCCoE; neither is it intended to imply that the entities, equipment, products, or materials are necessarily the best available for the purpose.

NIST SPECIAL PUBLICATION 1800-32B

Securing the Industrial Internet of Things:

Cybersecurity for Distributed Energy Resources

Volume B:
Approach, Architecture, and Security Characteristics

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DISCLAIMER

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While NIST and the NCCoE address goals of improving management of cybersecurity and privacy risk through outreach and application of standards and best practices, it is the stakeholder's responsibility to fully perform a risk assessment to include the current threat, vulnerabilities, likelihood of a compromise, and the impact should the threat be realized before adopting cybersecurity measures such as this recommendation.

National Institute of Standards and Technology Special Publication 1800-32B, Natl. Inst. Stand. Technol. Spec. Publ. 1800-32B, 56 pages, (September 2021), CODEN: NSPUE2

FEEDBACK

You can improve this guide by contributing feedback. As you review and adopt this solution for your own organization, we ask you and your colleagues to share your experience and advice with us.

Comments on this publication may be submitted to: energy_nccoe@nist.gov.

Public comment period: September 21, 2021, through October 20, 2021

All comments are subject to release under the Freedom of Information Act.

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NATIONAL CYBERSECURITY CENTER OF EXCELLENCE

The National Cybersecurity Center of Excellence (NCCoE), a part of the National Institute of Standards and Technology (NIST), is a collaborative hub where industry organizations, government agencies, and academic institutions work together to address businesses' most pressing cybersecurity issues. This public-private partnership enables the creation of practical cybersecurity solutions for specific industries, as well as for broad, cross-sector technology challenges. Through consortia under Cooperative Research and Development Agreements (CRADAs), including technology partners—from Fortune 50 market leaders to smaller companies specializing in information and operational technology security—the NCCoE applies standards and best practices to develop modular, adaptable example cybersecurity solutions using commercially available technology. The NCCoE documents these example solutions in the NIST Special Publication 1800 series, which maps capabilities to the NIST Cybersecurity Framework and details the steps needed for another entity to re-create the example solution. The NCCoE was established in 2012 by NIST in partnership with the State of Maryland and Montgomery County, Maryland.

To learn more about the NCCoE, visit https://www.nccoe.nist.gov/. To learn more about NIST, visit https://www.nist.gov.

NIST CYBERSECURITY PRACTICE GUIDES

NIST Cybersecurity Practice Guides (Special Publication 1800 series) target specific cybersecurity challenges in the public and private sectors. They are practical, user-friendly guides that facilitate adoption of standards-based approaches to cybersecurity. They show members of the information security community how to implement example solutions that help them align with relevant standards and best practices, and provide users with the materials lists, configuration files, and other information they need to implement a similar approach.

The documents in this series describe example implementations of cybersecurity practices that businesses and other organizations may voluntarily adopt. These documents do not describe regulations or mandatory practices, nor do they carry statutory authority.

ABSTRACT

The Industrial Internet of Things (IIoT) refers to the application of instrumentation and connected sensors and other devices to machinery and vehicles in the transport, energy, and other critical infrastructure sectors. In the energy sector, distributed energy resources (DERs) such as solar photovoltaics including sensors, data transfer and communications systems, instruments, and other commercially available devices that are networked together. DERs introduce information exchanges between a utility's distribution control system and the DERs to manage the flow of energy in the distribution grid.

This practice guide explores how information exchanges among commercial- and utility-scale DERs and electric distribution grid operations can be monitored and protected from certain cybersecurity threats and vulnerabilities.

The NCCoE built a reference architecture using commercially available products to show organizations how several cybersecurity capabilities, including communications and data integrity, malware detection, network monitoring, authentication and access control, and cloud-based analysis and visualization can be applied to protect distributed end points and reduce the IIoT attack surface for DERs.

KEYWORDS

data integrity; distributed energy resource; industrial internet of things; malware; microgrid; smart grid

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The Technology Partners/Collaborators who participated in this build submitted their capabilities in response to a notice in the Federal Register. Respondents with relevant capabilities or product components were invited to sign a Cooperative Research and Development Agreement (CRADA) with NIST, allowing them to participate in a consortium to build this example solution. We worked with:

Technology Partner/Collaborator	Product
Anterix	LTE infrastructure and communications on wireless broadband
Cisco	Cisco Identity Services Engine; Cisco Cyber Vision; Cisco Firepower Threat Defense
Dots and Bridges	subject matter expertise
Radiflow	iSID Industrial Threat Detection
Spherical Analytics	Immutably™, Proofworks™, and Scrivener™
Sumo Logic	Sumo Logic Enterprise
TDi Technologies	ConsoleWorks
University of Maryland	campus DER microgrid infrastructure
Xage Security	Xage Security Fabric

DOCUMENT CONVENTIONS

The terms “shall” and “shall not” indicate requirements to be followed strictly to conform to the publication and from which no deviation is permitted. The terms “should” and “should not” indicate that among several possibilities, one is recommended as particularly suitable without mentioning or excluding others, or that a certain course of action is preferred but not necessarily required, or that (in the negative form) a certain possibility or course of action is discouraged but not prohibited. The terms “may” and “need not” indicate a course of action permissible within the limits of the publication. The terms “can” and “cannot” indicate a possibility and capability, whether material, physical, or causal.

CALL FOR PATENT CLAIMS

This public review includes a call for information on essential patent claims (claims whose use would be required for compliance with the guidance or requirements in this Information Technology Laboratory

(ITL) draft publication). Such guidance and/or requirements may be directly stated in this ITL Publication or by reference to another publication. This call also includes disclosure, where known, of the existence of pending U.S. or foreign patent applications relating to this ITL draft publication and of any relevant unexpired U.S. or foreign patents.

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b) assurance that a license to such essential patent claim(s) will be made available to applicants desiring to utilize the license for the purpose of complying with the guidance or requirements in this ITL draft publication either:

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Such assurance shall indicate that the patent holder (or third party authorized to make assurances on its behalf) will include in any documents transferring ownership of patents subject to the assurance, provisions sufficient to ensure that the commitments in the assurance are binding on the transferee, and that the transferee will similarly include appropriate provisions in the event of future transfers with the goal of binding each successor-in-interest.

The assurance shall also indicate that it is intended to be binding on successors-in-interest regardless of whether such provisions are included in the relevant transfer documents.

Such statements should be addressed to: energy_nccoe@nist.gov

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1 Summary

An increasing number of distributed energy resources (DERs) are connecting to the distribution grid. These DERs introduce two-way information exchanges between a utility's distribution control system and the DERs, or an aggregator, to manage the flow of energy in the distribution grid. These information exchanges often employ Industrial Internet of Things (IIoT) technologies that lack the communications security present in conventional utility systems. Managing, trusting, and securing the information exchanges between DERs and utility distribution control systems or other DERs presents significant challenges.

The National Institute of Standards and Technology's (NIST's) National Cybersecurity Center of Excellence (NCCoE) collaborated with stakeholders in the electricity sector, the University of Maryland (UMD), and cybersecurity technology vendors to build a laboratory environment that represents a distribution utility interconnected with a campus DER microgrid. Using this environment, we are exploring how information exchanges between commercial- and utility-scale DERs and the electric distribution grid can be monitored, trusted, and protected.

The goals of this NIST Cybersecurity Practice Guide are to help organizations:

- remotely monitor and control utility-owned and customer-managed DER assets
- protect and trust data and communications traffic of grid-edge devices and networks
- capture an immutable record of control commands across DERs
- support secure edge-to-cloud data flows, visualization, and continuous intelligence

For ease of use, the following provides a short description of each section in this volume.

Section 1, Summary, presents the challenge addressed by this NCCoE project, including our approach to addressing the challenge, the solution demonstrated, and the benefits of the solution.

Section 2, How to Use This Guide, explains how business decision makers, program managers, information technology (IT) and operational technology (OT) professionals might use each volume of the guide.

Section 3, Approach, offers a detailed treatment of the scope of the project, the risk assessment that informed the solution, and the technologies and components that industry collaborators supplied to build the example solution.

Section 4, Architecture, specifies the components of the example solution and details how data and communications flow between and among DERs and the distribution grid.

Section 5, Security Characteristic Analysis, provides details about the tools and techniques used to test and understand the extent to which the project example solution meets its objective of demonstrating that information exchanges among DERs and electric distribution grid operations can be monitored and protected from certain cybersecurity compromises.

Section 6, Future Project Considerations, is a brief treatment of other applications that NIST might explore in the future to further protect DER communications.

The appendixes provide acronyms, a glossary of terms, and a list of references cited in this volume.

1.1 Challenge

Small-scale DERs—such as solar photovoltaics—are growing rapidly and transforming the power grid. The distribution grid is becoming a multisource grid of interconnected devices and systems driven by two-way data communication and power flows. These data and power flows often rely on IIoT technologies that are connected to both the DERs' power production assets and various wired and wireless networks. These edge devices have an embedded level of digital intelligence that allows DER assets to be monitored and tracked, and through the edge devices, share data on their status and communicate with other devices across DER networks and beyond.

A distribution utility may need to remotely communicate with thousands of DERs—some of which may not even be owned or configured by the utility—to control the operating points and monitor the status of these devices. Many companies are not equipped to provide secure access to DERs and to monitor and trust the rapidly growing amount of data coming from them or flowing into them. The ability of utilities and DER operators to trust these information exchanges is essential to these companies' business. Any disruption or manipulation of the data could have negative consequences on utility and DER operations, and on their customers. Securing DER communications will be critical to maintain the reliability of the distribution grid. Any attack that can deny, disrupt, or tamper with DER communications could prevent a utility from performing necessary control commands and could diminish grid resiliency.

1.2 Solution

The NCCoE collaborated with stakeholders in the electricity sector, UMD, and cybersecurity technology providers to build an environment that represents a distribution utility interconnected with a campus DER microgrid. Within this ecosystem, we explore how information exchanges among DERs and electric distribution grid operations can be protected from certain cybersecurity compromises. The example solution demonstrates the following capabilities:

- **communications and data integrity** to ensure that information is not modified in transit
- **authentication and access control** to ensure that only known, authorized systems can exchange information
- **command register** that maintains an independent, immutable record of information exchanges between distribution grid and DER operators

- **malware detection** to monitor information exchanges and processing to identify potential malware infections
- **behavioral monitoring** to detect deviations from operational norms
- **analysis and visualization** processes to monitor data, identify anomalies, and alert operators

The example solution documented in the practice guide uses technologies and security capabilities from our project collaborators. The solution aligns with the security standards and guidelines of the NIST Cybersecurity Framework; NIST Interagency or Internal Report 7628 Revision 1: *Guidelines for Smart Grid Cybersecurity* [1]; and NIST Special Publication (SP) 1108r4, *Framework and Roadmap for Smart Grid Interoperability Standards, Release 4.0* [2].

1.3 Benefits

The NCCoE's practice guide can help your organization:

- develop a risk-based approach for connecting and managing DERs and other grid-edge devices that is built on NIST and industry standards
- provide integrity of energy transactions by monitoring and protecting IIoT digital communications
- enhance reliability and stability of the grid by better protecting DERs from cyber attacks
- assure that distribution operators retain control of DERs independent of a cyber event
- provide an immutable record of commands to and responses from utility-owned and customer-managed DERs

2 How to Use This Guide

This NIST Cybersecurity Practice Guide demonstrates a standards-based reference architecture and provides users with the information they need to replicate secure and trusted information exchanges in a DER environment. This reference architecture is modular and can be deployed in whole or in part.

This guide contains three volumes:

- NIST SP 1800-32A: *Executive Summary*
- NIST SP 1800-32B: *Approach, Architecture, and Security Characteristics*–what we built and why **(you are here)**
- NIST SP 1800-32C: *How-To Guides*–instructions for building the example solution

Depending on your role in your organization, you might use this guide in different ways:

Business decision makers, including chief security, risk, compliance, and technology officers, will be interested in the *Executive Summary,* NIST SP 1800-32A, which describes the following topics:

- challenges that enterprises face in monitoring, protecting, and trusting information exchanges among and between DERs
- example solution built at the NCCoE and UMD
- cybersecurity and operational benefits of adopting the example solution

Technology or security program managers who are concerned with how to identify, understand, assess, and mitigate risk will be interested in this part of the guide, NIST SP 1800-32B, which describes what we did and why. The following sections will be of particular interest:

- Section 3.4.3, Risk, provides a description of the risk analysis we performed
- Section 3.4.4, Security Control Map and Technologies, maps the security characteristics of this reference architecture to cybersecurity standards and best practices and the technologies used in our example solution

You might share the *Executive Summary,* NIST SP 1800-32A, with your leadership team members to help them understand the importance of adopting standards-based cybersecurity for DERs.

IT and OT professionals who want to implement an approach such as this will find the entire practice guide useful. You can use the how-to portion of the guide, NIST SP 1800-32C, to replicate all or parts of the example solution created in our lab. The how-to portion of the guide will provide specific product installation, configuration, and integration instructions for implementing the example solution. We do not re-create the product manufacturers' documentation, which is generally widely available. Rather, we show how we incorporated the products together in our environment to create an example solution.

This guide assumes that IT and OT professionals have experience implementing security products within the enterprise. While we are using a suite of commercial products to address this challenge, this guide does not endorse these particular products. Your organization can adopt this solution or one that adheres to these guidelines in whole, or you can use this guide as a starting point for tailoring and implementing parts of the reference architecture to provide a high level of assurance in the integrity of the data for secure information exchanges between DERs and utilities. Your organization's security experts should identify the products that will best integrate with your existing tools and IT, OT, and related grid monitoring and control system infrastructure. Section 3.4.4, Security Control Map and Technologies, lists the products we used and maps them to the cybersecurity controls provided by this reference architecture.

A NIST Cybersecurity Practice Guide does not describe a "single" solution but rather a possible solution. This is a draft guide. We seek feedback on its contents and welcome your input. Comments and suggestions will improve subsequent versions of this guide. Please contribute your thoughts to energy_nccoe@nist.gov.

2.1 Typographic Conventions

The following table presents typographic conventions used in this volume.

Typeface/Symbol	Meaning	Example
Italics	file names and path names; references to documents that are not hyperlinks; new terms; and placeholders	For language use and style guidance, see the *NCCoE Style Guide*.
Bold	names of menus, options, command buttons, and fields	Choose **File** > **Edit.**
`Monospace`	command-line input, onscreen computer output, sample code examples, and status codes	`mkdir`
`Monospace Bold`	command-line user input contrasted with computer output	**`service sshd start`**
blue text	link to other parts of the document, a web URL, or an email address	All publications from NIST's NCCoE are available at https://www.nccoe.nist.gov.

3 Approach

IIoT devices within DERs may communicate and exchange information across the open internet or private multi-tenant networks. These information exchanges expand the attack surface of traditional energy generation and distribution networks and the assets that connect to them. To address this challenge, the NCCoE offers a risk-based approach to cybersecurity and proactive cybersecurity defense mechanisms that organizations can use to assure that information exchanges between and among DERs can be monitored, secured, and trusted.

The NCCoE collaborated with an Energy Sector Community of Interest that included technology and cybersecurity vendors, subject matter experts from the electric power industry, academia, and government to define the project scope and cybersecurity challenges, DER use cases, data flows and information exchanges, and a reference architecture.

We then assembled a team of cybersecurity vendors and subject matter experts to refine the solution and build a laboratory prototype of the reference architecture. The prototype example solution uses a combination of logical and physical infrastructure at the NCCoE and on the UMD campus.

3.1 Audience

This guide is intended for individuals and organizations responsible for safe, secure, responsive, and efficient operation and interconnection of DERs with the distribution grid. These could include distribution utilities, investor-owned utilities, municipal utilities, utility cooperatives, independent power producers, distribution and microgrid owners and operators (including their investors and insurers), DER aggregators, and DER vendors. The guide may also be of interest to anyone in industry, academia, or government who seeks general knowledge of DER cybersecurity.

3.2 Scope

This NCCoE project and reference architecture demonstrate an approach for improving the overall security of IIoT in a DER environment and address the following areas of interest:

- the information exchanges between and among DER systems and distribution facilities/entities and the cybersecurity considerations involved in these interactions
- the processes and cybersecurity technologies needed for trusted device identification and communication with other devices
- the ability to provide malware prevention, detection, and mitigation in operating environments where information exchanges occur
- cybersecurity analytics to help DER owners and operators analyze and react to potential security events in their operating environment

3.3 Assumptions

This project is guided by the following assumptions:

- The solution was developed in a lab environment to mimic commercial- and utility-scale DERs connecting to the distribution grid. We did not interconnect with an actual distribution utility as part of the project.
- An organization has access to the skills and resources necessary to implement the cybersecurity capabilities highlighted in the project.
- The IIoT components and devices used in the project are trustworthy (i.e., there are no supply chain cybersecurity concerns) on initial connection to the lab environment. NIST's Cybersecurity for IoT program has defined a set of capabilities that device manufacturers should consider integrating into their IoT devices and that consumers should consider enabling/configuring in those devices. A more thorough discussion of IoT device cybersecurity capabilities as it relates to this project is available in Appendix C.

3.4 Risk Assessment

NIST SP 800-30 Revision 1, *Guide for Conducting Risk Assessments* states that risk is "a measure of the extent to which an entity is threatened by a potential circumstance or event, and typically a function of: (i) the adverse impacts that would arise if the circumstance or event occurs; and (ii) the likelihood of occurrence." The guide further defines risk assessment as "the process of identifying, estimating, and prioritizing risks to organizational operations (including mission, functions, image, reputation), organizational assets, individuals, other organizations, and the Nation, resulting from the operation of an information system. Part of risk management incorporates threat and vulnerability analyses, and considers mitigations provided by security controls planned or in place."

The NCCoE recommends that any discussion of risk management, particularly at the enterprise level, begins with a comprehensive review of NIST SP 800-37 Revision 2, *Risk Management Framework for Information Systems and Organizations*, material that is available to the public. The Risk Management Framework (RMF) guidance, as a whole, proved to be invaluable in giving us a baseline to assess risks and evaluate the security characteristics of the reference architecture, example solution, and this guide.

We performed two types of risk assessment in this project:

- Initial analysis of the risk factors based on discussions with the Energy Sector Community of Interest and key stakeholders in the electric power industry, academia, and the cybersecurity technology domain. This analysis led to creating the *Securing the Industrial Internet of Things: Cybersecurity for Distributed Energy Resources* project description.
- Analysis of how to secure the components, connections, and information exchanges within the reference architecture and to minimize any vulnerabilities they might introduce. See Section 5, Security Characteristic Analysis.

3.4.1 Threats

NIST SP 800-30 Revision 1 defines a threat as "any circumstance or event with the potential to adversely impact organizational operations." For this project, threats are viewed from the standpoint of cybersecurity and the cyber events that could impact or compromise the integrity or control of DER information exchanges.

DERs employ industrial control systems (ICS). The Cybersecurity and Infrastructure Security Agency (CISA) ICS-Computer Emergency Readiness Team (CERT) defines cyber-threat sources to ICS as "persons who attempt unauthorized access to a control system device and/or network using a data communications pathway" [3]. CISA ICS-CERT, along with NIST SP 800-82 Revision 2, *Guide to Industrial Control Systems (ICS) Security*, identifies malicious actors who may pose threats to ICS infrastructure, including foreign intelligence services (i.e., national government organizations whose intelligence-gathering and espionage activities seek to harm U.S. interests), criminal groups such as organized crime groups that seek to attack for monetary gain, and hackers.

The Electric Power Research Institute (EPRI) outlined several potential cybersecurity threats to DERs in its December 2015 publication *Electric Sector Failure Scenarios and Impact Analyses—Version 3.0*. EPRI's threat events influenced the scope of this NCCoE project. Specifically, our reference architecture addresses several scenarios where a malicious actor attempts to gain access to DER systems to deploy malware, to manipulate or disrupt data and information exchanges, or to assume control of a utility or microgrid management system. These "attacks" could happen independently or together as part of a larger effort to ultimately gain control of the distribution grid or a utility's business network. As such, our reference architecture is being built and tested to address threats to data integrity, industrial control malware protection and detection, and device and data authenticity.

3.4.2 Vulnerabilities

NIST defines a vulnerability as a "weakness in an information system, system security procedures, internal controls, or implementation that could be exploited or triggered by a threat source." A vulnerability may exist inherently within a device or within the design, operation, installation, and architecture of a system. This project does not specifically address vulnerabilities related to devices, software, hardware, or networks used in the example solution or to the cybersecurity policies that a distribution grid operator has in place. We encourage a consistent and comprehensive approach to detecting vulnerabilities. While we understand the constraints of scanning and patching industrial networks and devices, we also believe that overlooking known vulnerabilities increases cybersecurity risk. The chances of a malicious actor gaining unauthorized access increase if an exploitable vulnerability is left unaddressed. NIST SP 800-82 categorizes ICS vulnerabilities into the following categories with examples:

- **policy and procedure–**incomplete, inappropriate, or nonexistent security policy, including its documentation, implementation guides (e.g., procedures), and enforcement
- **architecture and design–**design flaws, development flaws, poor administration, and connections with other systems and networks
- **configuration and maintenance–**misconfiguration and poor maintenance
- **physical–**lack of or improper physical access control, malfunctioning equipment
- **software development–**improper data validation, security capabilities not enabled, inadequate authentication privileges
- **communication and network–**nonexistent authentication, insecure protocols, improper firewall configuration

Performing vulnerability management and remediation tasks can provide the DER or utility operator at least some level of assurance that they have reduced or mitigated the possibility of an exploit. Vulnerabilities will vary from network to network, and even those specific to particular devices may vary depending on the disposition or deployment of that device in an operating environment.

Finally, knowledge of deployed assets is paramount in securing an organization's ICS infrastructure and mitigating risks associated with asset-based vulnerabilities. NIST Special Publication 1800-23, *Energy Sector Asset Management*, describes a solution for monitoring and managing deployed OT assets.

3.4.3 Risk

Risk management is the ongoing process of identifying, assessing, and responding to risk as it relates to an organization's mission objectives. To manage risk, organizations should understand the likelihood that an event will occur and its potential impacts. An organization should also consider statutory and policy requirements that may influence or inform cybersecurity decisions.

Information system-related security risks are those risks that arise from loss of confidentiality, integrity, or availability of information or information systems and that reflect potential adverse impacts to organizational operations (including mission, functions, image, or reputation), organizational assets, individuals, other organizations, and the nation. For the energy sector, a primary risk to OT networks is the loss of power production and distribution assets. As described in the threats section earlier, loss in the trustworthiness of the data, loss of control of the industrial network, or introduction of malware into OT can have serious consequences.

This practice guide is informed by cybersecurity risk management processes. We provide part of the information needed to make informed decisions—based on business needs and risk assessments—to select and prioritize cybersecurity activities that are deemed necessary by your organization.

3.4.4 Security Control Map and Technologies

Table 3-1 maps the security characteristics of our reference architecture to the NIST Cybersecurity Framework [4] security Functions, Categories, and Subcategories and the North American Electric Reliability Corporation (NERC) Critical Infrastructure Protection (CIP) Reliability Standards [5] that it supports. The technologies used in this project are mapped to the Cybersecurity Framework Subcategories they support. We selected the Subcategories that address the threats, vulnerabilities, and risks discussed above. Your organization can use Table 3-1 to identify the corresponding NIST SP 800-53 Rev 5 controls necessary to achieve the desired outcomes. While our reference architecture focuses on the Protect and Detect Functions of the Cybersecurity Framework, there are more Functions, Categories, and Subcategories in the framework than appear here. Your organization should select the Cybersecurity Framework Subcategories and controls that help mitigate your business-specific cybersecurity risks.

449 **Table 3-1 Security Characteristics and Controls Mapping—NIST Cybersecurity Framework**

Function	Category	Subcategory	NIST 800-53, Revision 5 Control(s)	Related NERC CIP ID(s)	Product (s) Used
PROTECT (PR)	**Identity Management, Authentication, and Access Control (PR.AC):** Access to physical and logical assets and associated facilities is limited to authorized users, processes, and devices and is managed consistent with the assessed risk of unauthorized access to authorized activities and transactions.	**PR.AC-1:** Identities and credentials are issued, managed, verified, revoked, and audited for authorized devices, users, and processes.	IA-1, IA-2, IA-3, IA-4, IA-5, IA-7, IA-8, IA-9, IA-10, IA-11, IA-12	CIP-004-6-R4 CIP-004-6-R5 CIP-007-6-R5	Cisco Identity Services Engine (ISE) TDi Technologies ConsoleWorks Xage Security Fabric
		PR.AC-3: Remote access is managed.	AC-1, AC-17, AC-19, AC-20, SC-15	CIP-003-7-R2 CIP-004-6-R4 CIP-004-6-R5 CIP-005-5-R1 CIP-005-5-R2 CIP-005-6-R2 CIP-013-1-R1	Xage Security Fabric
		PR.AC-4: Access permissions and authorizations are managed, incorporating the principles of least privilege and separation of duties.	AC-1, AC-2, AC-3, AC-5, AC-6, AC-14, AC-16, AC-24	CIP-004-6-R4 CIP-004-6-R5 CIP-005-6-R2 CIP-007-6-R5 CIP-013-1-R1	Anterix LTE network Cisco ISE Cisco Firepower Threat Defense TDi Technologies ConsoleWorks Xage Security Fabric

Function	Category	Subcategory	NIST 800-53, Revision 5 Control(s)	Related NERC CIP ID(s)	Product (s) Used
		PR.AC-5: Network integrity is protected (e.g., network segregation, network segmentation).	AC-4, AC-10, SC-7, SC-10, SC-20	CIP-005-5-R1 CIP-007-6-R1	Cisco Firepower Threat Defense Spherical Analytics Immutably Xage Security Fabric
	Data Security (PR.DS): Information and records (data) are managed consistent	**PR.DS-1:** Data at rest is protected.	MP-2, MP-3, MP-4, MP-5, MP-6, MP-7, MP-8, SC-28	**CIP-011-2-R2-R2**	Anterix LTE network

Function	Category	Subcategory	NIST 800-53, Revision 5 Control(s)	Related NERC CIP ID(s)	Product (s) Used
	with the organization's risk strategy to protect the confidentiality, integrity, and availability of information.	**PR.DS-2:** Data in transit is protected.	SC-8, SC-11	CIP-003-7-R2 CIP-004-6-R4 CIP-004-6-R5 CIP-005-5-R1 CIP-005-5-R2 CIP-011-2-R1	Spherical Analytics Immutably
		PR.DS-6: Integrity-checking mechanisms are used to verify software, firmware, and information integrity.	SI-7, SI-10	CIP-010-2-R1 CIP-010-3-R1 CIP-010-2-R2 CIP-011-2-R1 CIP-013-1-R1	Spherical Analytics Immutably Sumo Logic Enterprise Xage Security Fabric Cisco Cyber Vision TDi Technologies ConsoleWorks.
DETECT (DE)	**Anomalies and Events (DE.AE):** Anomalous activity is detected, and the potential impact of events is understood.	**DE.AE-1:** A baseline of network operations and expected data flows for users and systems is established and managed.	AC-4, CA-3, CM-2, SC-16, SI-4	No mapping	Radiflow iSID TDi Technologies ConsoleWorks Cisco Cyber Vision

Function	Category	Subcategory	NIST 800-53, Revision 5 Control(s)	Related NERC CIP ID(s)	Product (s) Used
		DE.AE-2: Detected events are analyzed to understand attack targets and methods.	AU-6, CA-7, RA-5, IR-4, SI-4	CIP-003-7-R2 CIP-005-5-R1 CIP-007-6-R4 CIP-008-5-R1 CIP-008-5-R2 CIP-008-5-R4	Radiflow iSID. Sumo Logic Enterprise Cisco Cyber Vision
		DE.AE-3: Event data are collected and correlated from multiple sources and sensors.	AU-6, CA-7, CP-2, IR-4, IR-5, IR-8, SI-4	CIP-007-6-R4	Radiflow iSID. Sumo Logic Enterprise Cisco Cyber Vision

Function	Category	Subcategory	NIST 800-53, Revision 5 Control(s)	Related NERC CIP ID(s)	Product (s) Used
		DE.AE-5: Incident alert thresholds are established.	IR-4, IR-5, IR-8	CIP-007-6-R4 CIP-007-6-R5 CIP-008-5-R1	Radiflow iSID. Cisco Cyber Vision
	Security Continuous Monitoring (DE.CM): The information system and assets are monitored to identify cybersecurity events and verify the effectiveness of protective measures.	**DE.CM-1:** The information system and assets are monitored to identify cybersecurity events and verify the effectiveness of protective measures.	AU-12, CA-7, CM-3, SC-5, SC-7, SI-4	CIP-005-5-R1	Radiflow iSID TDi Technologies ConsoleWorks NIST physical access control systems
		DE.CM-2: The physical environment is monitored to detect potential cybersecurity events.	CA-7, PE-6, PE-20	CIP-003-7-R2 CIP-006-6-R1 CIP-006-6-R2 CIP-014-2-R5	Cisco Cyber Vision
		DE.CM-4: Malicious code is detected.	SC-44, SI-3, SI-4, SI-8	CIP-003-7-R2 CIP-007-6-R3 CIP-007-6-R4 CIP-010-2-R4	Radiflow iSID Spherical Analytics Cisco Cyber Vision

Function	Category	Subcategory	NIST 800-53, Revision 5 Control(s)	Related NERC CIP ID(s)	Product (s) Used
		DE.CM-7: Monitoring for unauthorized personnel, connections, devices, and software is performed.	AU-12, CA-7, CM-3, CM-8, PE-6, PE-20, SI-4	CIP-003-7-R2 CIP-005-5-R1 CIP-006-6-R1 CIP-007-6-R3 CIP-007-6-R4 CIP-007-6-R5 CIP-013-3-R2 Cip-010-2-R4	Radiflow iSID

3.5 Cybersecurity Workforce Considerations

Table 3-2 identifies the cybersecurity work roles that most closely align with the Cybersecurity Framework security Categories and Subcategories demonstrated in our reference architecture. The work roles are based on the National Initiative for Cybersecurity Education (NICE) Workforce Framework for Cybersecurity (NICE Framework). Note that the work roles shown may apply to more than one NIST Cybersecurity Framework Category.

More information about NICE and other work roles can be found in NIST SP 800-181 Revision 1, *Workforce Framework for Cybersecurity (NICE Framework).*

Table 3-2 Cybersecurity Work Roles Aligned to Reference Architecture

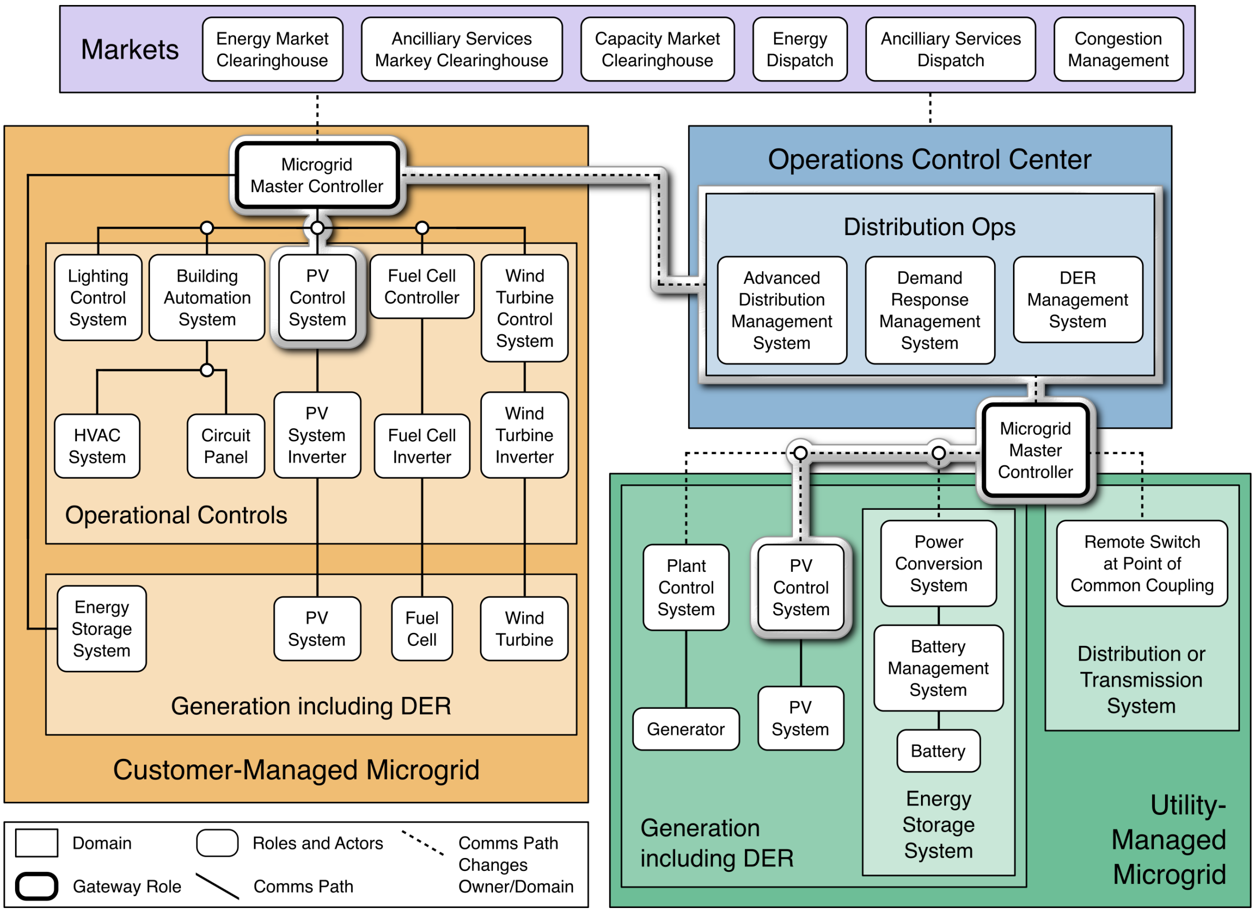
NICE Work Role ID	NICE Work Role	Work Role Description	Category	Specialty Area	Cybersecurity Framework Subcategory Mapping
OM-ADM-001	System Administrator	Responsible for setting up and maintaining a system or specific components of a system (e.g., installing, configuring, and updating hardware and software; establishing and managing user accounts; overseeing or conducting backup and recovery tasks; implementing operational and technical security controls; and adhering to organizational security policies and procedures).	Operate and Maintain	Systems Administration	PR.AC-1, PR.AC-3, PR.AC-4
SP-SYS-001	Information Systems Security Developer	Designs, develops, tests, and evaluates information system security throughout the systems development life cycle.	Securely Provision	Systems Development	PR.AC-5, PR.DS-1, PR.DS-2, PR.DS-6, DE.AE-1
PR-CDA-001	Cyber Defense Analyst	Uses data collected from a variety of cyber defense tools (e.g., IDS alerts, firewalls, network traffic logs) to analyze events that occur within their	Protect and Defend	Cyber Defense Analysis	DE.AE-2, DE.AE-3, DE.AE-5, DE.CM-1, DE.CM-4, DE.CM-7

NICE Work Role ID	NICE Work Role	Work Role Description	Category	Specialty Area	Cybersecurity Framework Subcategory Mapping
		environments and to mitigate threats.			
OM-ANA-001	Systems Security Analyst	Responsible for the analysis and development of the integration, testing, operations, and maintenance of systems security.	Operate and Maintain	Systems Analysis	DE.AE-1, PR.AC-1, PR.AC-3

4 Architecture

NIST SP 1108r4 defines four communication pathway scenarios: legacy, high-DER, hybrid, and microgrid. In this publication we provide a reference architecture to address the cybersecurity of some of the communications pathways in the microgrid scenario shown in Figure 1.

Figure 1 Microgrid Communications Pathways Scenario



In this scenario, the Distribution Ops systems, within a utility Operations Control Center, exchange information with a Microgrid Master Control system and through this system to a PV Control System. This architecture addresses the security of these information exchanges.

This architecture helps ensure that both the DER operator and the local utility have confidence that the information exchanges are legitimate.

4.1 Architecture Description

The project reference architecture demonstrates the following capabilities to protect, monitor, and audit DER information exchanges.

- All information exchanges are by and between authenticated and authorized entities.
- The networks used to exchange information are monitored, and suspicious activity is detected and reported.

- A distributed ledger of information exchanges is maintained by a third party to allow both DER operators and the utility to independently verify the information exchanges.
- A DER operator log collection, data analysis and visualization capability provides controlled results sharing with the utility and other DER operators.

Figure 2 and Figure 3 depict the reference architectures used to protect information exchanges.

Figure 2 Information Exchange, Monitoring, and Distributed Ledger Reference Architecture

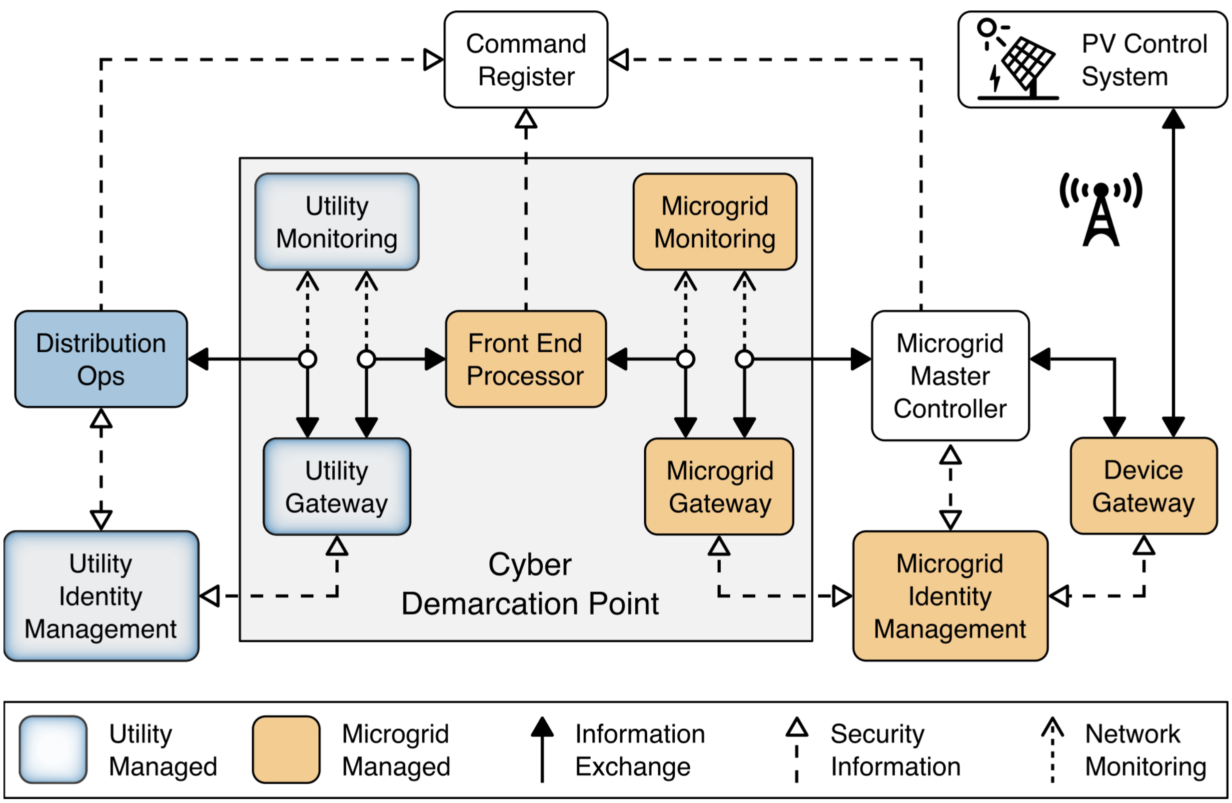


Figure 2 shows the elements of the reference architecture for protecting information exchanges, monitoring network traffic, and recoding information exchanges in a distributed ledger. The core element of this architecture is the cyber demarcation point. The cyber demarcation point separates a utility network and a microgrid network that is owned and controlled by a DER operator. The cyber demarcation point is responsible for independently enforcing two distinct security policies—the utility's security policy and the microgrid owner's security policy. There is a cyber demarcation point at each DER operator site. It contains the following:

- The **utility gateway** component implements the utility's access policy. It verifies the identity of utility distribution ops systems exchanging information with the microgrid master controller and allows access based on the utility's defined access policy. The utility gateway's access policy uses the identity of the originating system to determine if a given information exchange is authorized. The identities and access policies are managed by the utility identity management element of the architecture. This gateway and the utility identity management element are owned, managed, and operated by the utility. We assume all information exchanges originate on the utility network via a request from the utility's distribution ops systems to the microgrid master controller.

- The **front-end processor** component receives information requests from the utility gateway, records them in the command register, and forwards them to the microgrid gateway.
- The **microgrid gateway** component implements the microgrid access policy. It receives information requests from the front-end processor and passes authorized requests into the microgrid master controller. This gateway is owned, managed, and operated by the microgrid operator.
- The **utility cyber monitoring** component examines network and application traffic on the utility network and alerts utility cybersecurity personnel if suspicious activity is detected. This component is owned, managed, and operated by the utility.
- The **microgrid cyber monitoring** component examines network and application traffic on the microgrid network and alerts microgrid cybersecurity personnel if suspicious activity is detected. This component is owned, managed, and operated by the microgrid operator.

In addition to the cyber demarcation point, other elements of the architecture contribute to cybersecurity.

- The **distribution ops systems** record every information exchange they originate in the command register.
- The **microgrid master controller** records every information exchange it receives from the microgrid gateway in the command register and forwards appropriate commands to the device gateway.
- The **device gateway** implements a device-specific access policy. It receives requests from the microgrid master controller and passes authorized requests to the PV control system. The device gateway's access policy uses the identity of the microgrid master controller to determine if a given information exchange is authorized. The identities and access policies are managed by the microgrid identity management element of the architecture. A device gateway allows the microgrid gateway to implement coarse-grained access policies that are not device-specific. The microgrid gateway can allow a request independent of the device. The device gateways can then implement fine-grained policies that are device-specific. This allows the microgrid gateway policies to be independent of the specific devices currently accessible on the microgrid network. Note that the reference architecture allows but does not require the microgrid gateway policy to be independent of the specific devices on the microgrid network. Use of the device gateway also allows micro-segmentation of the microgrid network.

This architecture allows both the utility and the microgrid operator to control access to DERs on the microgrid. Both must agree to allow access to a specific PV control system. Similarly, both the utility and the microgrid operator can detect suspicious activity. There is no requirement for the utility or the microgrid operator to use the same products to implement these capabilities. There is a potential security benefit in each organization choosing different products, which provides a degree of diversity in an implementation. The selected products, however, must be able to exchange information via defined protocols such as Sunspec Modbus.

Device gateways may connect to PV control systems via wired or wireless network segments. Figure 2 shows a wireless connection.

The reference architecture assumes the DER microgrid is neither owned nor operated by the utility. The microgrid operator and the utility may each independently collect audit trails that record information exchanges. In this way, there is no single authoritative record of these exchanges. A complete audit trail would have to be constructed by combining audit records from the utility and the microgrid operator.

The distribution ops, front-end processor, and microgrid master controller in the reference architecture record information exchanges in the command register. The command register is a distributed ledger operated by a trusted third party. It provides an accurate, immutable record of all information exchanges that may be reviewed by both the utility and the microgrid operators. The ledger provides an authoritative source for determining who said what to whom when and is a complete audit trail of information exchanges.

Figure 3 Log Collection, Data Analysis and Visualization Reference Architecture

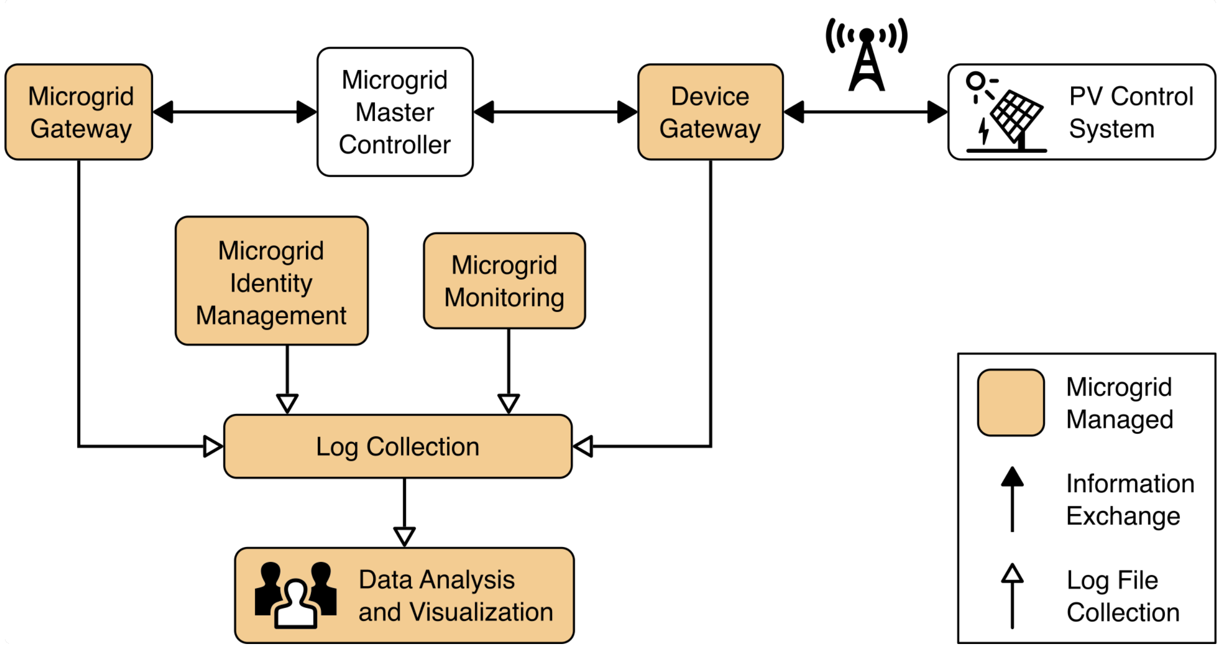


Figure 3 illustrates the capabilities to collect, analyze, and visualize information from the log files generated by microgrid systems. These log files are gathered from microgrid systems by a log collector which aggregates the log data and sends it to a cloud-based analysis and visualization capability. The microgrid operator's cyber defense analysts have full access to all the log information and analysis results. The microgrid operator may choose to share select results with the utility. It is easier to realize this selective sharing by using a cloud platform than it would be using an on-premise analysis platform. The cloud analytics platform can also enable select information sharing between and among microgrid operators.

Figure 4 Privileged User Management

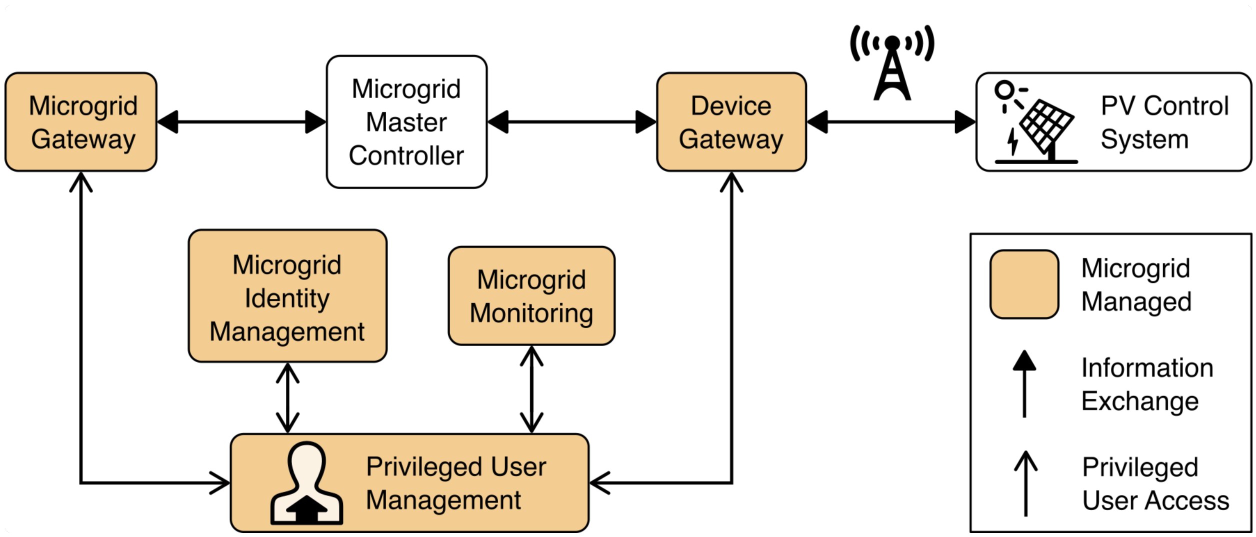


Figure 4 illustrates a capability to manage the privileged users responsible for installation, configuration, operation, and maintenance of elements of the reference architecture. Privileged user management capabilities protect privileged access credentials, control access to management interfaces, and provide accountability for all privileged user actions in managing products on the microgrid.

4.2 Example Solution Description

A laboratory prototype instance of the reference architecture, called an "example solution," was constructed to verify the design. The example solution consists of a combination of logical and physical infrastructure at the NCCoE and on the UMD campus.

The utility network and the cyber demarcation point are represented in the example solution by virtual infrastructure in the NCCoE lab.

The microgrid network is represented by three distinct components: a virtual network in the NCCoE lab, the UMD campus network, and an LTE network installed on the UMD campus. Virtual private networks

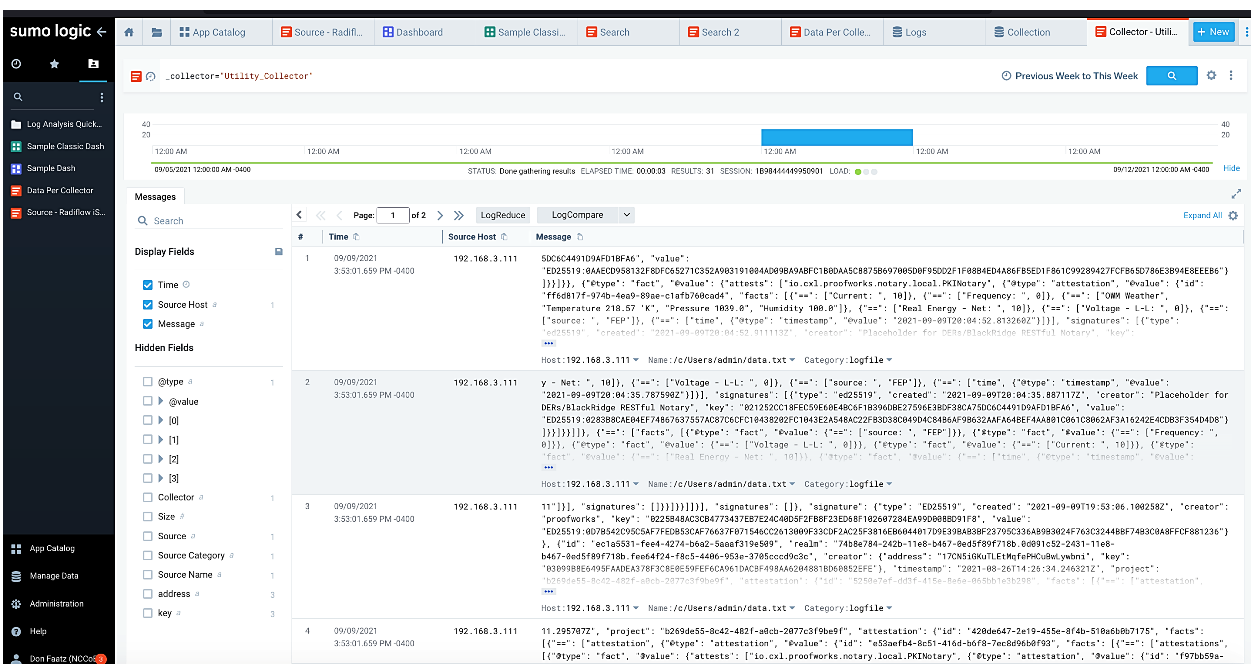
(VPNs) are used to connect the NCCoE lab to the UMD campus network and to connect the UMD campus network, via an LTE network, to solar arrays on two UMD parking garages.

- The distribution ops system was implemented by NCCoE-developed software that can send Sunspec Modbus commands to a PV control system and record those commands in the command register.
- The utility gateway and utility identity management elements of the architecture were implemented using the Xage Security Fabric product. Identities, devices, and access policies are defined within the product and no external identity store is needed. Identities, device definitions, and access policies are managed from a central manager and distributed to edge nodes at each microgrid location for use.
- The utility monitoring element of the architecture was implemented using the Radiflow iSID industrial control network monitoring product. iSID learns normal network behaviors and then detects anomalous activity.
- The front-end processor was implemented by NCCoE-developed software that receives Sunspec Modbus commands, records them in the command register, and forwards the command to the microgrid gateway.
- The microgrid identity management element was implemented using the Cisco Identity Services Engine (ISE). Identities and access policies are created and managed in ISE. ISE authenticates requests to access resources on the microgrid network and, based on policy, decides if the request should be allowed. The access decisions are enforced by an ISE-enabled switch and Cisco Firepower Threat Defense next-generation firewall implementing the microgrid and device gateways.
- The microgrid gateway was implemented using a Cisco Catalyst 3650 ISE-enabled network switch. The switch enforces access decision made by ISE. Connections through the switch must first authenticate to ISE. ISE makes an access decision and tells the switch to allow or deny the connection. The only connection allowed is a connection between the FEP and the Microgrid Master Controller.
- The microgrid monitoring element was implemented using Cisco Cyber Vision. Cyber Vision monitors network traffic, learns normal traffic flows and behaviors, and then detects deviations from normal and other anomalies.
- The Microgrid Master Controller was implemented by NCCoE-developed software that receives Sunspec Modbus commands, records them in the command register, and forwards the command to the device gateway.
- The command register was implemented using the Spherical Analytics Immutably software as a service product. Via a restful API, this product receives information from various other elements of the architecture, stores it, enriches it with configurable proofs, and stores it in a distributed ledger using blockchain technology. Figure 6 shows example records captured in the command register.

- The device gateway was implemented using a Cisco Firepower Threat Defense next-generation firewall. The firewall enforces access decision made by ISE. Connections through the firewall must first authenticate to ISE. ISE makes an access decision and tells the firewall to allow or deny the connection. The only connection allowed is a connection between the Microgrid Master Controller and the PV control system.
- The PV control system and associated PV array were implemented by solar array systems installed on parking garages at UMD.
- Connectivity between the device gateway and PV control systems at UMD parking garages was provided by an LTE network installed by Anterix at UMD.
- The log collection element was implemented with the open-source version of syslog-ng. Microgrid components that generated log data in syslog format were configured to send that data to a syslog-ng instance where it was aggregated.
- The data analysis and visualization element was implemented by Sumo Logic’s software as a service cloud-based data collection, analysis, and visualization product. Figure 5 shows an example visualization of analysis results. This example was produced by replaying network traffic provided by a utility over our network and observing that traffic with elements of the reference architecture. On the left side of the example, the large green and blue graph shows the amount of data provided by various collectors. Above that is a graph of login activity to systems. Below that is a graphic showing operational power faults. On the right side of the example, is a list of the top communication failure alarms and a pie chart showing what percentage of alarms are generated by each source.
- The privileged user management element was implemented using TDi Technologies ConsoleWorks product. ConsoleWorks acts as a jump box that manages privileged access credentials, controls access to privileged functions and management interfaces, and captures all privileged user activity in an audit trail.

Figure 5 Example of Analysis and Visualization

Figure 6 Example Command Register Data



Details of the installation, configuration, and integration of these products into the example solution are provided in Volume C of this guide.

While the NCCoE used a suite of commercial products to address this challenge, this guide does not endorse these products, nor does it guarantee compliance with any regulatory initiatives. Your organization's information security experts should identify the products that will best integrate with your existing tools and IT or operational technology (OT) system infrastructure. Your organization can adopt this solution or one that adheres to these guidelines in whole, or you can use this guide as a starting point for tailoring and implementing parts of a solution.

5 Security Characteristic Analysis

This section discusses the results of a comprehensive security evaluation of the reference architecture shown in Figure 1 and how it supports the Cybersecurity Framework Subcategories that we identified and mapped in Table 3-1. The purpose of the security characteristic analysis is to understand the extent to which the project example solution meets its objective of demonstrating that information exchanges among DERs and electric distribution grid operations can be monitored and protected from certain cybersecurity compromises. In addition, it seeks to understand the security benefits and drawbacks of the example solution.

5.1 Assumptions and Limitations

The security characteristic analysis has the following limitations:

- The analysis is not a comprehensive test of all security components nor a red-team exercise.
- The analysis cannot identify all weaknesses.
- The analysis does not include the lab infrastructure. We assume that the IT infrastructure used in the example solution is configured securely and properly managed. Testing this infrastructure would reveal only weaknesses in implementation that would not be relevant to those adopting this reference architecture.
- The analysis considers only those product capabilities explicitly used in the example solution. Products may have additional capabilities that are not considered.
- The products used to implement the utility, microgrid, and DER gateways use identity to grant or allow access. The gateways are not firewalls and do not provide network protocol-level access control.
- While identities are used to control access, identity and access management technologies and processes are not addressed in the reference architecture or the example solution. See NIST SP 1800-2, *Identity and Access Management for Electric Utilities*, for more information.
- The example solution includes a limited privileged user management capability. NIST SP 1800-18, *Privileged Account Management for the Financial Services Sector,* provides additional guidance on managing privileged user access.

5.2 Example Solution Testing

Testing verifies that the products we integrated in the lab environment work together as intended by the reference architecture. For this project, we designed six test scenarios that are defined in Table 5-1 through Table 5-6. These test scenarios are presented in terms of the reference architecture element and are independent of the specific products used to implement the example solution.

5.2.1 Test Scenario 1: Communication Between the Utility and a DER Is Secure

This test case verifies that authenticated and authorized systems on the utility network can communicate with a DER connected to the microgrid network.

Table 5-1 Test Procedures: Communication Between the Utility and a DER Is Secure

Procedure	▪ The utility distribution ops systems make requests for information (information exchanges) from the PV Control System. ▪ The PV control system is implemented by solar arrays at UMD.
Architectural Requirements	▪ Identity-based access management allows authenticated and authorized systems to traverse the cyber demarcation point and access PV Control System.
Capabilities/ Requirements	▪ The utility identity management element provides an identity and associated credentials to the distribution ops systems allowing them to authenticate to the utility gateway. ▪ The utility gateway authenticates the distribution ops systems and enforces the access policy provided by the utility identity management system ▪ The microgrid identity management element provides an identity and associated credentials to the front-end processor and the microgrid master controller allowing them to authenticate to the microgrid gateway and the device gateway. ▪ The microgrid gateway authenticates the front-end processor and enforces the access control policy provided by the microgrid identity management system. ▪ The device gateway authenticates the microgrid master controller and enforces the access control policy provided by the microgrid identity management system. ▪ Wireless connectivity element provides communication between the device gateway and the PV control system.

Expected Results	▪ Devices and users with proper authentication and authorization can communicate between the utility and the PV control system. ▪ Devices and users without proper authentication and/or authorization are unable to communicate between the utility and the PV control system.
Actual Results	▪ Passed
Overall Results	▪ Passed

5.2.2 Test Scenario 2: Integrity of Command Register Data and Communication Is Verified

This test case verifies data providence and integrity across the system for commands being exchanged between the utility and the PV control system.

Table 5-2 Test Procedure: Integrity of Command Register Data and Communication Is Verified

Procedure	▪ The utility distribution ops systems make requests for information (information exchanges) from the PV Control System. ▪ The utility and the microgrid operator verify the record of the information exchanges recorded in the command register.
Architectural Requirements	▪ An audit trail of information exchanges between the utility's distribution ops systems and the PV control system is maintained.
Capabilities/ Requirements	▪ Elements along the communications path between the distribution ops systems and the PV control system are capable of recording information exchanges in the command register. ▪ The command register is capable of cross-checking and verifying log integrity.
Expected Results	▪ The command register records all information exchanges between the utility and the PV control system. ▪ The command register verifies integrity of events throughout individual communication life cycles. ▪ The command register provides notification of integrity failure events throughout individual communication life cycles.

Actual Results	▪ Passed
Overall Results	▪ Passed

685 ### 5.2.3 Test Scenario 3: Log File Information Can Be Captured and Analyzed

686 This test case verifies the capabilities of capturing and analyzing log data within the microgrid network.

687 **Table 5-3 Test Procedure: Log File Information Can Be Captured and Analyzed**

Procedure	▪ The utility distribution ops systems make requests for information (information exchanges) from the PV Control System. ▪ Log file data is captured by the syslog aggregators on the NCCoE lab data collection network. ▪ Log files are routinely transferred by the syslog aggregators to Sumo Logic for analysis. ▪ Log file analysis results are presented to microgrid cyber analysts via a Sumo Logic dashboard.
Architectural Requirements	▪ The microgrid monitoring element, the microgrid identity management element, the device gateway element and the microgrid gateway element record events in their respective logs.
Capabilities/ Requirements	▪ All microgrid applications and services can record data in an exportable and accessible log. ▪ The event information captured in logs can be analyzed by audit analysis tools.
Expected Results	▪ Log data is collected across the elements on the microgrid networks. ▪ Log data is successfully transferred to the data analysis and visualization element. ▪ The data analysis capability reads, interprets, and analyzes all logs that are ingested. ▪ The visualization capability presents the result of data analysis.
Actual Results	▪ Syslog information was transferred from the monitoring components to the data visualization and analysis component. Results of analysis were displayed on a dashboard.

Overall Results	▪ Passed

5.2.4 Test Scenario 4: Log File Analysis Can Be Shared

This test case verifies that the log analysis findings can be shared through proper channels.

Table 5-4 Test Procedure: Log File Analysis Can Be Shared

Procedure	▪ The microgrid operator shares a subset of the data analysis results with the utility. ▪ The utility operator views the data analysis results shared by the microgrid operator
Architectural Requirements	▪ The data analysis and visualization element is able to selectively share information with other organizations.
Capabilities Requirements	▪ The data analysis and visualization element can limit access to log data and analysis results based on a defined access control policy.
Expected Results	▪ The microgrid operator can specify access control policies that allow access to s subset of log data and analysis results by the utility operator. ▪ The utility operator is able to access only the log data and analysis results explicitly allowed by the policy the microgrid operator defined.
Actual Results	▪ The SaaS product that implements log file analysis has data sharing capabilities, however, those capabilities have not yet been tested in the example solution.
Overall Result	▪ Passed

5.2.5 Test Scenario 5: Malicious Activity Is Detected

This test case verifies the system's ability to detect anomalous or malicious behavior on the network.

Table 5-5 Test Procedure: Malicious Activity Is Detected

Procedure	▪ The utility distribution ops systems make requests for information (information exchanges) from the PV Control System

	▪ The utility monitoring element and the microgrid monitoring element are observing network traffic.
Architectural Requirements	▪ The utility and microgrid monitoring elements can observe all information exchanged between the distribution ops systems and the PV control system. ▪ Log information from the utility and microgrid monitoring elements is sent to the data analysis and visualization element.
Capabilities Requirements	▪ The microgrid and utility monitoring elements are able to identify suspicious activity in the information exchanges through the cyber demarcation point and report these in their log data. ▪ The data analysis and visualization element is able to analyze suspicious events and identify events which represent potential incidents.
Expected Results	▪ The data analysis and visualization element identifies potential incidents and report them to cybersecurity personnel for action.
Actual Results	▪ Passed
Overall Result	▪ Passed

5.2.6 Test Scenario 6: Privileged User Access Is Managed

This test case verifies that privileged users are authenticated and authorized to access only those devices to which they have been given proper privileges.

Table 5-6 Test Procedure: Privileged User Access Is Managed

Procedure	▪ A privileged user authenticates to the privileged user management element. ▪ The privileged user accesses the management interface of the microgrid monitoring, microgrid gateway, microgrid identity management element and device gateway element.
Architectural Requirements	▪ The privileged user management element controls access to the management interface of the microgrid monitoring, microgrid gateway, microgrid identity management element and device gateway elements.

	▪ The privileged user management element records all privileged user action in an audit log.
Capabilities Requirements	▪ The privileged user management element authenticates users attempting to access management interface ▪ The privileged user management element controls access to management interfaces and functions on a per-privileged user basis. ▪ The privilege user management system records all activity in an audit trail. ▪ The privileged user management element sends log information to the data analysis and visualization element.
Expected Results	▪ Authorized privileged users are able to authenticate to the privileged user management element and access authorized management interfaces. ▪ Privileged users are unable to access management interfaces or management commands they are not authorized to perform. ▪ All authentications, access decisions and privileged user actions are captures in the privileged user management element audit trail.
Actual Results	▪ Passed
Overall Results	▪ Passed

5.3 Scenarios and Findings

Security evaluation of the reference architecture involves assessing how well the architecture addresses the security characteristics that it is intended to support. The Cybersecurity Framework Subcategories were used to provide structure to the security assessment. Using the Cybersecurity Framework Subcategories as a basis for organizing the analysis allows systematic consideration of the reference architecture's support for the intended security characteristics.

In the project description, we described a sequence of events that could lead to a malicious entity being able to masquerade as either a utility operator or a microgrid operator. If that were to occur, the utility could not trust the information that it would receive from the microgrid operators. Likewise, the microgrid operators could not trust the utility's information exchange.

This section analyzes the example solution in terms of the Cybersecurity Framework's specific Subcategories supported, creating trust in information exchanges between the utility and the microgrid operation.

5.3.1 Identity Management, Authentication, and Access Control

5.3.1.1 PR.AC-1: Identities and Credentials Are Issued, Managed, Verified, Revoked, and Audited for Authorized Devices, Users, and Processes

This Cybersecurity Framework Subcategory is supported in the reference architecture by the utility identity management, microgrid identity management, and privileged user management elements of the architecture. The utility can establish identities and credentials using the utility identity management element. These identities and credentials are used by the utility gateway. The microgrid operator can establish identities, credentials, and access policies using the microgrid identity management element. These identities and access rules are used by the microgrid gateway and by the device gateway.

The privileged user management element manages the privileged access credentials used to access the management interfaces of architecture elements in the microgrid environment.

5.3.1.2 PR.AC-3: Remote Access Is Managed

This Cybersecurity Framework Subcategory is supported by the reference architecture's cyber demarcation point. The cyber demarcation point uses identity to control access by the utility to devices on the microgrid network. The reference architecture has two separate policy domains: the utility domain and the microgrid operator domain. The cyber demarcation point consists of a utility gateway and a microgrid gateway. The utility controls the identities used and the access policy enforced by the utility gateway. The microgrid operator controls the identities used and the access policy enforced by the microgrid gateway. These two gateways control remote access by the utility to devices on the microgrid network.

5.3.1.3 PR.AC-4: Access Permissions and Authorizations Are Managed, Incorporating the Principles of Least Privilege and Separation of Duties

This Cybersecurity Framework Subcategory is supported by the reference architecture's cyber demarcation point. The cyber demarcation point uses identity to control access by the utility to devices on the microgrid network. The reference architecture has two separate policy domains: the utility domain and the microgrid operator domain. The cyber demarcation point consists of a utility gateway and a microgrid gateway. The utility controls the access policy enforced by the utility gateway. The microgrid operator controls the access policy enforced by the microgrid gateway. These two gateways control remote access by the utility to devices on the microgrid network.

5.3.1.4 PR.AC-5: Network Integrity Is Protected (e.g., Network Segregation, Network Segmentation)

This Cybersecurity Framework Subcategory is supported by the reference architecture's cyber demarcation point and by network segmentation within the microgrid.

The utility is not exchanging information directly with the microgrid, but it is exchanging information through the cyber demarcation point. The reference architecture provides gateways to represent the microgrid and utility independently. Thus, the utility would manage communications and security interactions through its gateway; the microgrid operator would also manage its gateway and the assets on its side. The device gateways within the microgrid network enable fine-grained segmentation of resources on that network.

5.3.2 Data Security

5.3.2.1 PR.DS-1: Data at Rest Is Protected

This Cybersecurity Framework Subcategory is supported by the reference architecture's command register capability. The command register provides protection at rest for the audit trail of information exchanges between the utility and microgrid operator. The ledger ensures the integrity of the audit trail records. The distributed nature of the ledger ensures availability of the audit trail records.

5.3.2.2 PR.DS-2: Data in Transit Is Protected

This Cybersecurity Framework Subcategory is supported using VPNs to encrypt traffic between the NCCoE lab, the UMD campus network, and the solar arrays located on parking garages at UMD. In addition to the VPN, the data is further protected in transit between the UMD campus network and the DERs (solar arrays) by security measures built into LTE (Long Term Evolution), the wireless network standard implemented in the reference architecture.

5.3.2.3 PR.DS-6: Integrity-Checking Mechanisms Are Used to Verify Software, Firmware, and Information Integrity

This Cybersecurity Framework Subcategory is supported by the reference architecture's command register.

The command register provides an immutable, fully distributed audit trail accessible by all parties involved in information exchanges. Using the command register, the full sequence of events between the utility and DER operators is observable by all parties.

5.3.3 Anomalies and Events

5.3.3.1 DE.AE-1: A Baseline of Network Operations and Expected Data Flows for Users and Systems Is Established and Managed

This Cybersecurity Framework Subcategory is supported by the utility cyber monitoring and microgrid cyber monitoring components of the cyber demarcation point in the reference architecture. The cyber monitoring components are self-training. They monitor network traffic and observe the normal behavior and flow of information into and out of the cyber demarcation.

5.3.3.2 DE.AE-2: Detected Events Are Analyzed to Understand Attack Targets and Methods

This Cybersecurity Framework Subcategory is supported by the utility cyber monitoring and microgrid cyber monitoring components of the cyber demarcation point and data analysis and visualization in the reference architecture. They monitor network traffic and observe the normal behavior and flow of information into and out of the cyber demarcation.

The data analysis and visualization element of the architecture analyzes log data from services on the microgrid network to identify suspicious behavior and to alert analysts. Log data is compared with the expected normal behavioral characteristics that are learned over time. Deviations from the expected normal behavior are reported as events.

5.3.3.3 DE.AE-3: Event Data Are Collected and Correlated from Multiple Sources and Sensors

This Cybersecurity Framework Subcategory is supported by the reference architecture's data analysis and visualization capability. The data analysis and visualization capability collects log information from multiple sources within the microgrid network. This data is sent to a cloud analytics platform. At the cloud analytics platform, the log data is analyzed to identify evidence of malicious or unexpected activity.

This Cybersecurity Framework Subcategory is supported by the utility monitoring and microgrid monitoring components of the cyber demarcation point. These components can collect monitoring data from multiple locations within the cyber demarcation point for correlation.

This Cybersecurity Framework Subcategory is supported by the command register in the reference architecture. The command register captures a complete audit trail of information exchanges between a utility and DER operators who provide power to the utility. This audit trail can be analyzed for anomalies in the way information exchanges occur.

5.3.3.4 DE.AE-5: Incident Alert Thresholds Are Established

This Cybersecurity Framework Subcategory is supported by the utility cyber monitoring and microgrid cyber monitoring components of the cyber demarcation point as well as by the data analysis and visualization capability. Each of these monitoring and analysis capabilities has established thresholds for detecting anomalies and generating alerts.

5.3.4 Security Continuous Monitoring

5.3.4.1 The Information System and Assets Are Monitored to Identify Cybersecurity Events and Verify the Effectiveness of Protective Measures

This Cybersecurity Framework Subcategory is supported by the utility cyber monitoring and microgrid cyber monitoring components of the cyber demarcation point, and by the log analysis capability. Each of these monitors aspects of the system and identifies cybersecurity events.

5.3.4.2 DE.CM-2: The Physical Environment Is Monitored to Detect Potential Cybersecurity Events

This Cybersecurity Framework Subcategory is supported by the physical security systems at the NCCoE and UMD. Both the NCCoE and UMD have physical access control systems in place to control and monitor access to the physical locations where the example solution components are installed. NIST monitors the NCCoE physical access control system. UMD monitors its physical security system.

5.3.4.3 DE.CM-4: Malicious Code Is Detected

This Cybersecurity Framework Subcategory is supported by the utility cyber monitoring and microgrid cyber monitoring components of the cyber demarcation point. These components can detect some malicious code types based on analysis of monitored network traffic.

5.3.4.4 DE.CM-7: Monitoring for Unauthorized Personnel, Connections, Devices, and Software Is Performed

This Cybersecurity Framework Subcategory is supported by the microgrid cyber monitoring component of the cyber demarcation point in the reference architecture.

The microgrid cyber monitoring component develops a model of the expected devices and information flows. Unexpected devices or connections are detected and reported.

6 Future Project Considerations

The NCCoE recognizes that the reference architecture and example solution described in this practice guide demonstrate some of the tenets and principles of a zero trust architecture as defined in NIST SP 800-207, Zero Trust Architecture. While most discussions around zero trust architectures focus on implementations for IT business networks and use cases, future NCCoE Energy Sector projects might consider implementing a zero trust architecture in an ICS environment. For example, we might consider extending this architecture and example solution to include dynamic access control for DERs or other grid-edge devices connecting to the distribution grid.

Appendix A List of Acronyms

CISA	Cybersecurity and Infrastructure Security Agency
DER	Distributed Energy Resource
EPRI	Electric Power Research Institute
EPS	Electric Power System
ICS	Industrial Control System
ICS-CERT	Industrial Control Systems–Computer Emergency Readiness Team
IIoT	Industrial Internet of Things
IT	Information Technology
LTE	Long-Term Evolution
NCCoE	National Cybersecurity Center of Excellence
NIST	National Institute of Standards and Technology
OT	Operational Technology
UMD	University of Maryland
VPN	Virtual Private Network

Appendix B References

[1] The Smart Grid Interoperability Panel-Smart Grid Cybersecurity Committee, *Guidelines for Smart Grid Cybersecurity*, National Institute of Standards and Technology (NIST) Interagency or Internal Report 7628 Revision 1, Gaithersburg, Md., Sept. 2014, 290 pp. Available: https://nvlpubs.nist.gov/nistpubs/ir/2014/NIST.IR.7628r1.pdf.

[2] A. Gopstein et al., *NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 4.0*, NIST SP 1108rev4, NIST, Gaithersburg, Md., February 18, 2021. Available: https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.1108r4.pdf

[3] Cybersecurity and Infrastructure Security Agency, Industrial Control Systems Cyber Emergency Response Team, “Cyber Threat Source Descriptions.” Available: https://www.us-cert.gov/ics/content/cyber-threat-source-descriptions.

[4] Framework for Improving Critical Infrastructure Cybersecurity, Version 1.1, NIST, Gaithersburg, Md., Apr. 16, 2018. Available: https://nvlpubs.nist.gov/nistpubs/CSWP/NIST.CSWP.04162018.pdf

[5] Mapping of NIST Cybersecurity Framework v1.1 to NERC CIP Reliability Standards, NIST, Gaithersburg, Aug. 8, 2020. Available: PDR: Mapping of NIST Cybersecurity Framework v1.1 to NERC CIP Reliability Standards

[6] NIST Cybersecurity for IoT Program, Feb. 2021. Available: https://www.nist.gov/programs-projects/nist-cybersecurity-iot-program

Appendix C Benefits of IoT Cybersecurity Capabilities

The National Institute of Standards and Technology's (NIST's) Cybersecurity for the Internet of Things (IoT) program [6] supports development and application of standards, guidelines, and related tools to improve the cybersecurity of connected devices and the environments in which they are deployed. By collaborating with stakeholders across government, industry, international bodies, and academia, the program aims to cultivate trust and foster an environment that enables innovation on a global scale.

Computing devices that integrate physical and/or sensing capabilities and network interface capabilities are being designed, developed, and deployed at an ever-increasing pace. These devices are fulfilling customer needs in all sectors of the economy. Many of these computing devices are connected to the internet. A novel characteristic of these devices is their combination of connectivity and the ability to sense and/or affect the physical world. As devices become smaller and more complex, with an increasing number of features, the security of those devices also becomes more complex.

NIST's Cybersecurity for IoT program has defined a set of capabilities that device manufacturers should consider integrating into their IoT devices and that consumers should consider enabling/configuring in those devices. **Device cybersecurity capabilities** are cybersecurity features or functions that IoT devices or other system components (e.g., a gateway, proxy, IoT Platform) provide through technical means (i.e., device hardware and software). Many IoT devices have limited processing and data storage capabilities and may not be able to provide these **device cybersecurity capabilities** on their own; consequently, they may rely on other system components to provide these technical capabilities on their behalf. **Nontechnical supporting capabilities** are actions that a manufacturer or third-party organization performs in support of the cybersecurity of an IoT device. Examples of nontechnical support include providing information about software updates, instructions for configuration settings, and supply chain information.

Used together, **device cybersecurity capabilities** and **nontechnical supporting capabilities** can help mitigate cybersecurity risks related to the use of IoT devices while assisting customers in achieving their goals. **Device cybersecurity capabilities** and **nontechnical supporting capabilities**—if properly defined and integrated into Industrial Internet of Things (IIoT) devices in a distributed energy resources (DER) environment—can assist in securely deploying and configuring an IIoT DER ecosystem.

C.1 IoT Cybersecurity Capabilities Mapping

Table 5-7 below lists the **device cybersecurity capabilities and nontechnical supporting capabilities** as they map to the NIST Cybersecurity Framework Subcategories of particular importance to this project. It is acknowledged that IoT devices vary in their capabilities, and there may not be a clear delineation between the **device cybersecurity capabilities** that are provided by the IoT devices and those provided by another system component. It is also understood that the capabilities of cyber-physical components are evolving, so many of the mappings are not necessarily exact.

The mapping presents a summary of both technical and nontechnical capabilities that could enhance the security of an IIoT DER ecosystem. It is acknowledged that many of the **device cybersecurity capabilities** may not be available in modern IoT devices and that other system elements (e.g., proxies, gateways) or other risk mitigation strategies (e.g., network segmentation) may be necessary.

896 **Table 5-1 Mapping of Device Cybersecurity Capabilities and Nontechnical Supporting Capabilities to NIST Cybersecurity**
897 **Framework Subcategories of the IIoT Project**

Cybersecurity Framework v1.1 Subcategory	Device Cybersecurity Capabilities	Manufacturer Nontechnical Supporting Capabilities	Related NERC CIP ID(s)
PR.AC-1: Identities and credentials are issued, managed, verified, revoked, and audited for authorized devices, users, and processes.	▪ Ability to uniquely identify the IoT device logically. ▪ Ability to uniquely identify a remote IoT device. ▪ Ability for the device to support a unique device ID. ▪ Ability to configure IoT device access control policies using IoT device identity. ▪ Ability to verify the identity of an IoT device. ▪ Ability to add a unique physical identifier at an external or internal location on the device authorized entities can access. ▪ Ability to set and change authentication configurations, policies, and limitations settings for the IoT device. ▪ Ability to create unique IoT device user accounts. ▪ Ability to identify unique IoT device user accounts. ▪ Ability to create organizationally defined accounts that support privileged roles with automated expiration conditions. ▪ Ability to establish organizationally defined user actions for accessing the IoT device and/or device interface. ▪ Ability to enable automation and reporting of account management activities. ▪ Ability to establish conditions for shared/group accounts on the IoT device. ▪ Ability to administer conditions for shared/group accounts on the IoT device. ▪ Ability to restrict the use of shared/group accounts on the IoT device according to organizationally defined conditions.	▪ Providing details for how to establish unique identification for each IoT device associated with the system and critical system components within which it is used. ▪ Providing communications and documentation detailing how to perform account management activities, using the technical IoT device capabilities, or through supporting systems and/or tools. ▪ Providing the details necessary to establish and implement unique identification for each IoT device associated with the system and critical system components within which it is used. ▪ Providing the details necessary to require unique identifiers for each IoT device associated with the system and critical system components within which it is used. ▪ Providing education explaining how to establish and enforce approved authorizations for logical access to IoT device information and system resources. ▪ Providing education explaining how to control access to IoT devices implemented within IoT device customer information systems. ▪ Providing education explaining how to enforce authorized access at the system level.	CIP-004-6-R4 CIP-004-6-R5 CIP-007-6-R5
PR.AC-3: Remote access is managed.	▪ Ability to configure IoT device access control policies using IoT device identity. ○ Ability for the IoT device to differentiate between authorized and unauthorized remote users. ▪ Ability to authenticate external users and systems.	N/A	CIP-003-7-R2 CIP-004-6-R4 CIP-004-6-R5 CIP-005-5-R1 CIP-005-5-R2

Cybersecurity Framework v1.1 Subcategory	Device Cybersecurity Capabilities	Manufacturer Nontechnical Supporting Capabilities	Related NERC CIP ID(s)
	▪ Ability to securely interact with authorized external, third-party systems. ▪ Ability to identify when an external system meets the required security requirements for a connection. ▪ Ability to establish secure communications with internal systems when the device is operating on external networks. ▪ Ability to establish requirements for remote access to the IoT device and/or IoT device interface, including: ○ usage restrictions ○ configuration requirements ○ connection requirements ○ manufacturer established requirement ▪ Ability to enforce the established local and remote access requirements. ▪ Ability to prevent external access to the IoT device management interface. ▪ Ability to control the IoT device's logical interface (e.g., locally or remotely). ▪ Ability to detect remote activation attempts. ▪ Ability to detect remote activation of sensors.		CIP-005-6-R2 CIP-013-1-R1
PR.AC-4: Access permissions and authorizations are managed, incorporating the principles of least privilege and separation of duties.	▪ Ability to assign roles to IoT device user accounts. ▪ Ability to support a hierarchy of logical access privileges for the IoT device based on roles (e.g., admin, emergency, user, local, temporary). ○ Ability to establish user accounts to support role-based logical access privileges. ○ Ability to administer user accounts to support role-based logical access privileges. ○ Ability to use organizationally defined roles to define each user account's access and permitted device actions. ○ Ability to support multiple levels of user/process account functionality and roles for the IoT device.	▪ Providing the tools, assistance, instructions, and other types of information to support establishing a hierarchy of role-based privileges within the IoT device. ▪ Providing details about the specific types of manufacturer's needs to access the IoT device interfaces, such as for specific support, updates, ongoing maintenance, and other purposes. ▪ Providing documentation with instructions for the IoT device customer to follow for how to restrict interface connections that enable specific activities.	CIP-004-6-R4 CIP-004-6-R5 CIP-005-6-R2 CIP-007-6-R5 CIP-013-1-R1

Cybersecurity Framework v1.1 Subcategory	Device Cybersecurity Capabilities	Manufacturer Nontechnical Supporting Capabilities	Related NERC CIP ID(s)
	▪ Ability to apply least privilege to user accounts. ○ Ability to create additional processes, roles (e.g., admin, emergency, temporary) and accounts as necessary to achieve least privilege. ○ Ability to apply least privilege settings within the device (i.e., to ensure that the processes operate at privilege levels no higher than necessary to accomplish required functions). ○ Ability to limit access to privileged device settings that are used to establish and administer authorization requirements. ○ Ability for authorized users to access privileged settings. ▪ Ability to create organizationally defined accounts that support privileged roles with automated expiration conditions. ▪ Ability to enable automation and reporting of account management activities. ▪ Ability to establish conditions for shared/group accounts on the IoT device. ▪ Ability to administer conditions for shared/group accounts on the IoT device. ▪ Ability to restrict the use of shared/group accounts on the IoT device according to organizationally defined conditions. ▪ Ability to implement dynamic access control approaches (e.g., service-oriented architectures) that rely on: ○ run-time access control decisions facilitated by dynamic privilege management. ○ organizationally defined actions to access/use device. ▪ Ability to allow information sharing capabilities based upon the type and/or role of user attempting to share the information.	▪ Providing descriptions of the types of access to the IoT device that the manufacturer will require on an ongoing or regular basis. ▪ Providing detailed instructions for how to implement management and operational controls based on the role of the IoT device user, and not on an individual basis. ▪ Providing documentation and/or other communications describing how to implement management and operational controls to protect data obtained from IoT devices and associated systems from unauthorized access, modification, and deletion. ▪ Providing a detailed description of the other types of devices and systems that will access the IoT device during customer use of the device, and how they will access it. ▪ Providing communications and detailed instructions for implementing a hierarchy of privilege levels to use with the IoT device and/or necessary associated information systems. ▪ Providing communications and documentation detailing how to perform account management activities, using the technical IoT device capabilities, or through supporting systems and/or tools. ▪ Providing education explaining how to establish and enforce approved authorizations for logical access to IoT device information and system resources. ▪ Providing education explaining how to control access to IoT devices implemented within IoT device customer information systems. ▪ Providing education explaining how to enforce authorized access at the system level.	

Cybersecurity Framework v1.1 Subcategory	Device Cybersecurity Capabilities	Manufacturer Nontechnical Supporting Capabilities	Related NERC CIP ID(s)
	▪ Ability to restrict access to IoT device software, hardware, and data based on user account roles, used with proper authentication of the identity of the user to determine type of authorization. ▪ Ability to establish limits on authorized concurrent device sessions. ▪ Ability to restrict updating actions to authorized entities. ▪ Ability to restrict access to the cybersecurity state indicator to authorized entities. ▪ Ability to revoke access to the IoT device.	▪ Providing education and supporting materials explaining how to establish roles and responsibilities for IoT device data security, using the device capabilities and/or other services that communicate or interface with the device. ▪ Providing education and supporting materials describing the IoT device capabilities for role-based controls, and how to establish different roles within the IoT device. ▪ Providing education and supporting materials for how to establish roles to support IoT device policies, procedures, and associated documentation.	
PR.AC-5 Network integrity is protected (e.g., network segregation, network segmentation).	N/A	N/A	CIP-005-5-R1 CIP-007-6-R1
PR.DS-1: Data-at-rest is protected.	▪ Ability to execute cryptographic mechanisms of appropriate strength and performance. ▪ Ability to obtain and validate certificates. ▪ Ability to perform authenticated encryption algorithms. ▪ Ability to change keys securely. ▪ Ability to generate key pairs. ▪ Ability to store encryption keys securely. ▪ Ability to cryptographically store passwords at rest, as well as device identity and other authentication data. ▪ Ability to support data encryption and signing to prevent data from being altered in device storage. ▪ Ability to secure data stored locally on the device. ▪ Ability to secure data stored in remote storage areas (e.g., cloud, server). ▪ Ability to utilize separate storage partitions for system and user data.	▪ Providing detailed instructions for how to implement management and operational controls for securely handling and retaining IoT device data, associated systems data, and data output from the IoT device. ▪ Providing education describing how to securely handle and retain IoT device data, associated systems data, and data output from the IoT device to meet requirements of the IoT device customers' organizational security policies, contractual requirements, applicable Federal laws, Executive Orders, directives, policies, regulations, standards, and other legal requirements.	CIP-011-2-R2-R2

Cybersecurity Framework v1.1 Subcategory	Device Cybersecurity Capabilities	Manufacturer Nontechnical Supporting Capabilities	Related NERC CIP ID(s)
	▪ Ability to protect the audit information through mechanisms such as: ○ encryption ○ digitally signing audit files ○ securely sending audit files to another device ○ other protections created by the device manufacturer		
PR.DS-2: Data in transit is protected.	▪ Ability to execute cryptographic mechanisms of appropriate strength and performance. ▪ Ability to perform authenticated encryption algorithms. ▪ Ability to change keys securely. ▪ Ability to store encryption keys securely. ▪ Ability to support trusted data exchange with a specified minimum-strength cryptography algorithm. ▪ Ability to support data encryption and signing to prevent data from being altered in transit. ▪ Ability to protect transmitted data from unauthorized access and modification. ▪ Ability to use cryptographic means to validate the integrity of data transmitted. ▪ Ability to protect the audit information through mechanisms such as: ○ encryption ○ digitally signing audit files ○ securely sending audit files to another device ○ other protections created by the device manufacturer	▪ Providing documentation and/or other communications describing how to implement management and operational controls to protect data obtained from IoT devices and associated systems from unauthorized access, modification, and deletion. ▪ Providing education describing how to securely handle and retain IoT device data, associated systems data, and data output from the IoT device to meet requirements of the IoT device customers' organizational security policies, contractual requirements, applicable Federal laws, Executive Orders, directives, policies, regulations, standards, and other legal requirements.	CIP-003-7-R2 CIP-004-6-R4 CIP-004-6-R5 CIP-005-5-R1 CIP-005-5-R2 CIP-011-2-R1
PR.DS-6: Integrity checking mechanisms are used to verify software, firmware, and information integrity.	▪ Ability to identify software loaded on the IoT device based on IoT device identity. ▪ Ability to verify digital signatures. ▪ Ability to run hashing algorithms. ▪ Ability to perform authenticated encryption algorithms. ▪ Ability to compute and compare hashes.	▪ Providing documentation and/or other communications describing how to implement management and operational controls to protect data obtained from IoT devices and associated systems from unauthorized access, modification, and deletion.	CIP-010-2-R1 CIP-010-3-R1 CIP-010-2-R2 CIP-011-2-R1 CIP-013-1-R1

Cybersecurity Framework v1.1 Subcategory	Device Cybersecurity Capabilities	Manufacturer Nontechnical Supporting Capabilities	Related NERC CIP ID(s)
	▪ Ability to utilize one or more capabilities to protect transmitted data from unauthorized access and modification. ▪ Ability to validate the integrity of data transmitted. ▪ Ability to verify software updates come from valid sources by using an effective method (e.g., digital signatures, checksums, certificate validation). ▪ Ability to verify and authenticate any update before installing it. ▪ Ability to store the operating environment (e.g., firmware image, software, applications) in read-only media (e.g., Read Only Memory).	▪ Providing communications to IoT device customers describing how to implement management and operational controls to protect IoT device data integrity and associated systems data integrity. ▪ Providing IoT device customers with the details necessary to support secure implementation of the IoT device and associated systems data integrity controls. ▪ Providing IoT device customers with documentation describing the data integrity controls built into the IoT device and how to use them. If there are no data integrity controls built into the IoT device, include documentation explaining to IoT device customers the ways to achieve IoT device data integrity. ▪ Providing details for how to review and update the IoT device and associated systems while preserving data integrity.	
DE.AE-1: A baseline of network operations and expected data flows for users and systems is established and managed.	N/A	▪ Providing documentation describing how to implement and securely deploy monitoring devices and tools for IoT devices and associated systems.	N/A
DE.AE-2: Detected events are analyzed to understand attack targets and methods.	N/A	▪ Providing documentation describing IoT device behavior indicators that could occur when an attack is being launched.	CIP-003-7-R2 CIP-005-5-R1 CIP-007-6-R4 CIP-008-5-R1 CIP-008-5-R2 CIP-008-5-R4

Cybersecurity Framework v1.1 Subcategory	Device Cybersecurity Capabilities	Manufacturer Nontechnical Supporting Capabilities	Related NERC CIP ID(s)
DE.AE-3: Event data are collected and correlated from multiple sources and sensors.	▪ Ability to provide a physical indicator of sensor use. ▪ Ability to send requested audit logs to an external audit process or information system (e.g., where its auditing information can be checked to allow for review, analysis, and reporting). ▪ Ability to keep an accurate internal system time.	▪ Providing documentation describing the types of usage and environmental systems data that can be collected from the IoT device.	CIP-007-6-R4
DE.AE-5: Incident alert thresholds are established.	▪ Ability to generate alerts for specific events. ▪ Ability to differentiate between when a device will likely operate as expected from when it may be in a degraded cybersecurity state.	N/A	CIP-007-6-R4 CIP-007-6-R5 CIP-008-5-R1
DE.CM-1: The information system and assets are monitored to identify cybersecurity events and verify the effectiveness of protective measures.	▪ Ability to monitor specific actions based on the IoT device identity. ▪ Ability to access information about the IoT device's cybersecurity state and other necessary data. ▪ Ability to monitor for organizationally defined cybersecurity events (e.g., expected state change) that may occur on or involving the IoT device. ▪ Ability to support a monitoring process to check for disclosure of organizational information to unauthorized entities. (The device may be able to perform this check itself or provide the information necessary for an external process to check). ▪ Ability to monitor communications traffic.	▪ Providing information that describes the types of system monitoring information generated from, or associated with, the IoT device and instructions for obtaining that information. ▪ Providing documentation describing the types of monitoring tools with which the IoT device is compatible, and recommendations for how to configure the IoT device to best work with such monitoring tools. ▪ Providing the details necessary to monitor IoT devices and associated systems. ▪ Providing documentation describing how to perform monitoring activities.	CIP-005-5-R1
DE.CM-2: The physical environment is monitored to detect potential cybersecurity events.	N/A	▪ Providing descriptions of the types of physical access practices, and manufacturer suggested hardware or other types of devices, that can be used to prevent unauthorized physical access to the IoT device. ▪ Providing descriptions of the physical access security procedures the manufacturer recommends for limiting physical access to the device and to associated device controls. ▪ Providing details of indications, and recommendations for how to determine, when unauthorized	CIP-003-7-R2 CIP-006-6-R1 CIP-006-6-R2 CIP-014-2-R5

Cybersecurity Framework v1.1 Subcategory	Device Cybersecurity Capabilities	Manufacturer Nontechnical Supporting Capabilities	Related NERC CIP ID(s)
		physical access to the IoT device was or is attempted or is occurring.	
DE.CM-4: Malicious code is detected.	N/A	▪ Providing education for how to implement malicious code protection in the IoT device and associated systems as well as how to detect and eradicate malicious code. ▪ Providing education for how to update the IoT device and related systems malicious code protection mechanisms when new releases are available, in accordance with organizational configuration management policy and procedures. ▪ If the IoT device manufacturer provides anti-malware for the associated IoT device, or if the IoT device has built-in anti-malware capabilities, the manufacturer should provide education to IoT device customers describing how to use and/or configure malicious code protection mechanisms in IoT devices, supporting anti-malware tools, and related systems. ▪ Providing education that include the details necessary to implement management and operational controls for malicious code detection and eradication.	CIP-003-7-R2 CIP-007-6-R3 CIP-007-6-R4 CIP-010-2-R4
DE.CM-7: Monitoring for unauthorized personnel, connections, devices, and software is performed.	▪ Ability to support a monitoring process to check for disclosure of organizational information to unauthorized entities. (The device may be able to perform this check itself or provide the information necessary for an external process to check). ▪ Ability to monitor changes to the configuration settings. ▪ Ability to detect remote activation attempts. ▪ Ability to detect remote activation of sensors. ▪ Ability to take organizationally defined actions when unauthorized hardware and software components are detected	▪ Providing appropriate tools, assistance, instructions, or other details describing the capabilities for monitoring the IoT device and/or for the IoT device customer to report actions to the monitoring service of the manufacturer’s supporting entity. ▪ Providing the details necessary to monitor IoT devices and associated systems. ▪ Providing documentation describing details necessary to identify unauthorized use of IoT devices and their associated systems.	CIP-003-7-R2 CIP-005-5-R1 CIP-006-6-R1 CIP-007-6-R3 CIP-007-6-R4 CIP-007-6-R5 CIP-013-3-R2 CIP-010-2-R4

Cybersecurity Framework v1.1 Subcategory	Device Cybersecurity Capabilities	Manufacturer Nontechnical Supporting Capabilities	Related NERC CIP ID(s)
	(e.g., disallow a flash drive to be connected even if a Universal Serial Bus [USB] port is present).	▪ Providing documentation that describes indicators of unauthorized use of the IoT device.	

C.2 Device Capabilities Supporting Security Characteristic Analysis Test Scenarios

Table 5-8 below builds on the security characteristic analysis test scenarios included in Section 5.2 of this document. The table lists both **device cybersecurity capabilities** and **nontechnical supporting capabilities** that map to the requirements for each of the test scenarios. If IoT devices are integrated into an IIoT DER ecosystem, selecting devices and/or third parties that provide these capabilities can help achieve the respective test scenario requirements.

It is acknowledged that IoT devices vary in their capabilities, and there may not be a clear delineation between the **device cybersecurity capabilities** that are provided by the IoT devices and those provided by another system component. It is also understood that the capabilities of cyber-physical components are evolving, so many of the mappings are not necessarily exact.

It is acknowledged that many of the **device cybersecurity capabilities** may not be available in some IoT devices and that other system elements (e.g., proxies, gateways) or other risk mitigation strategies (e.g., network segmentation) may be necessary. It is also understood that not every capability in the table is applicable to every use case. The table provides utilities and/or DER operators a listing of technical and nontechnical capabilities that might be important in IIoT DER ecosystems.

Table 5-2 - Device Cybersecurity Capabilities and Nontechnical Supporting Capabilities that Map to Each of the Security Test Scenarios

Scenario ID and Description with CSF Subcategories	Device Cybersecurity Capabilities	Manufacturer Nontechnical Supporting Capabilities
Scenario 1: Communication between the utility and a DER is secure: This test case will verify that authenticated and authorized systems on the utility network can communicate with a DER connected to the microgrid network.	▪ Ability to uniquely identify the IoT device logically. ▪ Ability to uniquely identify a remote IoT device. ▪ Ability for the device to support a unique device ID. ▪ Ability to configure IoT device access control policies using IoT device identity. ▪ Ability to verify the identity of an IoT device. ▪ Ability to add a unique physical identifier at an external or internal location on the device authorized entities can access. ▪ Ability to set and change authentication configurations, policies, and limitations settings for the IoT device. ▪ Ability to revoke access to the device. ▪ Ability to create unique IoT device user accounts. ▪ Ability to identify unique IoT device user accounts. ▪ Ability to create organizationally defined accounts that support privileged roles with automated expiration conditions. ▪ Ability to configure IoT device access control policies using IoT device identity. ▪ Ability to authenticate external users and systems. ▪ Ability to securely interact with authorized external, third-party systems. ▪ Ability to identify when an external system meets the required security requirements for a connection. ▪ Ability to establish secure communications with internal systems when the device is operating on external networks. ▪ Ability to establish requirements for remote access to the IoT device and/or IoT device interface. ▪ Ability to enforce the established local and remote access requirements. ▪ Ability to prevent external access to the IoT device management interface. ▪ Ability to assign roles to IoT device user accounts.	▪ Providing communications and documentation detailing how to perform account management activities, using the technical IoT device capabilities, or through supporting systems and/or tools. ▪ Providing the details necessary to establish and implement unique identification for each IoT device associated with the system and critical system components within which it is used. ▪ Providing the tools, assistance, instructions, and other types of information to support establishing a hierarchy of role-based privileges within the IoT device. ▪ Providing details about the specific types of manufacturer's needs to access the IoT device interfaces, such as for specific support, updates, ongoing maintenance, and other purposes. ▪ Providing education explaining how to control access to IoT devices implemented within IoT device customer information systems. ▪ Providing education explaining how to enforce authorized access at the system level. ▪ Providing detailed instructions and guidance for establishing activities performed by the IoT device that do not require identification or authentication. ▪ Providing documentation describing the specific IoT platforms used with the device to support required IoT authentication control techniques. ▪ Providing documentation with details describing external authentication by IoT platforms and associated authentication methods that can be used with the IoT device

Scenario ID and Description with CSF Subcategories	Device Cybersecurity Capabilities	Manufacturer Nontechnical Supporting Capabilities
	▪ Ability to support a hierarchy of logical access privileges for the IoT device based on roles. ▪ Ability to apply least privilege to user accounts ▪ Ability to enable automation and reporting of account management activities.	

Scenario 2: Integrity of Command Register data and communications is verified:
This test case will verify data providence and integrity across the system for commands being exchanged between the utility and the DER microgrid.
	▪ Ability to execute cryptographic mechanisms of appropriate strength and performance.
	▪ Ability to obtain and validate certificates.
	▪ Ability to change keys securely.
	▪ Ability to generate key pairs.
	▪ Ability to store encryption keys securely.
	▪ Ability to cryptographically store passwords at rest, as well as device identity and other authentication data.
	▪ Ability to support data encryption and signing to prevent data from being altered in device storage.
	▪ Ability to secure data stored locally on the device.
	▪ Ability to secure data stored in remote storage areas (e.g., cloud, server).
	▪ Ability to utilize separate storage partitions for system and user data.
	▪ Ability to protect the audit information through mechanisms such as:
	  ○ encryption
	  ○ digitally signing audit files
	  ○ securely sending audit files to another device
	  ○ other protections created by the device manufacturer
	▪ Ability to support trusted data exchange with a specified minimum-strength cryptography algorithm.
	▪ Ability to support data encryption and signing to prevent data from being altered in transit.
	▪ Ability to protect transmitted data from unauthorized access and modification.
	▪ Ability to use cryptographic means to validate the integrity of data transmitted.
	▪ Ability to identify software loaded on the IoT device based on IoT device identity
		▪ Providing detailed instructions for securely handling and retaining IoT device data, associated systems data, and data output from the IoT device.
		▪ Providing education describing how to securely handle and retain IoT device data, associated systems data, and data output from the IoT device to meet requirements of the IoT device customers' organizational security policies, contractual requirements, applicable Federal laws, Executive Orders, directives, policies, regulations, standards, and other legal requirements.
		▪ Providing documentation and/or other communications describing how to protect data obtained from IoT devices and associated systems from unauthorized access, modification, and deletion.
		▪ Providing communications to IoT device customers describing how to protect IoT device data integrity and associated systems data integrity.
		▪ Providing IoT device customers with the details necessary to support secure implementation of the IoT device and associated systems data integrity controls.
		▪ Providing IoT device customers with documentation describing the data integrity controls built into the IoT device and how to use them. If there are no data integrity controls built into the IoT device, include documentation explaining to IoT device customers the ways to achieve IoT device data integrity.
		▪ Providing details for how to review and update the IoT device and associated systems while preserving data integrity.

Scenario ID and Description with CSF Subcategories	Device Cybersecurity Capabilities	Manufacturer Nontechnical Supporting Capabilities
	▪ Ability to verify digital signatures. ▪ Ability to run hashing algorithms. ▪ Ability to perform authenticated encryption algorithms. ▪ Ability to compute and compare hashes. ▪ Ability to utilize one or more capabilities to protect transmitted data from unauthorized access and modification. ▪ Ability to validate the integrity of data transmitted. ▪ Ability to verify software updates come from valid sources by using an effective method (e.g., digital signatures, checksums, certificate validation). ▪ Ability to verify and authenticate any update before installing it. ▪ Ability to store the operating environment (e.g., firmware image, software, applications) in read-only media (e.g., Read Only Memory).	
Scenario 3: Log file information can be captured and analyzed: This test case will verify the capabilities of capturing and analyzing log data within the microgrid network.	▪ Ability to provide a physical indicator of sensor use. ▪ Ability to send requested audit logs to an external audit process or information system (e.g., where its auditing information can be checked to allow for review, analysis, and reporting). ▪ Ability to keep an accurate internal system time. ▪ Ability to generate alerts for specific events. ▪ Ability to differentiate between when a device will likely operate as expected from when it may be in a degraded cybersecurity state.	▪ Providing documentation describing how to implement and securely deploy monitoring devices and tools for IoT devices and associated systems. ▪ Providing documentation describing IoT device behavior indicators that could occur when an attack is being launched. ▪ Providing documentation describing the types of usage and environmental systems data that can be collected from the IoT device.
Scenario 4: Log file analysis can be shared: This test case will verify that the log analysis findings can be shared through proper channels.	▪ Ability to provide a physical indicator of sensor use. ▪ Ability to send requested audit logs to an external audit process or information system (e.g., where its auditing information can be checked to allow for review, analysis, and reporting). ▪ Ability to keep an accurate internal system time. ▪ Ability to generate alerts for specific events. ▪ Ability to differentiate between when a device will likely operate as expected from when it may be in a degraded cybersecurity state.	▪ Providing documentation describing how to implement and securely deploy monitoring devices and tools for IoT devices and associated systems. ▪ Providing documentation describing IoT device behavior indicators that could occur when an attack is being launched. ▪ Providing documentation describing the types of usage and environmental systems data that can be collected from the IoT device.

Scenario ID and Description with CSF Subcategories	Device Cybersecurity Capabilities	Manufacturer Nontechnical Supporting Capabilities
Scenario 5: Malicious activity is detected: This test case will verify the system's ability to detect anomalous or malicious behavior on the network.	▪ Ability to provide a physical indicator of sensor use. ▪ Ability to send requested audit logs to an external audit process or information system (e.g., where its auditing information can be checked to allow for review, analysis, and reporting). ▪ Ability to keep an accurate internal system time. ▪ Ability to generate alerts for specific events. ▪ Ability to differentiate between when a device will likely operate as expected from when it may be in a degraded cybersecurity state. ▪ Ability to monitor specific actions based on the IoT device identity. ▪ Ability to access information about the IoT device's cybersecurity state and other necessary data. ▪ Ability to monitor for organizationally defined cybersecurity events (e.g., expected state change) that may occur on or involving the IoT device. ▪ Ability to support a monitoring process to check for disclosure of organizational information to unauthorized entities. ▪ Ability to monitor communications traffic. ▪ Ability to support a monitoring process to check for disclosure of organizational information to unauthorized entities. ▪ Ability to monitor changes to the configuration settings. ▪ Ability to detect remote activation attempts. ▪ Ability to detect remote activation of sensors. ▪ Ability to take organizationally defined actions when unauthorized hardware and software components are detected (e.g., disallow a flash drive to be connected even if a Universal Serial Bus [USB] port is present).	▪ Providing documentation describing how to implement and securely deploy monitoring devices and tools for IoT devices and associated systems. ▪ Providing documentation describing IoT device behavior indicators that could occur when an attack is being launched. ▪ Providing documentation describing the types of usage and environmental systems data that can be collected from the IoT device. ▪ Providing information that describes the types of system monitoring information generated from, or associated with, the IoT device and instructions for obtaining that information. ▪ Providing documentation describing the types of monitoring tools with which the IoT device is compatible, and recommendations for how to configure the IoT device to best work with such monitoring tools. ▪ Providing the details necessary to monitor IoT devices and associated systems. ▪ Providing documentation describing how to perform monitoring activities. ▪ Providing education for how to implement malicious code protection in the IoT device and associated systems as well as how to detect and eradicate malicious code. ▪ Providing education for how to update the IoT device and related systems malicious code protection mechanisms when new releases are available, in accordance with organizational configuration management policy and procedures. ▪ Providing the details necessary to monitor IoT devices and associated systems. ▪ Providing documentation describing details necessary to identify unauthorized use of IoT devices and their associated systems. ▪ Providing documentation that describes indicators of unauthorized use of the IoT device.

Scenario ID and Description with CSF Subcategories	Device Cybersecurity Capabilities	Manufacturer Nontechnical Supporting Capabilities
Scenario 6: Privileged user access is managed: This test case will verify that privileged users are authenticated and authorized to access only those devices to which they have been given proper privileges. **PR.AC-1** **PR.AC-3** **PR.AC-4** **PR.AC-5**	▪ Ability to uniquely identify the IoT device logically. ▪ Ability to uniquely identify a remote IoT device. ▪ Ability for the device to support a unique device ID. ▪ Ability to configure IoT device access control policies using IoT device identity. ▪ Ability to verify the identity of an IoT device. ▪ Ability to add a unique physical identifier at an external or internal location on the device authorized entities can access. ▪ Ability to set and change authentication configurations, policies, and limitations settings for the IoT device. ▪ Ability to revoke access to the device. ▪ Ability to create unique IoT device user accounts. ▪ Ability to identify unique IoT device user accounts. ▪ Ability to create organizationally defined accounts that support privileged roles with automated expiration conditions. ▪ Ability to configure IoT device access control policies using IoT device identity. ▪ Ability to authenticate external users and systems. ▪ Ability to securely interact with authorized external, third-party systems. ▪ Ability to identify when an external system meets the required security requirements for a connection. ▪ Ability to establish secure communications with internal systems when the device is operating on external networks. ▪ Ability to establish requirements for remote access to the IoT device and/or IoT device interface. ▪ Ability to enforce the established local and remote access requirements. ▪ Ability to prevent external access to the IoT device management interface. ▪ Ability to assign roles to IoT device user accounts. ▪ Ability to support a hierarchy of logical access privileges for the IoT device based on roles. ▪ Ability to apply least privilege to user accounts	▪ Providing communications and documentation detailing how to perform account management activities, using the technical IoT device capabilities, or through supporting systems and/or tools. ▪ Providing the details necessary to establish and implement unique identification for each IoT device associated with the system and critical system components within which it is used. ▪ Providing the tools, assistance, instructions, and other types of information to support establishing a hierarchy of role-based privileges within the IoT device. ▪ Providing details about the specific types of manufacturer's needs to access the IoT device interfaces, such as for specific support, updates, ongoing maintenance, and other purposes. ▪ Providing education explaining how to control access to IoT devices implemented within IoT device customer information systems. ▪ Providing education explaining how to enforce authorized access at the system level. ▪ Providing detailed instructions and guidance for establishing activities performed by the IoT device that do not require identification or authentication. ▪ Providing documentation describing the specific IoT platforms used with the device to support required IoT authentication control techniques. ▪ Providing documentation with details describing external authentication by IoT platforms and associated authentication methods that can be used with the IoT device

Scenario ID and Description with CSF Subcategories	Device Cybersecurity Capabilities	Manufacturer Nontechnical Supporting Capabilities
	▪ Ability to enable automation and reporting of account management activities.	

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NIST SPECIAL PUBLICATION 1800-32C

Securing the Industrial Internet of Things:

Cybersecurity for Distributed Energy Resources

Volume C:
How-To Guides

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DRAFT

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https://www.nccoe.nist.gov/iiot

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National Institute of Standards and Technology Special Publication 1800-32C, Natl. Inst. Stand. Technol. Spec. Publ. 1800-32C, 65 pages, (September 2021), CODEN: NSPUE2

FEEDBACK

You can improve this guide by contributing feedback. As you review and adopt this solution for your own organization, we ask you and your colleagues to share your experience and advice with us.

Comments on this publication may be submitted to: energy_nccoe@nist.gov.

Public comment period: September 21, 2021, through October 20, 2021

All comments are subject to release under the Freedom of Information Act.

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NATIONAL CYBERSECURITY CENTER OF EXCELLENCE

The National Cybersecurity Center of Excellence (NCCoE), a part of the National Institute of Standards and Technology (NIST), is a collaborative hub where industry organizations, government agencies, and academic institutions work together to address businesses' most pressing cybersecurity issues. This public-private partnership enables the creation of practical cybersecurity solutions for specific industries, as well as for broad, cross-sector technology challenges. Through consortia under Cooperative Research and Development Agreements (CRADAs), including technology partners—from Fortune 50 market leaders to smaller companies specializing in information and operational technology security—the NCCoE applies standards and best practices to develop modular, adaptable example cybersecurity solutions using commercially available technology. The NCCoE documents these example solutions in the NIST Special Publication 1800 series, which maps capabilities to the NIST Cybersecurity Framework and details the steps needed for another entity to re-create the example solution. The NCCoE was established in 2012 by NIST in partnership with the State of Maryland and Montgomery County, Maryland.

To learn more about the NCCoE, visit https://www.nccoe.nist.gov/. To learn more about NIST, visit https://www.nist.gov.

NIST CYBERSECURITY PRACTICE GUIDES

NIST Cybersecurity Practice Guides (Special Publication 1800 series) target specific cybersecurity challenges in the public and private sectors. They are practical, user-friendly guides that facilitate adoption of standards-based approaches to cybersecurity. They show members of the information security community how to implement example solutions that help them align with relevant standards and best practices, and provide users with the materials lists, configuration files, and other information they need to implement a similar approach.

The documents in this series describe example implementations of cybersecurity practices that businesses and other organizations may voluntarily adopt. These documents do not describe regulations or mandatory practices, nor do they carry statutory authority.

ABSTRACT

The Industrial Internet of Things (IIoT) refers to the application of instrumentation and connected sensors and other devices to machinery and vehicles in the transport, energy, and other critical infrastructure sectors. In the energy sector, distributed energy resources (DERs) such as solar photovoltaics including sensors, data transfer and communications systems, instruments, and other commercially available devices that are networked together. DERs introduce information exchanges between a utility's distribution control system and the DERs to manage the flow of energy in the distribution grid.

This practice guide explores how information exchanges among commercial- and utility-scale DERs and electric distribution grid operations can be monitored and protected from certain cybersecurity threats and vulnerabilities.

The NCCoE built a reference architecture using commercially available products to show organizations how several cybersecurity capabilities, including communications and data integrity, malware detection, network monitoring, authentication and access control, and cloud-based analysis and visualization can be applied to protect distributed end points and reduce the IIoT attack surface for DERs.

KEYWORDS

data integrity; distributed energy resource; industrial internet of things; malware; microgrid; smart grid

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The Technology Partners/Collaborators who participated in this build submitted their capabilities in response to a notice in the Federal Register. Respondents with relevant capabilities or product components were invited to sign a Cooperative Research and Development Agreement (CRADA) with NIST, allowing them to participate in a consortium to build this example solution. We worked with:

Technology Partner/Collaborator	Product
Anterix	LTE infrastructure and communications on wireless broadband
Cisco	Cisco Identity Services Engine; Cisco Cyber Vision; Cisco Firepower Threat Defense
Dots and Bridges	subject matter expertise
Radiflow	iSID Industrial Threat Detection
Spherical Analytics	Immutably™, Proofworks™, and Scrivener™

Technology Partner/Collaborator	Product
Sumo Logic	Sumo Logic Enterprise
TDi Technologies	ConsoleWorks
University of Maryland	campus DER microgrid infrastructure
Xage Security	Xage Security Fabric

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The terms "shall" and "shall not" indicate requirements to be followed strictly to conform to the publication and from which no deviation is permitted. The terms "should" and "should not" indicate that among several possibilities, one is recommended as particularly suitable without mentioning or excluding others, or that a certain course of action is preferred but not necessarily required, or that (in the negative form) a certain possibility or course of action is discouraged but not prohibited. The terms "may" and "need not" indicate a course of action permissible within the limits of the publication. The terms "can" and "cannot" indicate a possibility and capability, whether material, physical, or causal.

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This public review includes a call for information on essential patent claims (claims whose use would be required for compliance with the guidance or requirements in this Information Technology Laboratory (ITL) draft publication). Such guidance and/or requirements may be directly stated in this ITL Publication or by reference to another publication. This call also includes disclosure, where known, of the existence of pending U.S. or foreign patent applications relating to this ITL draft publication and of any relevant unexpired U.S. or foreign patents.

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Such statements should be addressed to: energy_nccoe@nist.gov

Contents

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1 Introduction

This volume of the guide shows information technology (IT) professionals and security engineers how we implemented the example solution. We cover all of the products employed in this reference design. We do not re-create the product manufacturers' documentation, which is presumed to be widely available. Rather, these volumes show how we incorporated the products together in our environment.

Note: These are not comprehensive tutorials. There are many possible service and security configurations for these products that are out of scope for this reference design.

1.1 How to Use this Guide

This National Institute of Standards and Technology (NIST) Cybersecurity Practice Guide demonstrates a standards-based reference architecture and provides users with the information they need to use this architecture to ensure trustworthy information exchange between a utility's distribution operations systems and a microgrid control system. This reference architecture is modular and can be deployed in whole or in part.

This guide contains three volumes:

- NIST Special Publication (SP) 1800-32A: Executive Summary
- NIST SP 1800-32B: Approach, Architecture, and Security Characteristics – what we built and why
- NIST SP 1800-32C: How-To Guides – instructions for building the example solution (**you are here**)

Depending on your role in your organization, you might use this guide in different ways:

Business decision makers, including chief security and technology officers, will be interested in the *Executive Summary, NIST SP 1800-32A*, which describes the following topics:

- challenges utilities and microgrid operators can face in securely exchanging control and status information
- example solution built at the National Cybersecurity Center of Excellence (NCCoE)
- benefits of adopting the example solution

Technology or security program managers who are concerned with how to identify, understand, assess, and mitigate risk will be interested in *NIST SP 1800-32B*, which describes what we did and why. The following sections will be of particular interest:

- Section 3.4, Risk Assessment, describes the risk analysis we performed.
- Section 3.4.4, Security Control Map and Technologies, maps the security characteristics of this reference architecture to cybersecurity standards and best practices.

You might share the *Executive Summary, NIST SP 1800-32A*, with your leadership team members to help them understand the importance of adopting standards-based approaches to trustworthy information exchanges between distribution operations (distribution ops) and microgrid control systems.

IT and operational technology (OT) professionals who want to implement an approach like this will find this whole practice guide useful. You can use this How-To portion of the guide, *NIST SP 1800-32C*, to replicate all or parts of the example solution created in our lab. This How-To portion of the guide provides specific product installation, configuration, and integration instructions for implementing the example solution. We do not recreate the product manufacturers' documentation, which is generally widely available. Rather, we show how we incorporated the products together in our environment to create an example solution.

This guide assumes that IT and OT professionals have experience implementing security products within the enterprise. While we have used a suite of commercial products to address this challenge, this guide does not endorse these particular products. Your organization can adopt this solution or one that adheres to these guidelines in whole, or you can use this guide as a starting point for tailoring and implementing parts of the example solution to provide trustworthy information exchanges. Your organization's security experts should identify the products that will best integrate with your existing tools and OT infrastructure. We hope that you will seek products that are congruent with applicable standards and best practices. Section 2, Product Installation Guides, lists the products that we used and explain how they are used in the example solution to implement the reference architecture.

A NIST Cybersecurity Practice Guide does not describe "the" solution, but a possible solution. This is a draft guide. We seek feedback on its contents and welcome your input. Comments, suggestions, and success stories will improve subsequent versions of this guide. Please contribute your thoughts to energy_nccoe@nist.gov.

1.2 Typographic Conventions

The following table presents typographic conventions used in this volume.

Typeface/Symbol	Meaning	Example
Italics	file names and path names; references to documents that are not hyperlinks; new terms; and placeholders	For language use and style guidance, see the *NCCoE Style Guide*.
Bold	names of menus, options, command buttons, and fields	Choose **File > Edit.**
`Monospace`	command-line input, onscreen computer output, sample code examples, and status codes	`mkdir`
`Monospace Bold`	command-line user input contrasted with computer output	**`service sshd start`**
blue text	link to other parts of the document, a web URL, or an email address	All publications from NIST's NCCoE are available at https://www.nccoe.nist.gov.

1.3 Reference Architecture Summary

The reference architecture has three parts:

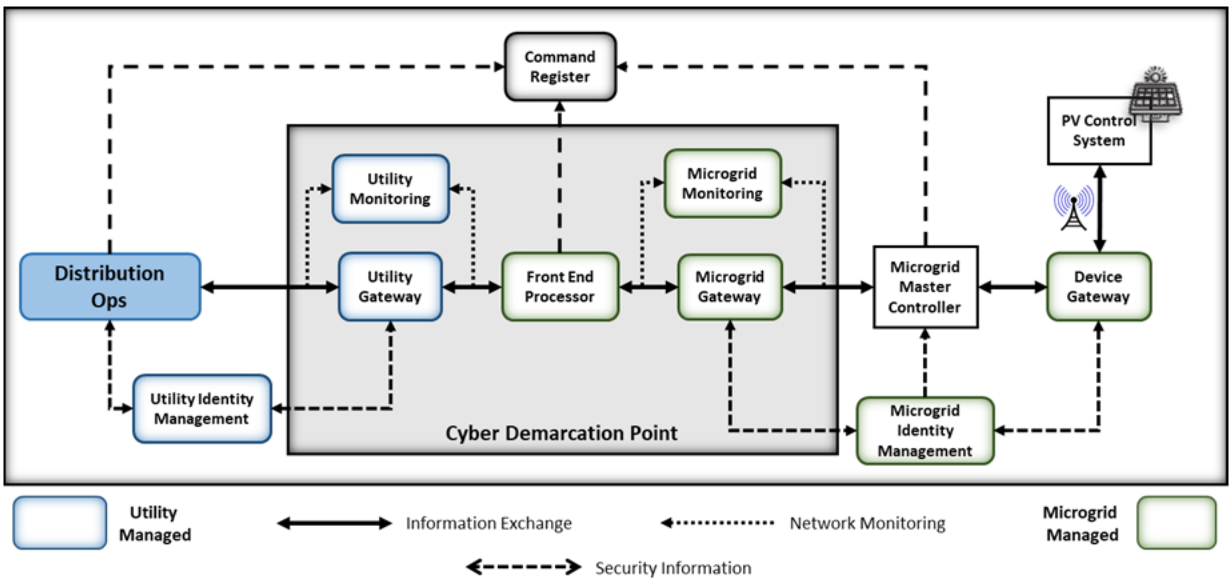
- information exchange, monitoring, and command register (Figure 1-1)
- log collection, data analysis and visualization (Figure 1-2)
- privileged user management (Figure 1-3)

The information exchange, monitoring, and command register portion of the architecture provides those gateway (GW) elements that ensure only authorized entities can exchange information, monitoring elements that detect anomalous and potentially malicious activities, and a command register that captures a complete record of all information exchanges. This portion of the reference architecture consists of:

- The **utility GW** component implements the utility's access policy.
- The **front-end processor** component receives information requests from the utility GW , records them in the command register, and forwards them to the microgrid GW.
- The **microgrid GW** component implements the microgrid access policy.
- The **utility cyber monitoring** component examines network and application traffic on the utility network and alerts utility cybersecurity personnel if anomalous activity is detected.

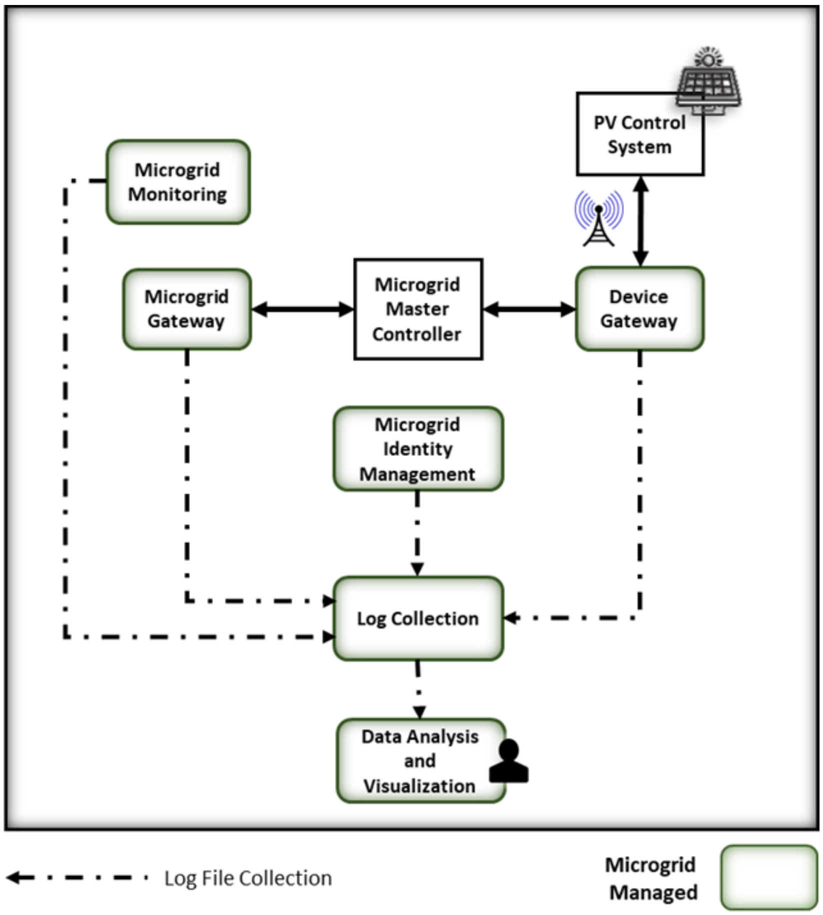
- The **microgrid cyber monitoring** component examines network and application traffic on the microgrid network and alerts microgrid cybersecurity personnel if anomalous activity is detected.
- The **distribution ops systems** record every information exchange they originate in the command register.
- The **microgrid master controller** records every information exchange it receives from the microgrid GW in the command register and forwards appropriate commands to the device GW.
- The **device GW** implements a device-specific access policy.
- * The **command register** records all information exchanges in a distributed ledger.
- The **PV control system** controls the photovoltaic (PV) Distributed Energy Resource (DER).

Figure 1-1 Information Exchange, Monitoring, and Command Register



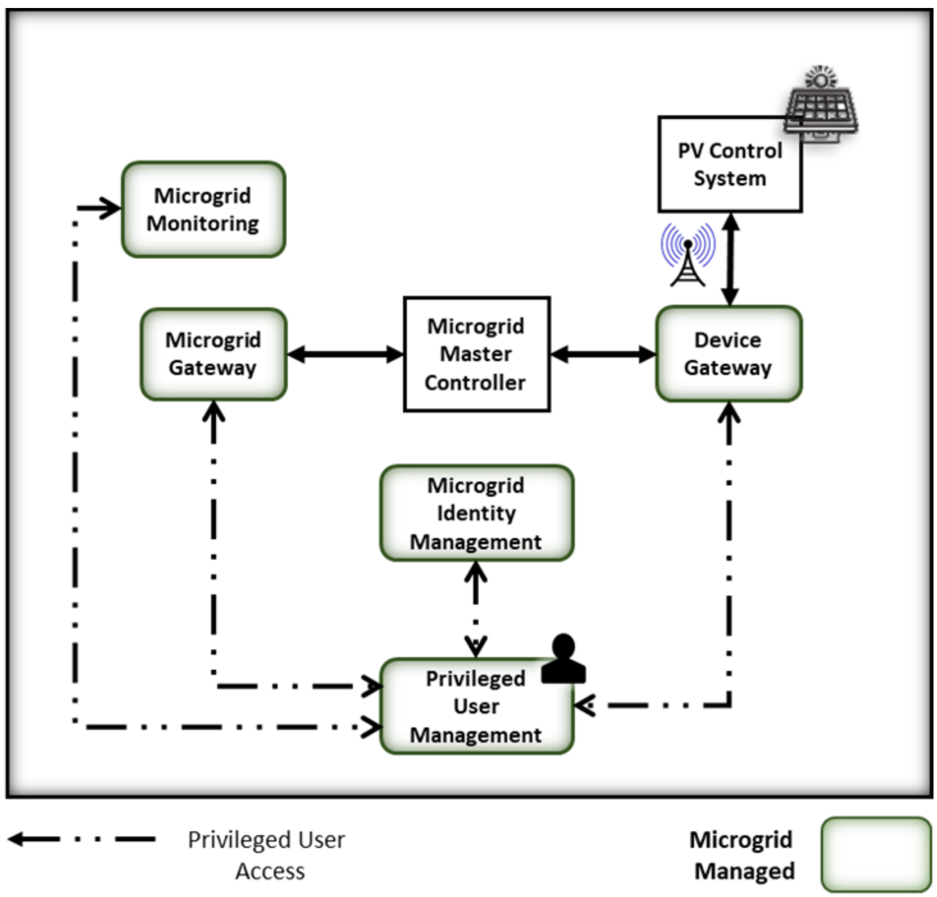
The log collection, data analysis and visualization portion of the reference architecture provides security information and event management capabilities for the microgrid operator and the ability to selectively share security-relevant information with the utility platform. The microgrid GW, microgrid monitoring device GW, and microgrid identity management elements of the reference architecture report event information to a log collection element. The log collection element forwards event information to an analysis and visualization capability that detects anomalies and reports them to microgrid operations personnel.

Figure 1-2 Log Collection, Data Analysis, and Visualization



The privileged user management portion of the reference architecture provides capabilities to manage the privileged users responsible for installation, configuration, operation, and maintenance of elements of the reference architecture. Privileged user management capabilities protect privileged access credentials, control access to management interfaces, and provide accountability for all privileged user actions in managing products on the microgrid.

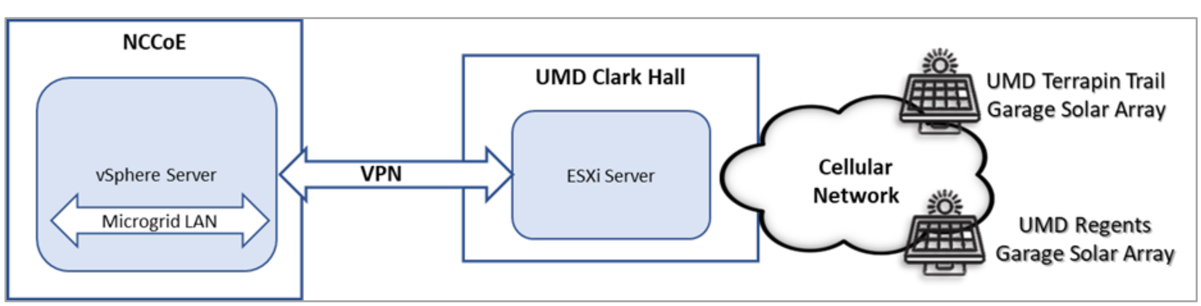
Figure 1-3 Privileged User Management



1.4 Laboratory Infrastructure

We constructed a laboratory prototype instance of the reference architecture, called the "example solution," to verify the design. The example solution is described in Section 1.5. The example solution consists of a combination of logical and physical infrastructure at the NCCoE and on the University of Maryland (UMD) campus. This section describes that laboratory infrastructure. Figure 1-4 presents a high-level overview of the project's lab infrastructure.

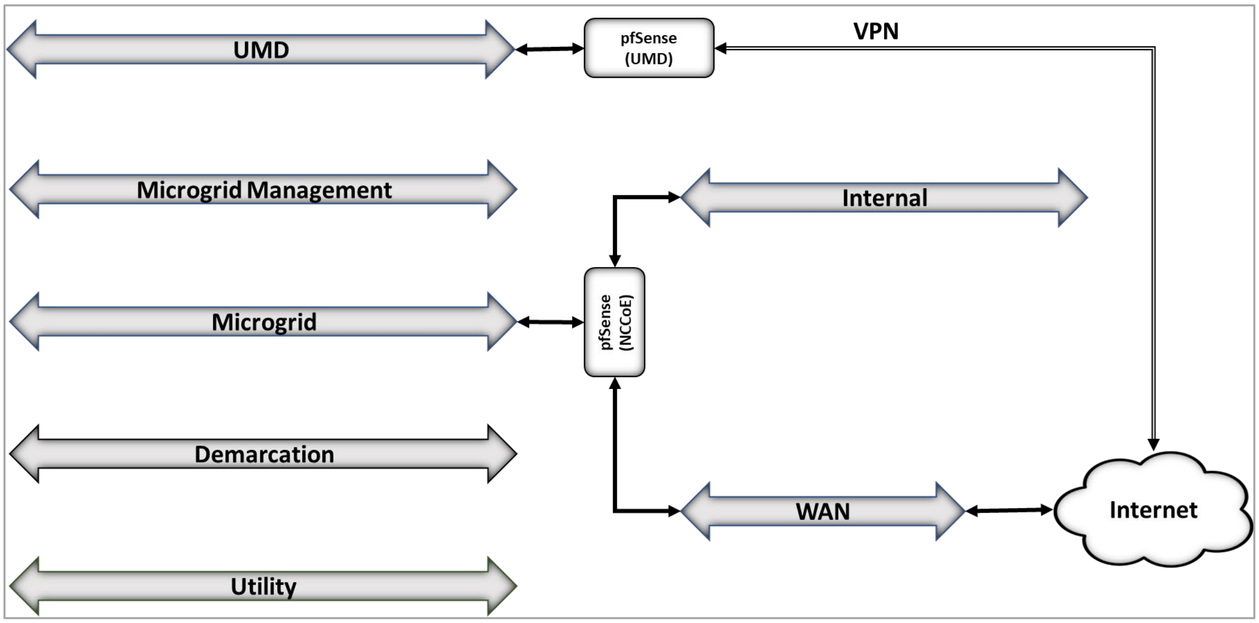
Figure 1-4 Overview of Laboratory Infrastructure



The core of our laboratory infrastructure is a virtual lab created in VMware vSphere 6.7. Within vSphere we defined several virtual networks. Each of these virtual networks represents a real-world network that would be part of a deployed instance of the reference architecture. Figure 1-5 illustrates these virtual networks.

A Virtual Private Network (VPN) connects the vSphere environment at NCCoE to UMD.

Figure 1-5 Project Virtual Networks

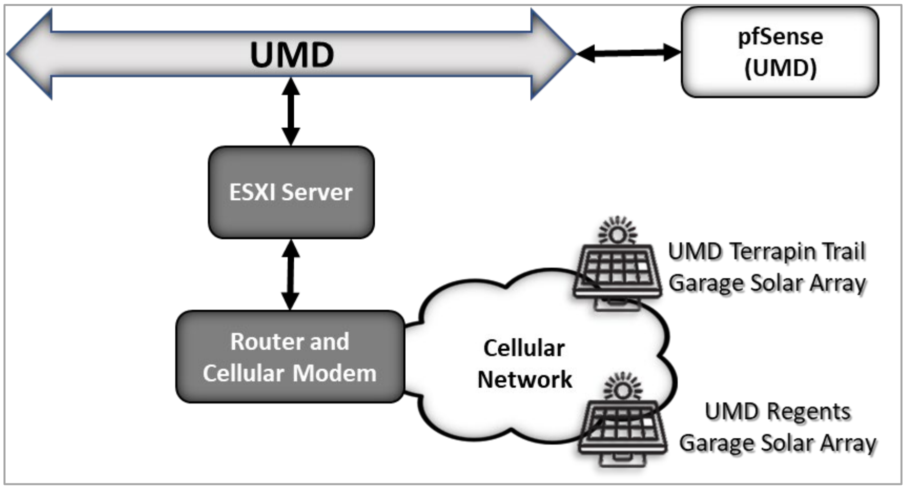


In addition to the core laboratory infrastructure, additional virtual and physical infrastructure was located at UMD’s Clark Hall, Terrapin Trail parking garage, and Regents parking garage. Each of the parking garages has a rooftop solar array.

A vmWare ESXI server on the UMD campus network allows us to deploy software to UMD. A cellular network connects the ESXI server to the solar arrays on the two UMD parking garages.

Figure 1-6 illustrates the extended infrastructure at UMD.

Figure 1-6 Project Infrastructure at UMD



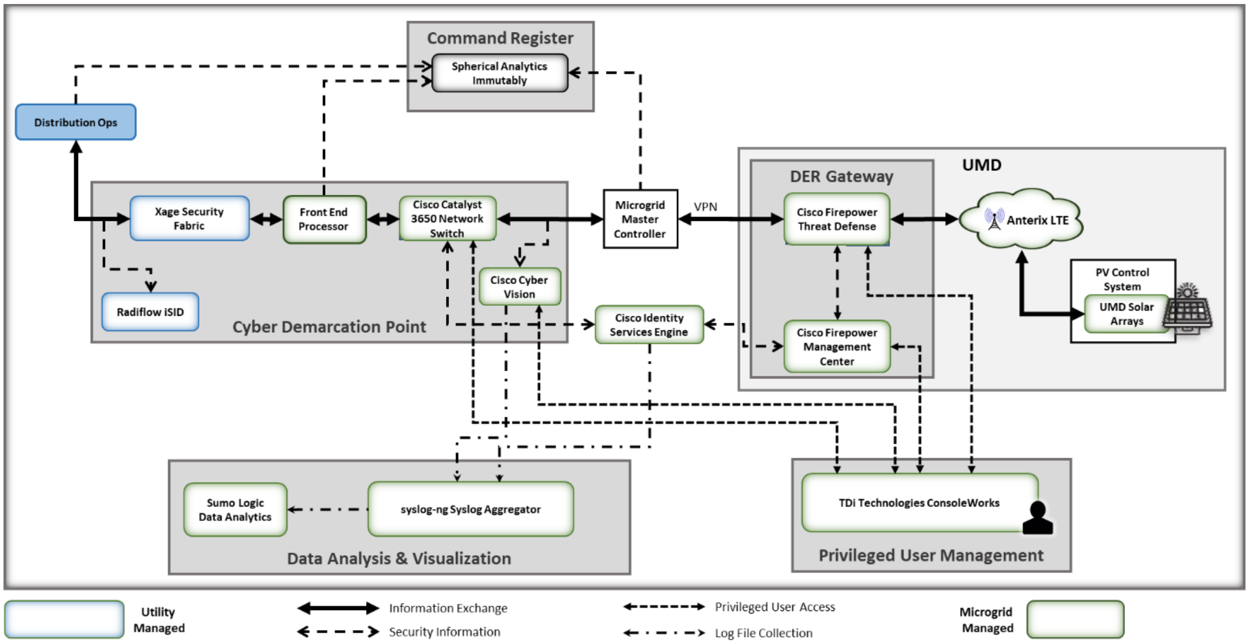
1.5 Example Solution Overview

Figure 1-7 shows how different products are integrated to create an implementation of the reference architecture referred to as the example solution.

The utility network and the cyber demarcation point of the reference architecture are represented in the example solution by virtual infrastructure in the NCCoE lab. The microgrid network is represented in the example solution by a virtual network in the NCCoE lab, the UMD campus network, and an LTE network installed on the UMD campus.

The components of the reference architecture's cyber demarcation are implemented using these products.

Figure 1-7 Commercial Products Integrated into Example Solution



The Xage Security Fabric is used to implement the utility identity management and utility GW component of the reference architecture. The Xage Security Fabric consists of five services, the Xage Broker, the Xage Manager, Xage Center nodes, a Xage Edge Node, and a Xage Enforcement Point. Installation and configuration of the Xage Security Fabric are described in Section 2.8.

Radiflow iSID is used to implement the utility monitoring component of the reference architecture. iSID is a single virtual appliance. Installation and configuration of Radiflow iSID are described in Section 2.4.1.

A Cisco Catalyst 3650 ISE-capable switch implements the microgrid GW component of the reference architecture. This switch requires the front-end processor to authenticate to connect. Further, the switch is policy enforcement point for access decisions made by ISE. ISE policy only allows the front-end processor to communicate with the Microgrid Master Controller.

A Cisco Firepower Threat Defense next-generation firewall implements the DER GW component of the reference architecture. This firewall requires the Microgrid Master Controller to authenticate to connect. Further, the firewall is a policy enforcement point for access decisions made by ISE. ISE policy only allows the Microgrid Master Controller to communicate with DERs.

Cisco Cyber Vision implements the microgrid monitoring component of the reference architecture. Cyber Vision is a single virtual appliance. Installation and configuration of Cisco Cyber Vision are described in Section 2.2.

The UMD solar arrays are not connected to the UMD campus network. Anterix designed and installed an LTE network to connect the solar arrays with our VPN enabling communication from the NCCoE lab to the solar arrays. Section 2.1 describes the Anterix design and implementation.

Cisco Identity Services Engine (ISE) provides the microgrid identity management component of the reference architecture. Authenticated identities and access policy decisions from Cisco ISE are enforced by the Cisco ISE-capable switches to control access to the Microgrid Master Controller and the DERs. Installation and configuration of Cisco ISE are described in Section 2.3.

Spherical Analytics Immutably implements the command register. Distribution ops systems, the front-end processor, and the microgrid master controller all send copies of information exchanges to Immutably's distributed ledger. Immutably is cloud-based software-as-a-service. Our configuration and use of Immutably are described in Section 2.5.

Distribution ops system, the front-end processor, and the microgrid master controller are emulated by NCCoE-developed software that sends copies of Modbus commands destined for the UMD solar arrays to Immutability.

The control systems of the UMD solar arrays represent the PV control system.

Sumo Logic implements the data analytics and visualization element of the reference architecture. Syslog data from the products and services in the cyber demarcation point and the microgrid are sent to Sumo Logic for aggregation, analysis, and visualization. Sumo Logic is a cloud-based software-as-a-service. Our configuration and use of Sumo Logic are described in Section 2.6.

TDi Technologies ConsoleWorks provides the privileged user management for products and services used on the microgrid. Access by privileged users to manage Cisco CyberVision and Cisco ISE is controlled by ConsoleWorks. Installation and configuration of ConsoleWorks are described in Section 2.7.

pfSense is used to create a virtual private network between the NCCoE lab and the UMD. pfSense is also used to control traffic out of the virtual lab to the Sumo Logic and Spherical Analytics cloud services. pfSense installation and configuration are described in Section 2.9.

syslog-ng is used to aggregate syslog data from products and services before sending the data to Sumo Logic. Installation and configuration of syslog-ng are described in Section 2.10.

2 Product Installation Guides

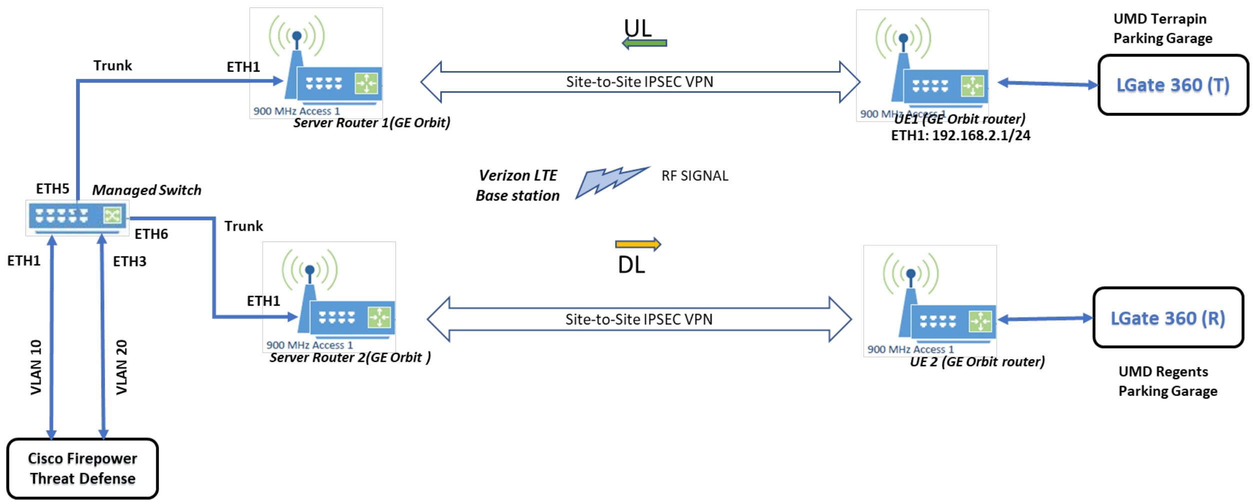
This section of the practice guide contains detailed instructions for installing and configuring all the products used in the example solution.

2.1 Anterix Long Term Evolution (LTE) Network

Anterix installed an LTE cellular network at UMD to provide connectivity from Clark Hall, where the NCCoE ESXI server is located, to the Regents and Terrapin Trail parking garages where the solar arrays are located. The installation included placing a router with a cellular interface at each parking garage and a managed network switch and two routers with cellular interfaces at Clark Hall. A point-to-point VPN is established over a cellular connection from a router in Clark Hall to a router at a parking garage.

A virtual Cisco Firepower Threat Defense next-generation firewallinstalled on the NCCoE ESXI server at Clark Hall implements the reference architecture's device gateway. This firewall controls access to the Anterix-managed switch which provides connectivity to a cellular point-to-point VPN that connects to the solar arrays. The LGate 360s provide a connection point to the solar array control systems that implement the PV Control System of the reference architecture. Figure 2-1 illustrates the cellular network installation.

Figure 2-1 Anterix Cellular Network Implementation



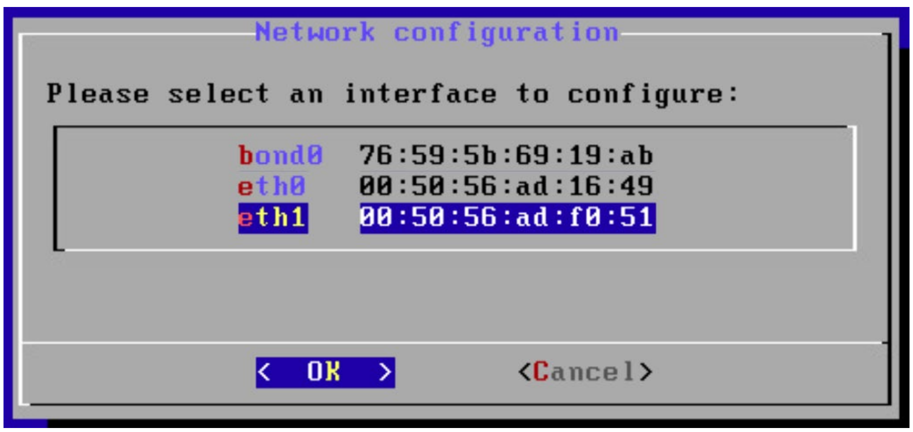
2.2 Cisco Cyber Vision

Cisco Cyber Vision implements the microgrid monitoring component of the reference architecture. It monitors the microgrid network for anomalous activity and provides alerts via syslog. These alerts are collected and sent to the data analysis and visualization component for presentation to microgrid operators.

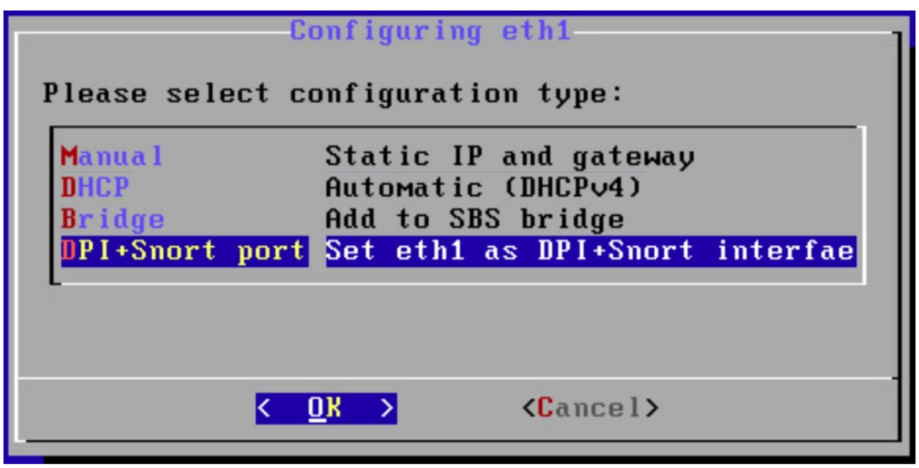
Cisco Cyber Vision was provided as a virtual appliance in an open virtualization appliance (OVA) file. The OVA file was deployed as a virtual machine in Sphere. We followed the instructions in Cisco's Cyber Vision All-in-One guide to complete the installation.

1. After the OVA has been deployed, check and verify the first network device (*eth0*) is used as the management interface by ensuring it has received an IP address. The second network device (*eth1*) should not have an IP address as that will be the monitoring port in this deployment. Note the MAC address (*link/ether* in the screenshot below) for *eth1* for the next step. When the MAC address is noted, type **`sbs-netconf`** to start the configuration process.

2. Using the MAC address in the previous step, select the correct interface to activate the monitoring connection, then click **OK**.

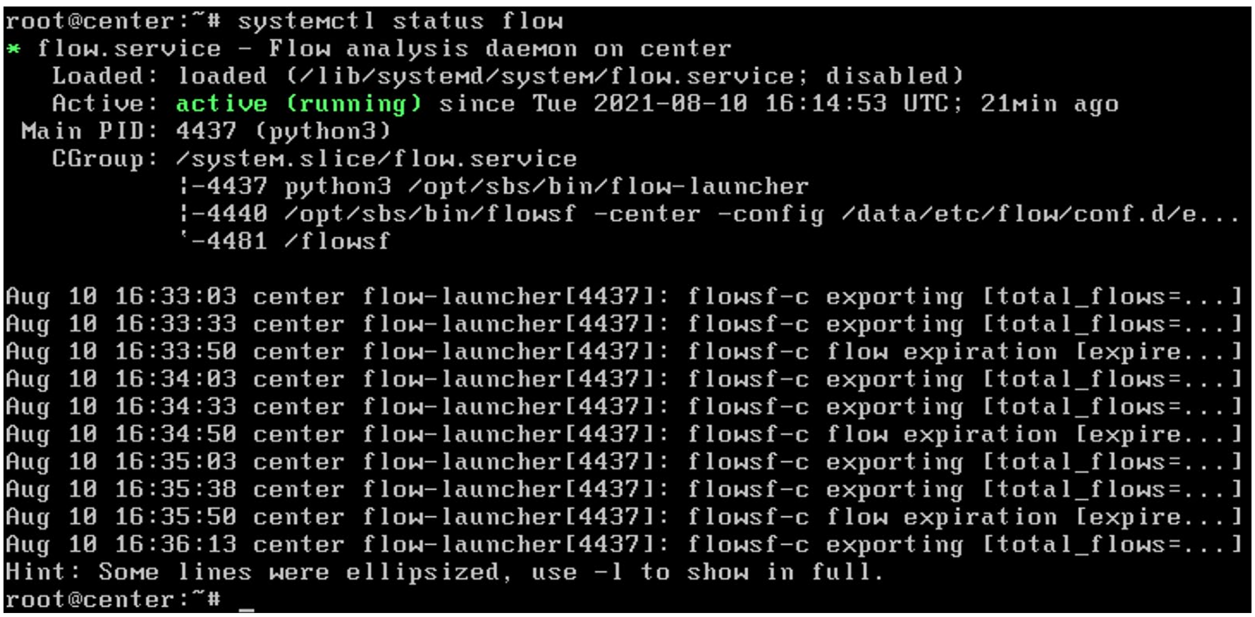


3. Select **DPI+Snort port** and click **OK**.

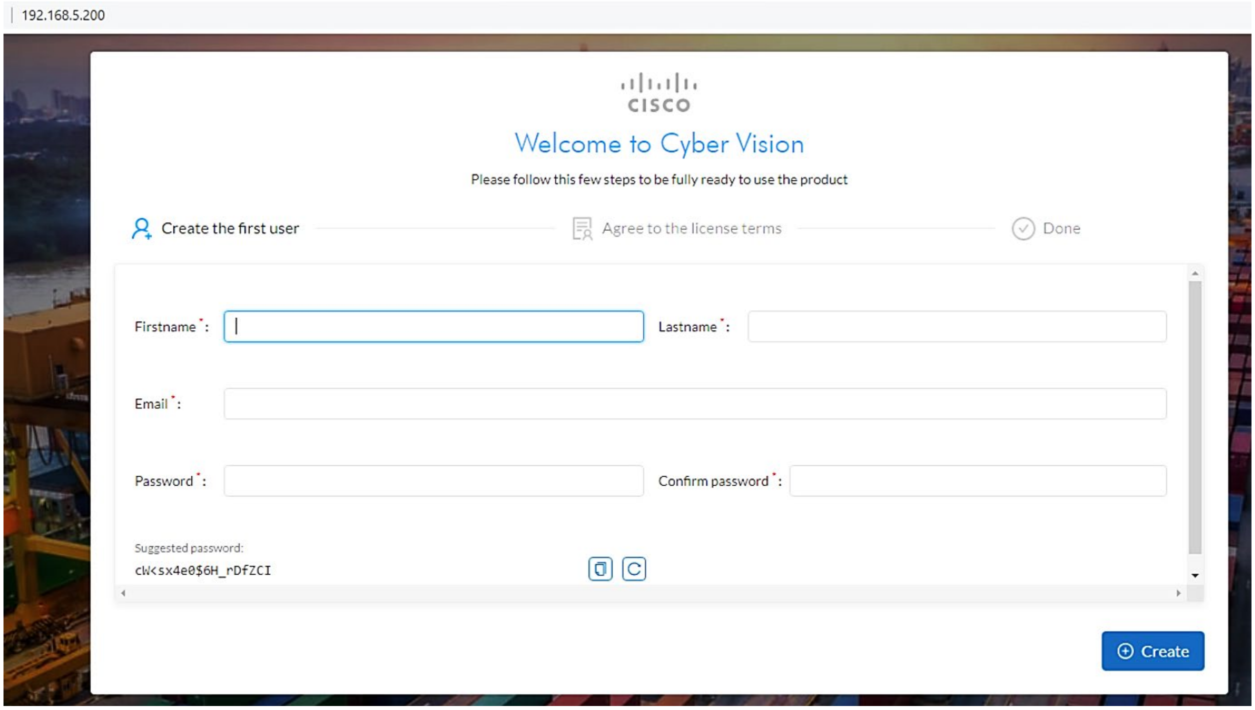


4. Leave the **Captur**e **filter**: block empty and click **OK.**

5. Verify that the service is running by typing **`systemctl status flow`** and verifying that the service is active and running.



6. Open up a browser on a system that is network routable to the Cyber Vision system and type the IP address into the URL. The **Welcome to Cyber Vision** screen shown below displays. Enter the user information and click **Create**.



7. Read the EULA and click **Agree**.

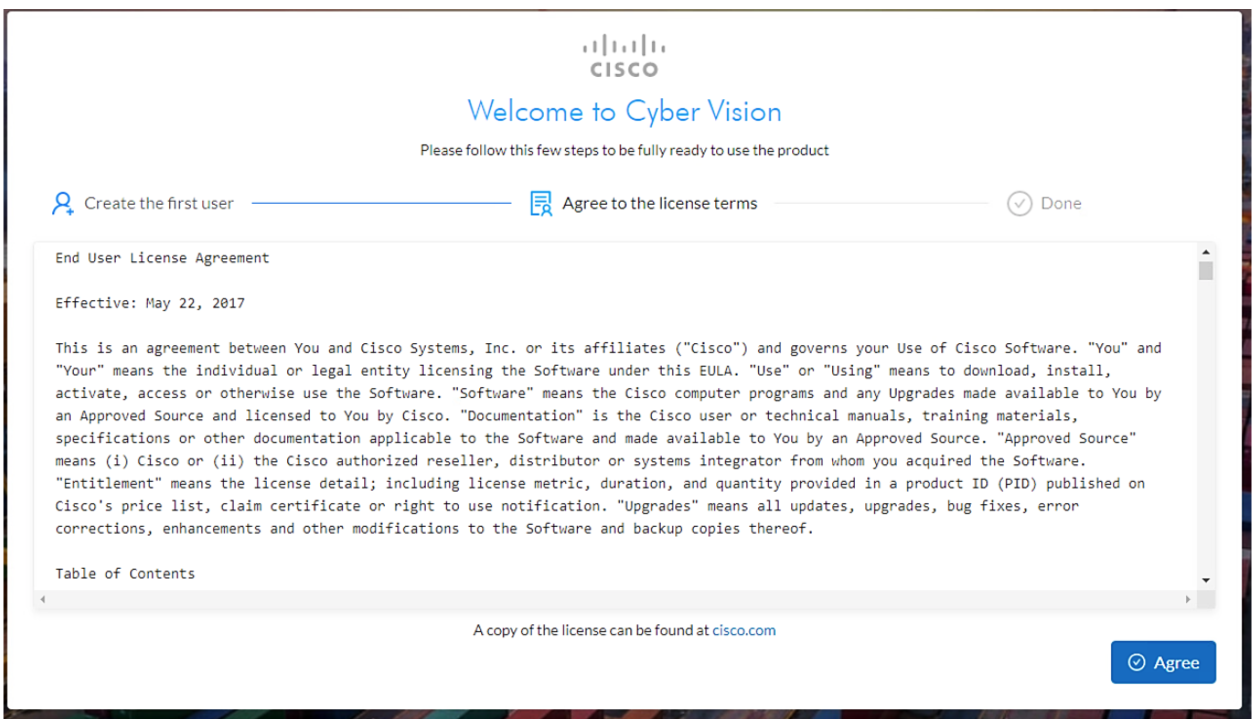
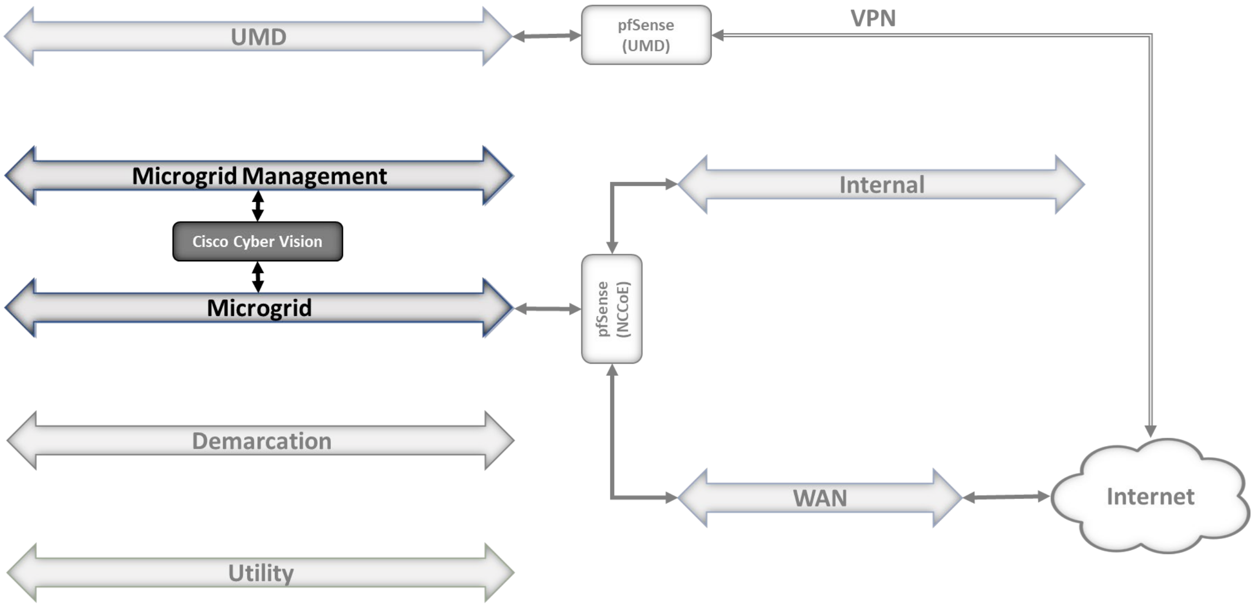


Figure 2-2 shows the location of Cisco Cyber Vision in the example solution.

Figure 2-2 Cisco Cyber Vision in the Example Solution



2.3 Cisco Identity Services Engine (ISE)

Cisco ISE provides the microgrid identity management component of the reference architecture. It works with Cisco ISE-enabled switches to provide authenticated identities that are used for access control.

2.3.1 Cisco ISE Installation and Configuration

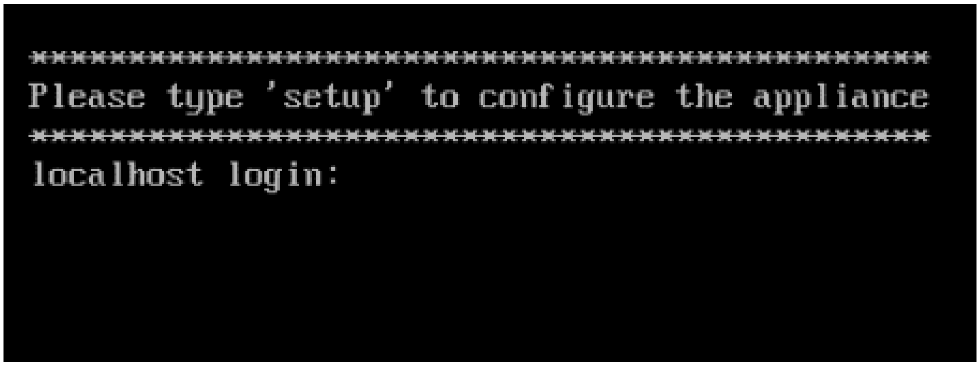
ISE was installed using the ISE 2.7 Installation Guide available at https://www.cisco.com/c/en/us/td/docs/security/ise/2-7/InstallGuide27/b_ise_InstallationGuide27/b_ise_InstallationGuide27_chapter_011.html#ID-1417-00000271

We followed steps 1 through 17 in the section titled "Configure a VMware Server" with the following selections:

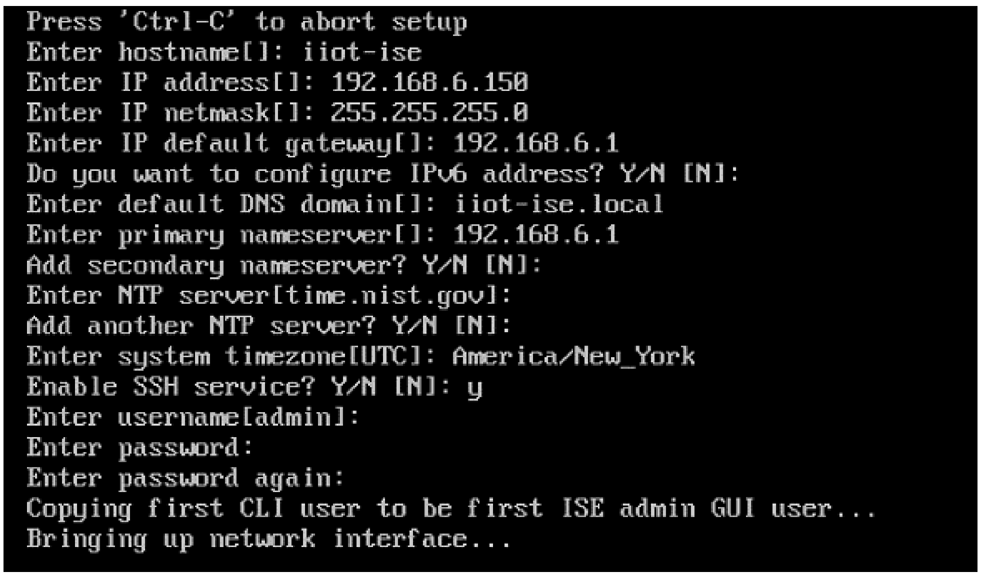
- Step 8: Small, `16 cores`
- Step 12: `200Gb, thick-provisioned hard drive`

After completing the installation we used the setup guide at https://www.cisco.com/c/en/us/td/docs/security/ise/2-7/InstallGuide27/b_ise_InstallationGuide27/b_ise_InstallationGuide27_chapter_010.html#id_11096 to configure ISE.

1. Start up the VM for ISE that was created and type setup on the login screen:



2. Fill in the appropriate information to configure the installation of ISE (as seen below):

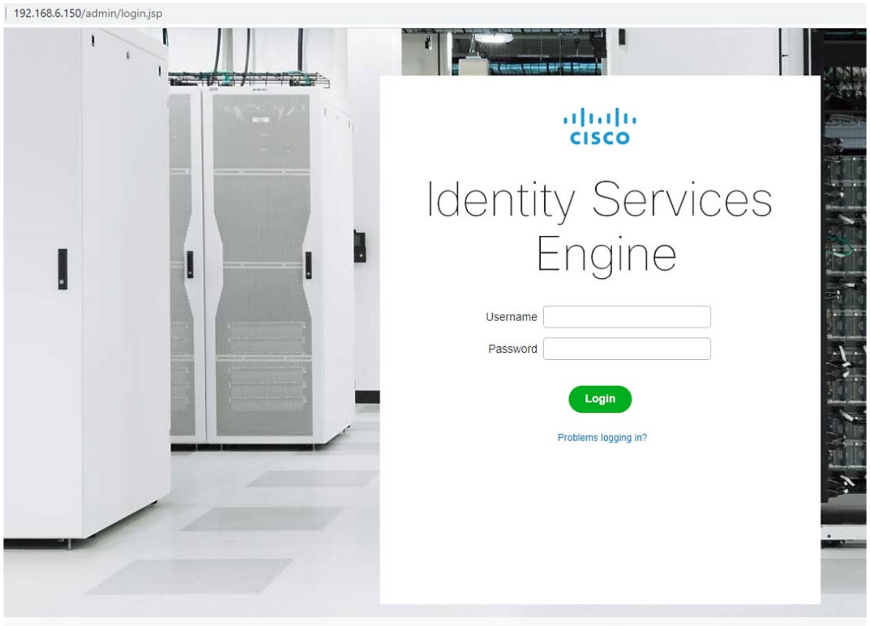


3. Once all configuration steps are complete, the ISE installation will begin. This may take several minutes.

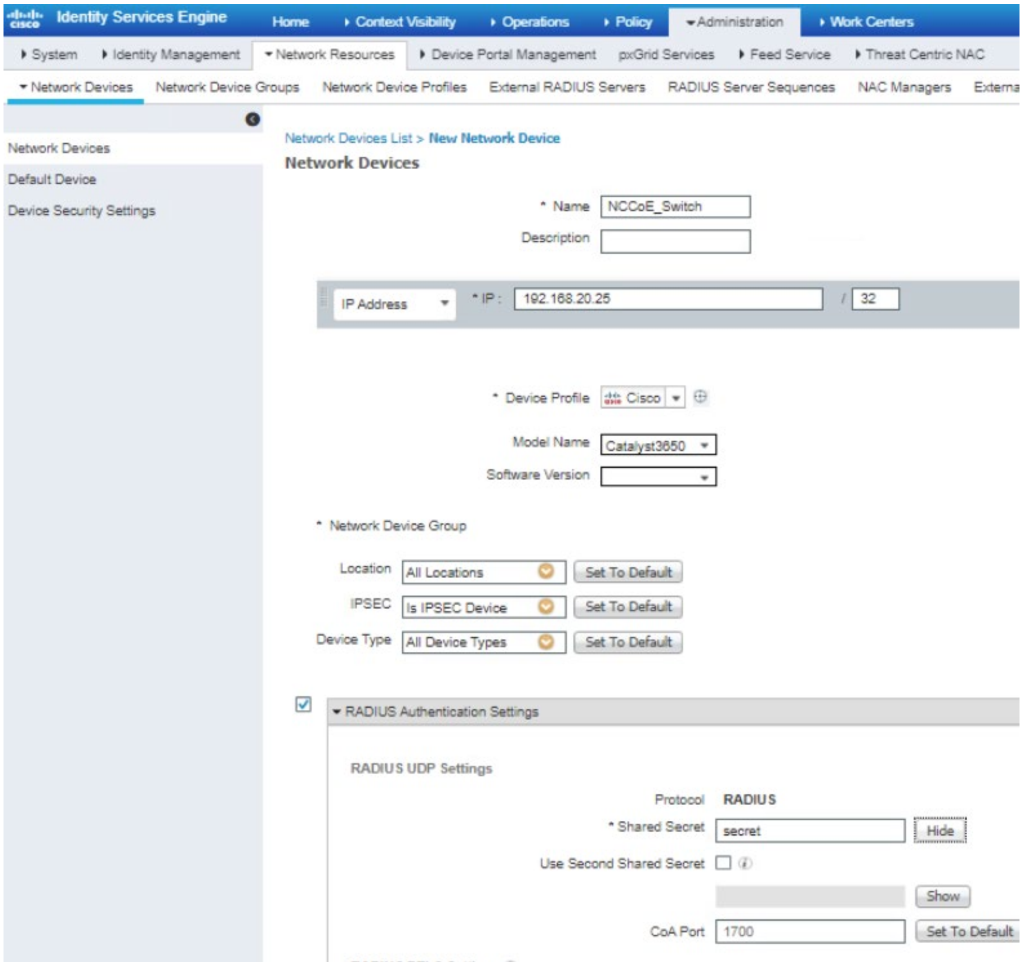
4. Once installation is complete, log in to ISE and run **`show application status ise`** to verify ISE installation is complete.

```
iiot-ise/admin# show application status ise

ISE PROCESS NAME                         STATE            PROCESS ID
--------------------------------------------------------------------
Database Listener                        running          15549
Database Server                          running          120 PROCESSES
Application Server                       running          25423
Profiler Database                        running          17525
ISE Indexing Engine                      running          26794
AD Connector                             running          28157
M&T Session Database                     running          17161
M&T Log Processor                        running          25623
Certificate Authority Service            running          27809
EST Service                              running          7951
SXP Engine Service                       disabled
Docker Daemon                            running          18442
TC-NAC Service                           disabled

Wifi Setup Helper Container              disabled
pxGrid Infrastructure Service            disabled
pxGrid Publisher Subscriber Service      disabled
pxGrid Connection Manager                disabled
pxGrid Controller                        disabled
PassiveID WMI Service                    disabled
PassiveID Syslog Service                 disabled
PassiveID API Service                    disabled
PassiveID Agent Service                  disabled
PassiveID Endpoint Service               disabled
PassiveID SPAN Service                   disabled
DHCP Server (dhcpd)                      disabled
DNS Server (named)                       disabled
ISE Messaging Service                    running          19822

iiot-ise/admin#
```

5. Open a web browser and log into the Cisco ISE webserver.



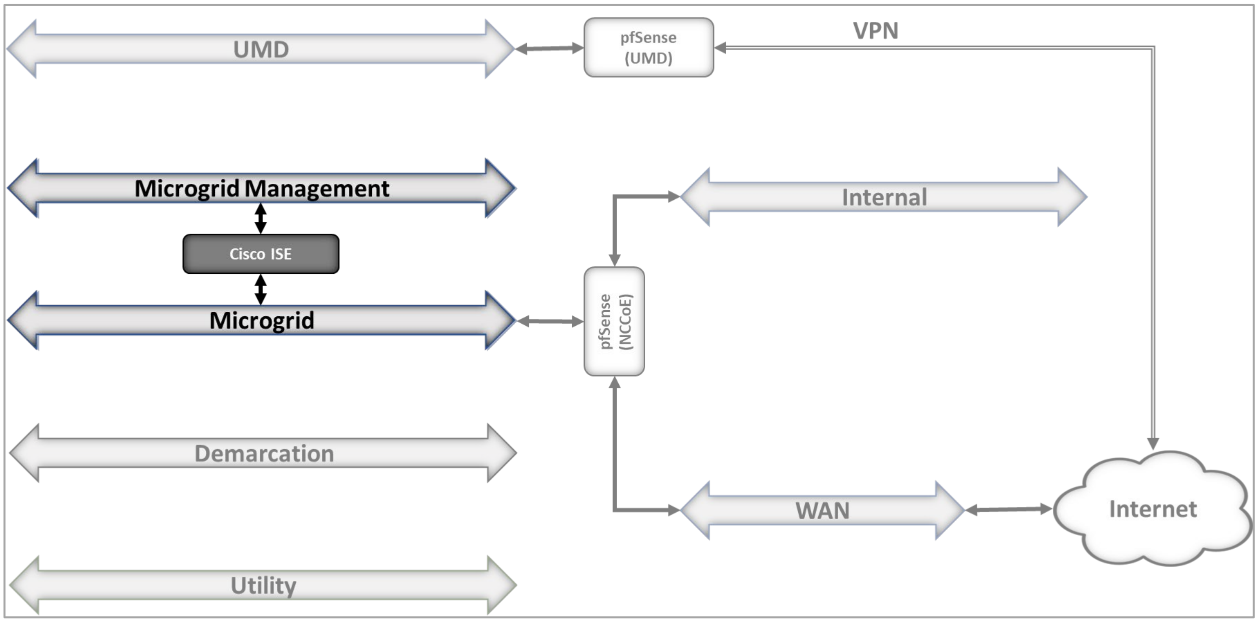
6. Once complete, go to **Administration > Network Resources > Network Devices** and click **New Network Device**. Add the switch that will be configured to control access with the settings shown below.



7. We configured three identities in ISE:
   - One identity was given access to both UMD solar arrays.
   - One identity was given access to only one UMD solar array.
   - One identity was given no access to the UMD solar arrays.

Figure 2-3 shows how Cisco ISE in positioned the example solution.

Figure 2-3 Cisco ISE Position in the Example Solution



2.3.2 Cisco ISE Switch Settings

In order to integrate Cisco ISE with the switches in the NCCoE lab, switch configuration is required. Run the required commands as shown in the following two screenshots.

```
IIOT_Catalyst3650>en
Password:
IIOT_Catalyst3650#conf t
Enter configuration commands, one per line.  End with CNTL/Z.
IIOT_Catalyst3650(config)#ip classless
IIOT_Catalyst3650(config)#ip route 0.0.0.0 0.0.0.0 192.168.20.1
IIOT_Catalyst3650(config)#ip http server
IIOT_Catalyst3650(config)#ip http secure-server
Failed to generate persistent self-signed certificate.
    Secure server will use temporary self-signed certificate.

IIOT_Catalyst3650(config)#ntp server 192.168.20.1
IIOT_Catalyst3650(config)#aaa new-model
IIOT_Catalyst3650(config)#aaa authentication dot1x default group radius
IIOT_Catalyst3650(config)#aaa authorization network default group radius
IIOT_Catalyst3650(config)#aaa authorization auth-proxy default group radius
IIOT_Catalyst3650(config)#aaa accounting dot1x default start-stop group radius
IIOT_Catalyst3650(config)#aaa session-id common
IIOT_Catalyst3650(config)#aaa accounting update periodic 5
IIOT_Catalyst3650(config)#aaa accounting system default start-stop group radius
```

```
IIOT_Catalyst3650(config)#radius server iiot-ise
IIOT_Catalyst3650(config-radius-server)#address ipv4 192.168.6.150 auth-port 1812 acct-port 1813
IIOT_Catalyst3650(config-radius-server)#key secret
IIOT_Catalyst3650(config-radius-server)#exit
IIOT_Catalyst3650(config)#dot1x system-auth-control
```

After completing the commands listed above, type exit then copy running-config startup-config to save the configuration to the switch.

2.3.3 Cisco Firepower Installation and Configuration

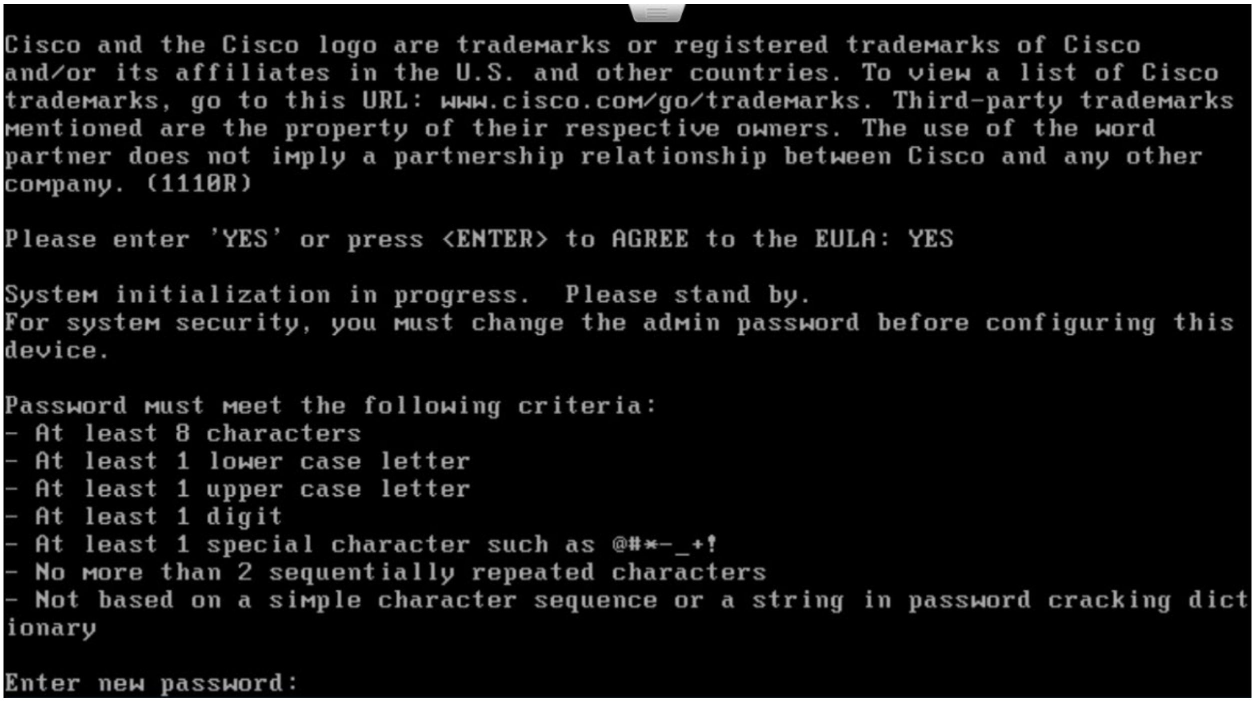
To handle identity authentication and authorization for protected resources at UMD, Cisco Firepower was utilized. Implementation included Firepower Management Center (FMC) and Firepower Threat Detection (FTD).

2.3.3.1 Cisco Firepower Threat Detection Installation and Configuration

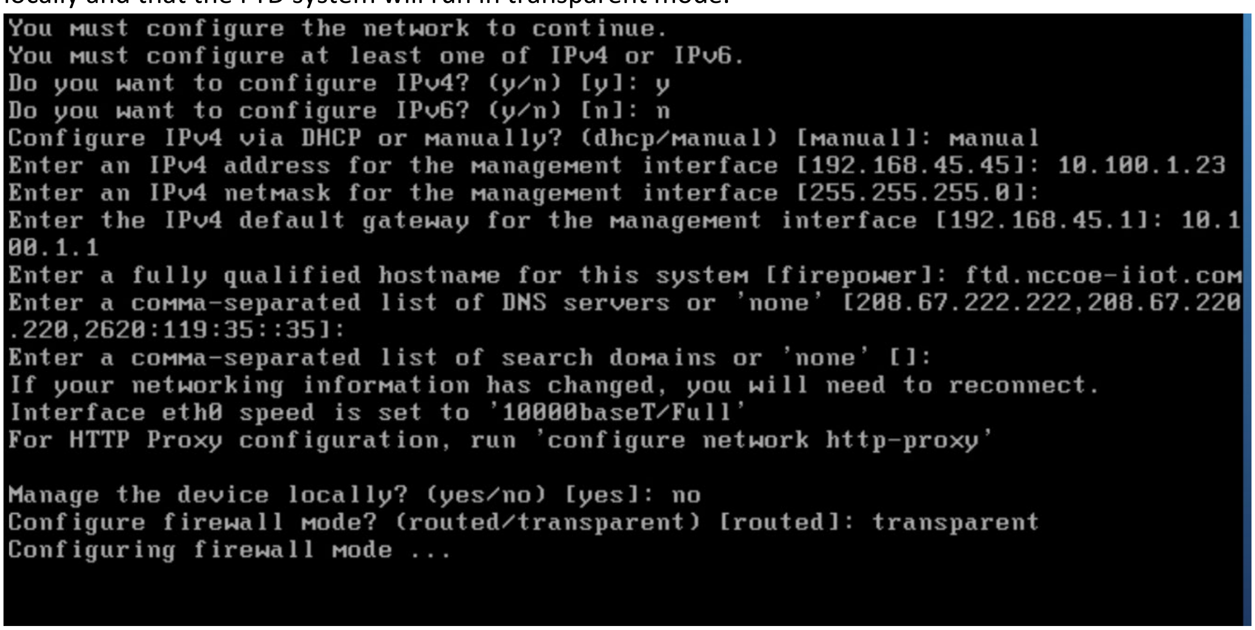
1. Obtain OVF and VMDK file from Cisco representative and deploy to virtual environment. Power on VM after deployment is completed.
2. Open VM Console and log in with username **admin** and password **Admin123**. Once logged in, view and accept the EULA.

```
End User License Agreement

Effective: May 22, 2017

This is an agreement between You and Cisco Systems, Inc. or its affiliates
("Cisco") and governs your Use of Cisco Software. "You" and "Your" means the
individual or legal entity licensing the Software under this EULA. "Use" or
"Using" means to download, install, activate, access or otherwise use the
Software. "Software" means the Cisco computer programs and any Upgrades made
available to You by an Approved Source and licensed to You by Cisco.
"Documentation" is the Cisco user or technical manuals, training materials,
specifications or other documentation applicable to the Software and made
available to You by an Approved Source. "Approved Source" means (i) Cisco or
(ii) the Cisco authorized reseller, distributor or systems integrator from whom
you acquired the Software. "Entitlement" means the license detail; including
license metric, duration, and quantity provided in a product ID (PID) published
on Cisco's price list, claim certificate or right to use notification.
"Upgrades" means all updates, upgrades, bug fixes, error corrections,
enhancements and other modifications to the Software and backup copies thereof.

This agreement, any supplemental license terms and any specific product terms
at www.cisco.com/go/softwareterms (collectively, the "EULA") govern Your Use of
the Software.

--More--_
```

3. Once completed, create a new password for the admin user.



4. Setup and configure network settings for FTD. Ensure that the device will not be managed locally and that the FTD system will run in transparent mode.



5. Configure the manager settings with the IP address of ISE and a registration key. The key opted to use in this build is **cisco123**. This key is required for integration into FMC.

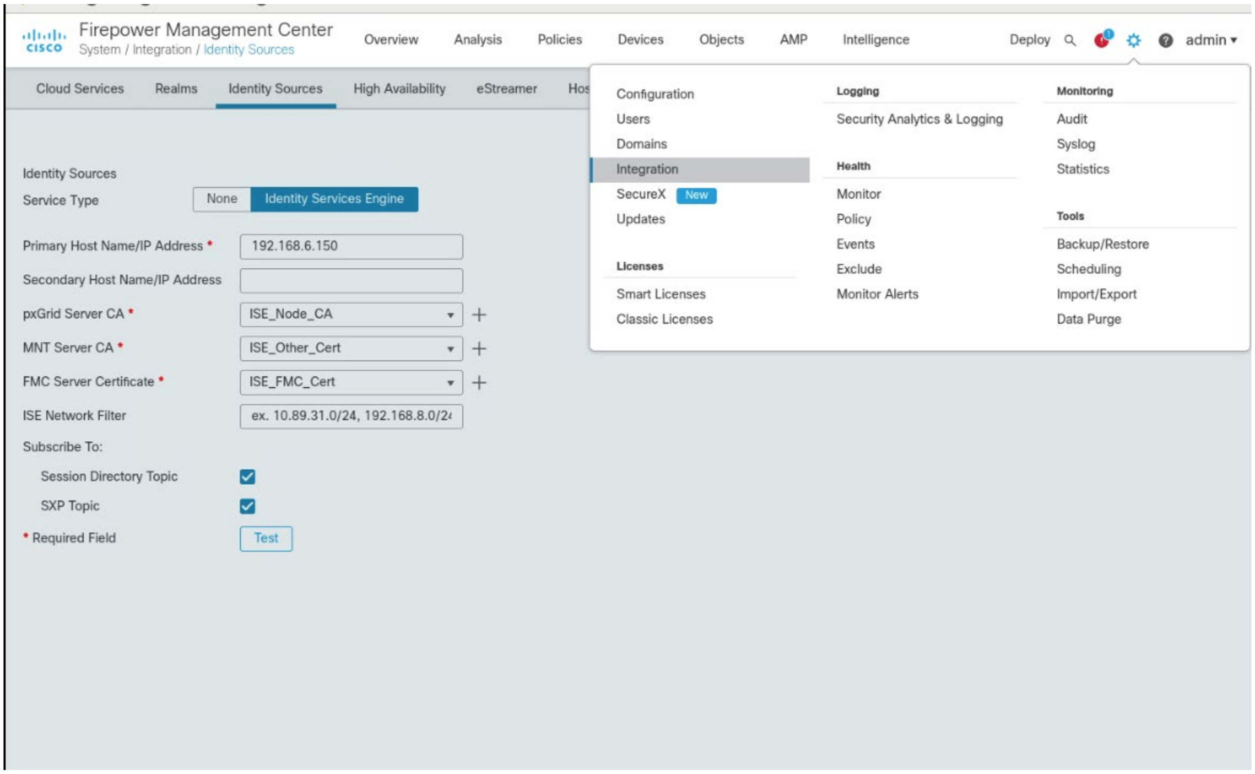
```
Later, using the web interface on the Firepower Management Center, you must
use the same registration key and, if necessary, the same NAT ID when you add
this sensor to the Firepower Management Center.
> configure manager add 10.100.1.22 cisco123
Manager successfully configured.
Please make note of reg_key as this will be required while adding Device in FMC.

> _
```

2.3.3.2 Cisco Firepower Management Center Installation and Configuration

1. Obtain OVF and VMDK file from Cisco representative and deploy to virtual environment. Power on VM after deployment is completed.
2. Open VM Console and log in with username **admin** and password **Admin123**. Once logged in, view and accept the EULA.
3. Configure network for FMC system. DHCP was utilized in this setup. Type **y** to verify configuration.

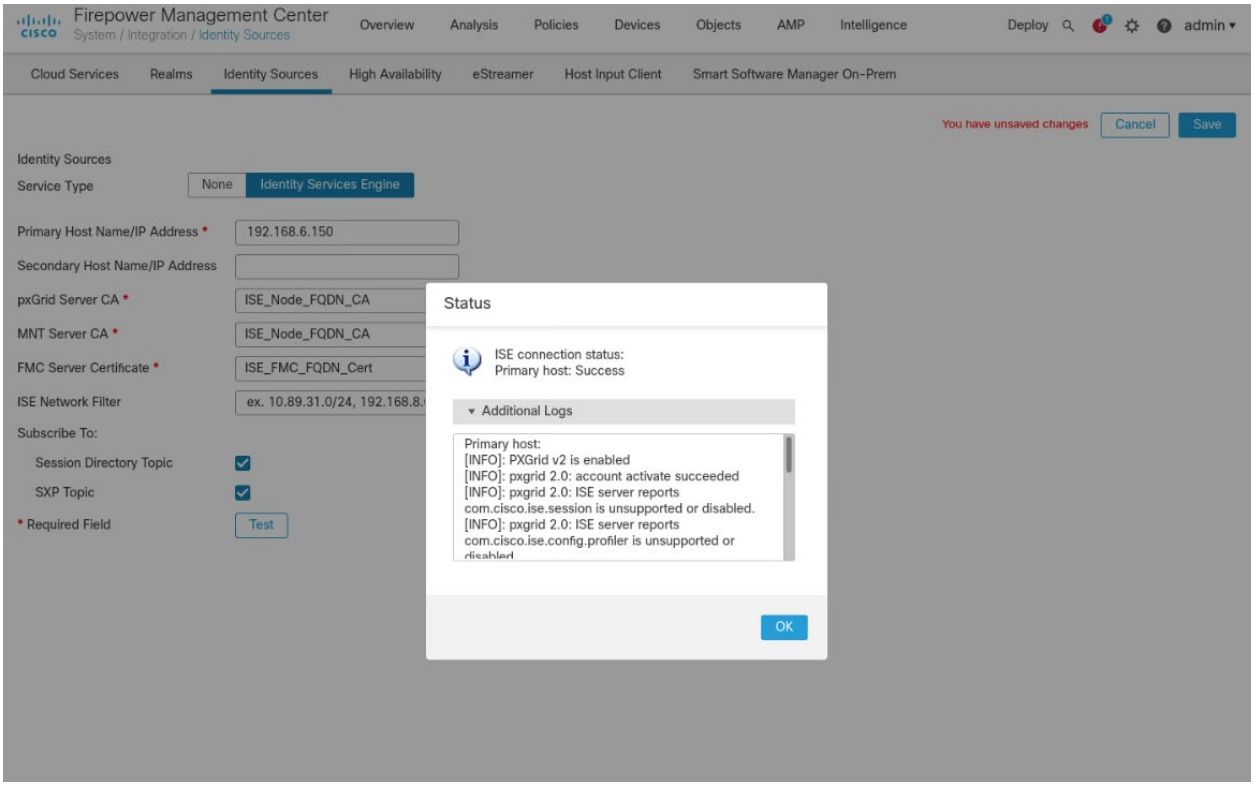
```
Enter a hostname or fully qualified domain name for this system [firepower]:
Configure IPv4 via DHCP or manually? (dhcp/manual) [dhcp]:
Enter a comma-separated list of DNS servers or 'none' [208.67.222.222,208.67.220
.220]: 10.100.1.1,8.8.8.8
Enter a comma-separated list of NTP servers [0.sourcefire.pool.ntp.org, 1.source
fire.pool.ntp.org]: 10.100.1.1

Hostname:              firepower
IPv4 configured via:   dhcp
DNS servers:           10.100.1.1,8.8.8.8
NTP servers:           10.100.1.1

Are these settings correct? (y/n) _
```

4. Once logging in to the web interface for FMC, click the gear icon in the top left, then select **Integration.** Select the tab at the top entitled **Identity Sources**.

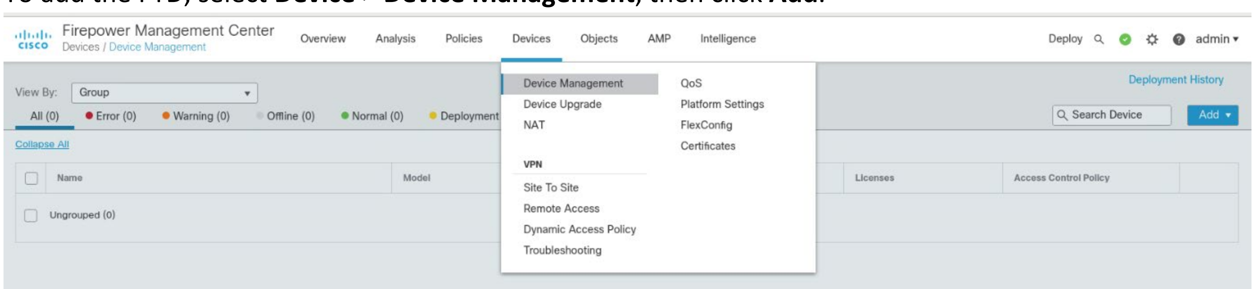


5. Fill out each line for the ISE instance. IP address or Fully Qualified Domain Name (FQDN), the pxGrid Server CA is the self-signed certificate in ISE, the same certificate is used for the MNT certificate, and the FMC Server Certificate is the certificate generated in ISE for the pxGrid. Ensure that the checkboxes for **Session Directory Topic** and **SXP Topic** are selected. Click **Test** to

verify successful connection, then click **Save**.

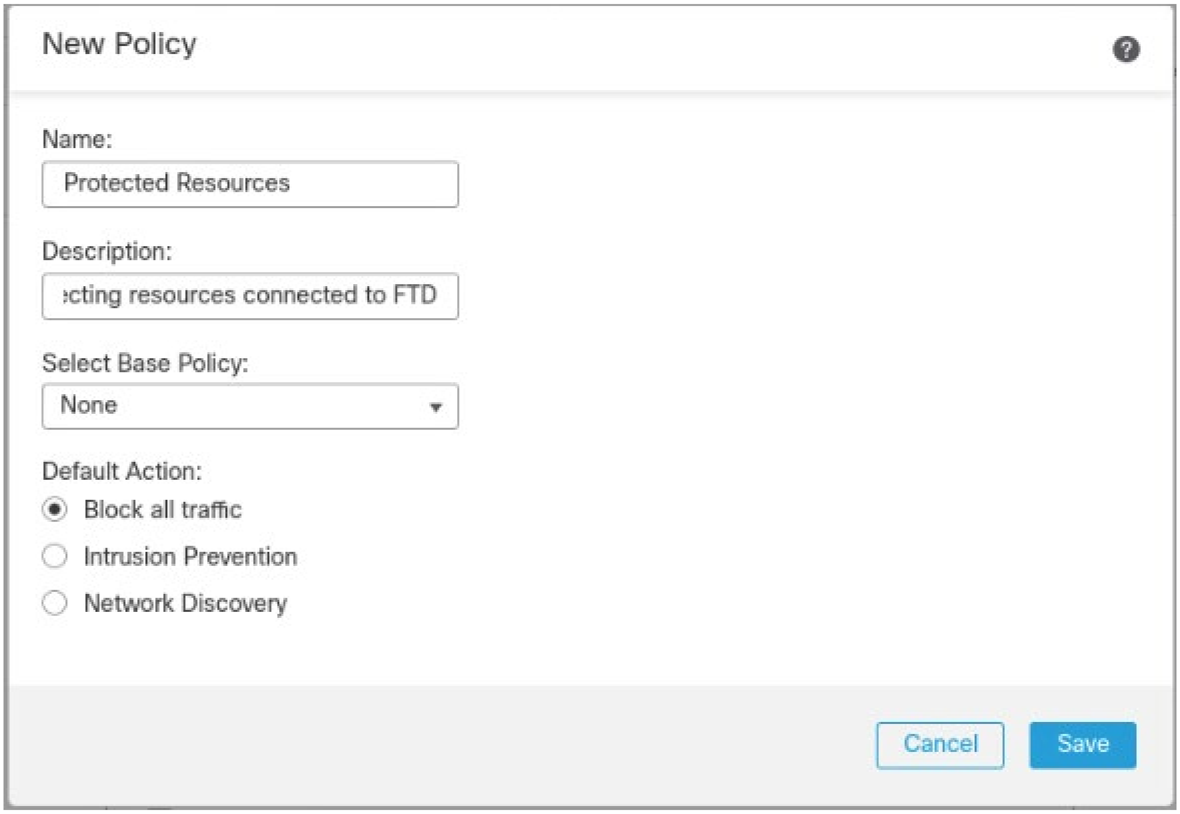


6. To add the FTD, select **Device** > **Device Management**, then click **Add**.

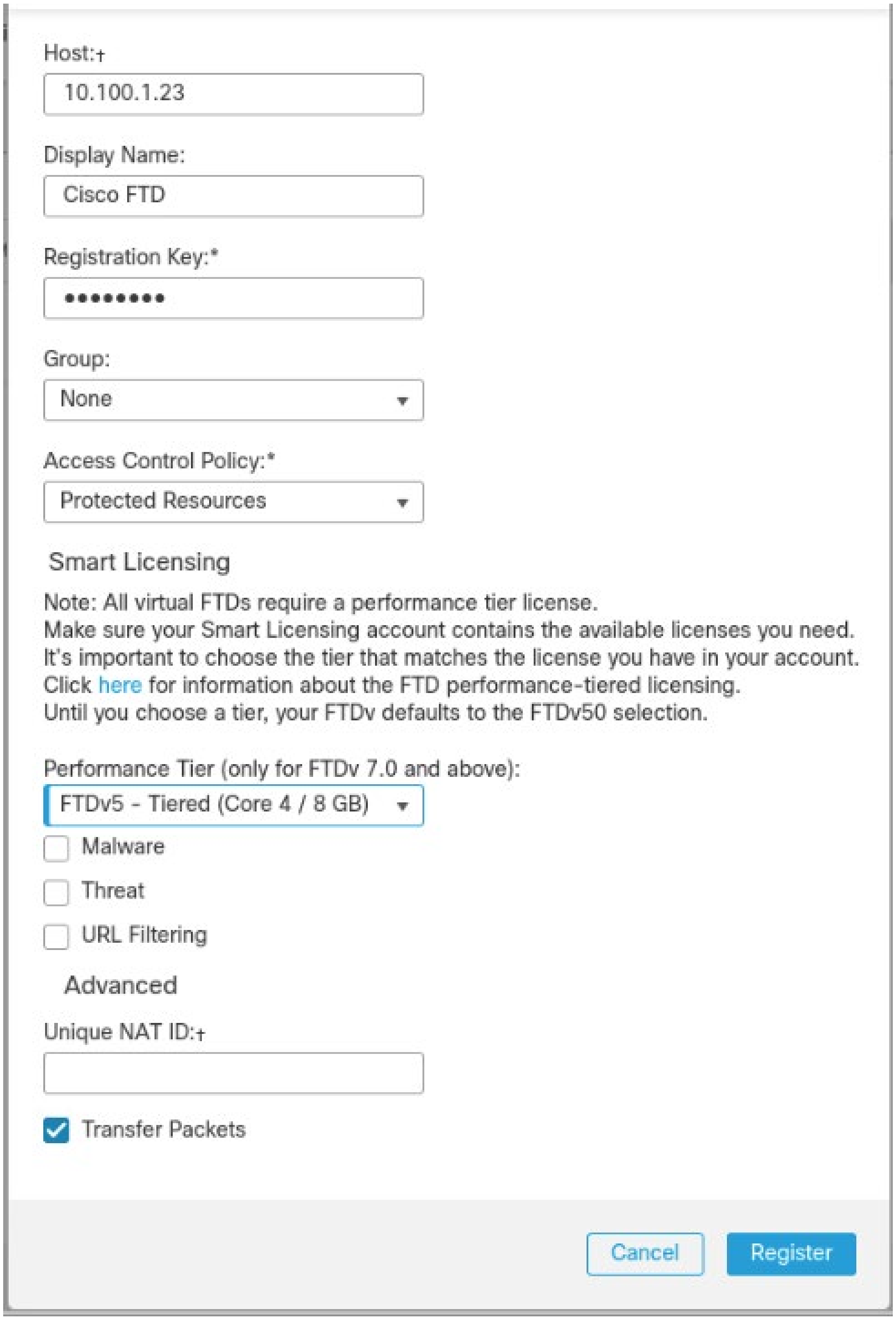


7. On the pop-up window, fill in all blanks, with the **Host** as the IP address of the FTD, a **Display Name**, and place copy the registration key created earlier to **Registration Key**. The lab used **cisco123** as the registration key. For **Access Control Policy**, click the drop-down box, then select **Create New Policy**. Give it a name, description, and ensure **Block all traffic** is selected as the

default action. Click **Save**.

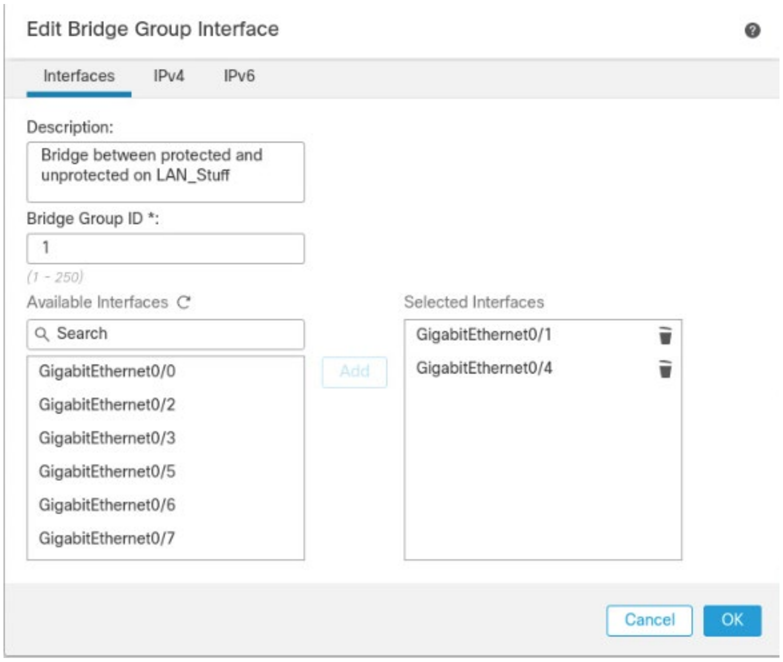


8. Select **FTDv5** for the Performance Tier and click **Register**.



9. The final setup required is to add a virtual interface. On the Device Management page, click the **Interfaces** tab if it is not already added, then click **Add Interfaces** on the left side of the screen. Then select **Bridge Group Interface**. Here we selected one interface for each side of the

transparent connection, then on the IPv4 tab assigned an IP address. The click **OK.**



2.4 Radiflow iSID

We implemented the utility cyber monitoring element of the reference architecture using Radiflow iSID. iSID is a passive monitoring, analysis, and detection platform that can be provided as either a physical or logical appliance. iSID learns the basic topology and behavior of the industrial control devices on the networks that it monitors. A typical deployment places an iSID appliance at a central location on the utility network and deploys iSAP smart collectors to various locations of interest on the utility network. In the example solution, for example, we could have placed smart collectors at UMD and in the NCCoE lab. To simplify the NCCoE lab example solution, a single virtual appliance was deployed in the NCCoE lab that acts as both the analysis and detection engine and the network collector.

iSID allows the utility operator to see all devices connected to the utility network, detect anomalous behavior on the network, and detect policy violations in communications occurring over the network. This information is made available to utility cyber analysts both through a collection of dashboards and through syslog data that can be collected by a Security Information and Event Management (SIEM) system.

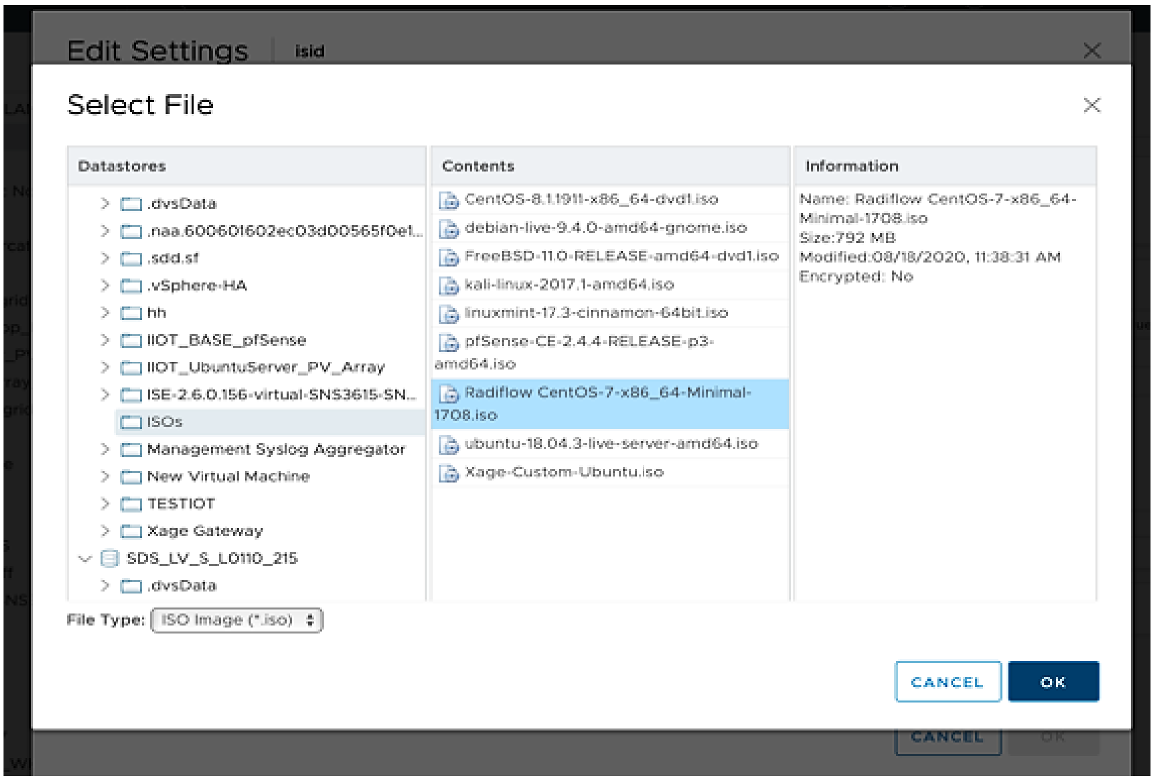
In the NCCoE example solution, iSID was placed on the utility virtual network (vLAN) between the distribution ops systems and the utility gateway. This placement provides information about traffic bound for the microgrid network from the utility network. Sensors could also be placed between the utility gateway and the front-end processor.

2.4.1 Radiflow iSID Installation and Configuration

This section discusses the Radiflow iSID installation and configuration procedures.

Setup a Radiflow Installation Manager (RIM) Server

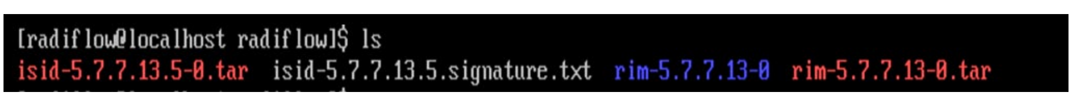
1. Create a Radiflow virtual machine (VM) using CentOS 1708 minimal International Standards Organization (ISO) file – CentOS-7-x86_64-Minimal-1708.iso.



2. Once the VM is up, use it to download the RIM from the download site.

3. Download the file from the website for install.

   We downloaded the file on the TEST machine, and then secure copied it to the Radiflow machine we created. Inside the Radiflow VM, files are uploaded into the 'radiflow' directory in the radiflow home directory (*cd/radiflow*). The files include iSID latest version – *isid-5.7.7.13.5-0.tar*, Radiflow Installation Manager (RIM) – *rim-5.7.7.13-0.tar* and iSID Signature file - *isid-5.7.7.13.5.signature.txt*– needed for installing iSID using RIM.



4. Extract RIM and run it.

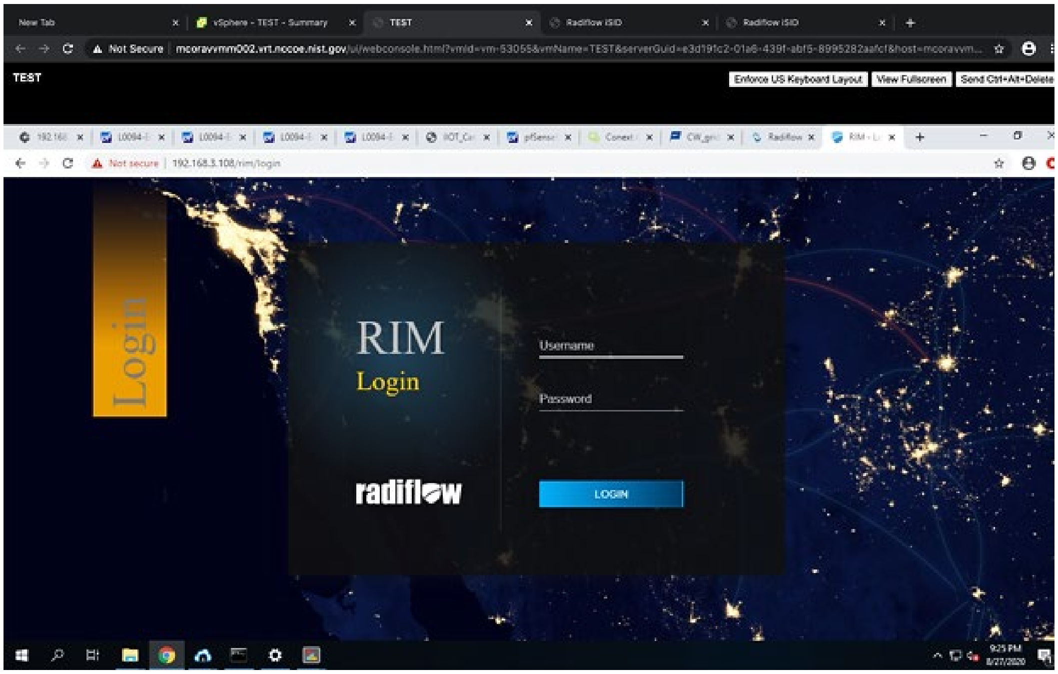
```
tar -xvf rim-5.7.7.13-0.tar
```

```
cd rim-5.7.7.13-0
su root
./start.sh
```

5. Enter 1 to configure the RIM server with the following:
   - IP address: 192.168.3.108
   - Subnet mask: 255.255.255.0
   - Gateway: 192.168.3.1
   - Interface name: ens192

Access and Test the RIM and iSID User Interface

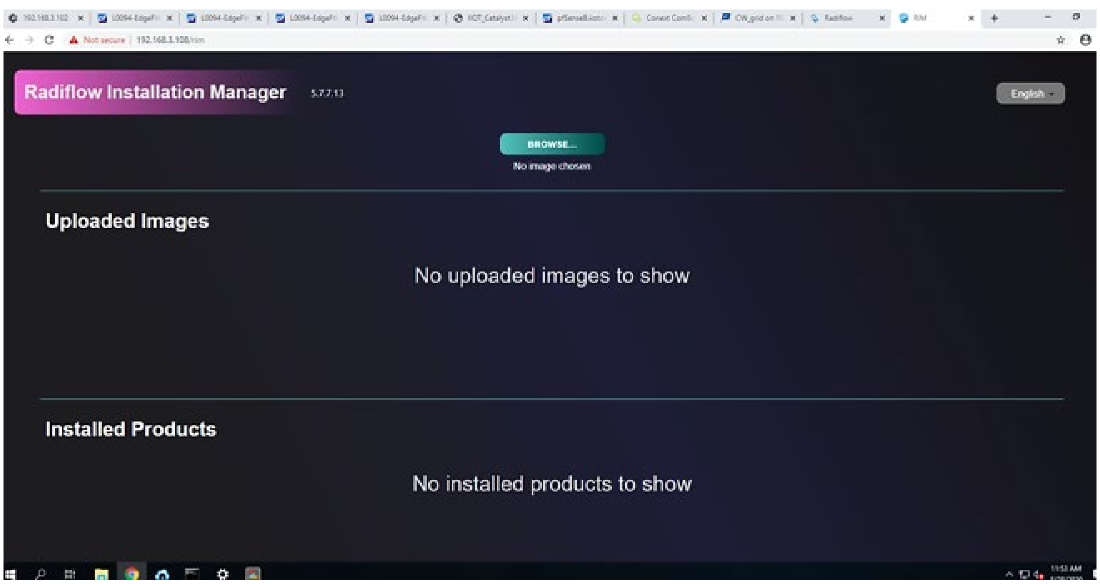
1. To access the RIM, open a web browser from the TEST VM (192.168.3.101) and navigate to the RIM server at https:192.168.3.108/rim.



2. To get access inside the RIM user interface login, enter the username and password:

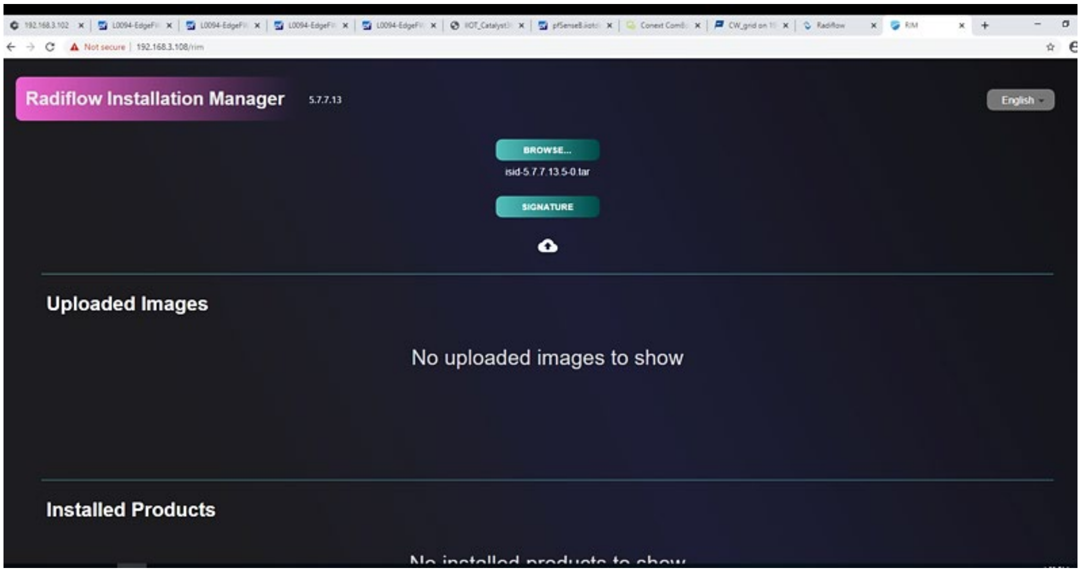
   Username: **radiflow**

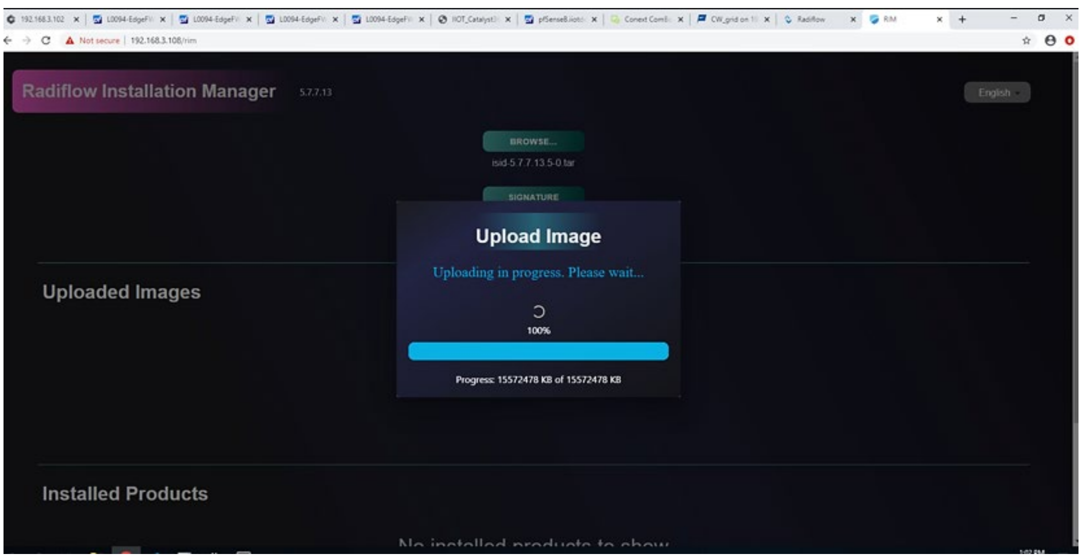
   Password: **Secured1492**



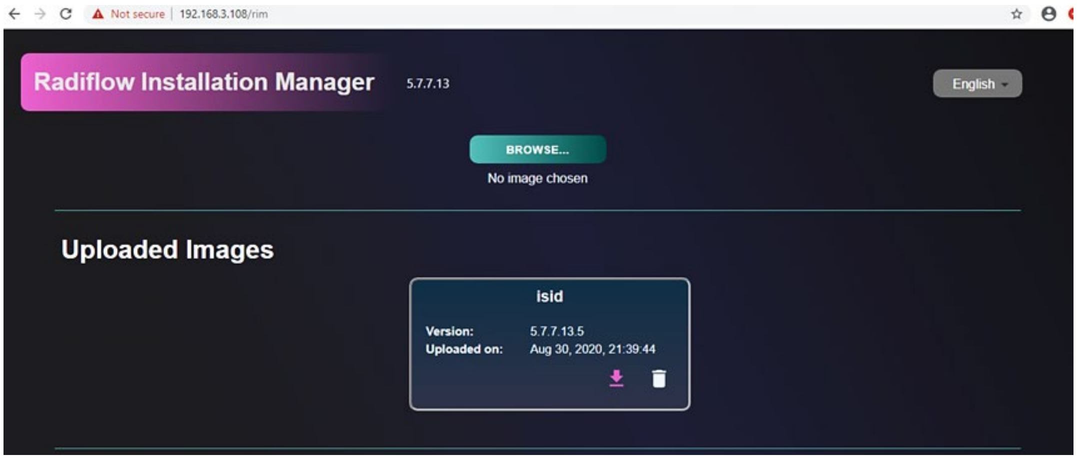
Inside this TEST machine, we have the files isid-5.7.7.13.5-0.tar and iSID Signature file isid-5.7.7.13.5.signature.txt

3. Click **Browse** and select the *isid-5.7.7.13.5-0.tar*.
4. Click **Add signature file** and select *isid-5.7.7.13.5.signature.txt*, then click **Upload**.



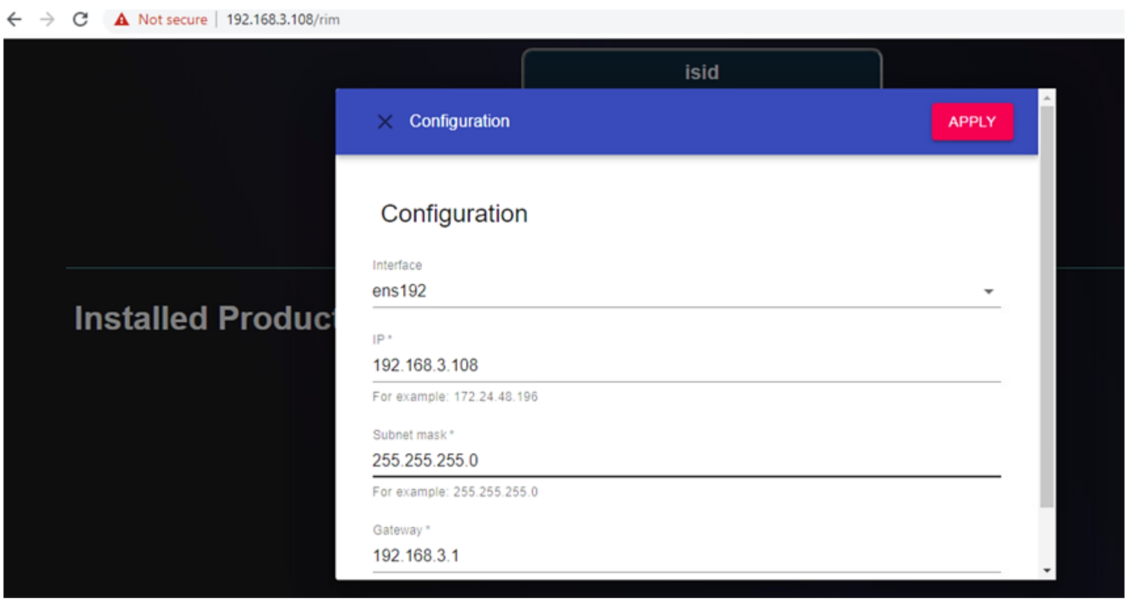


5. Successfully uploaded the image.

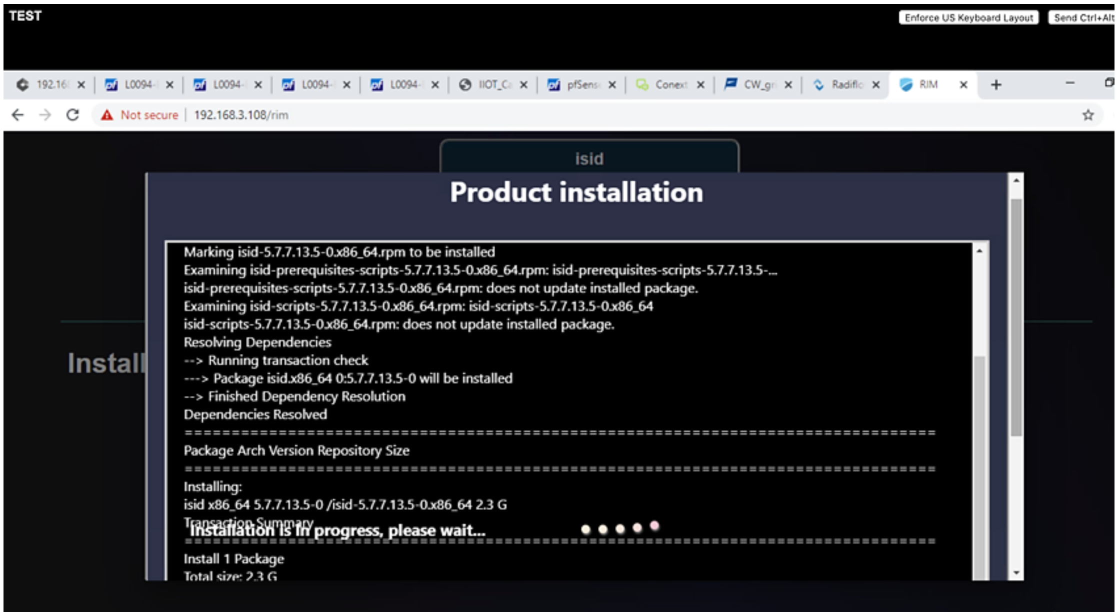


6. Install the uploaded image.

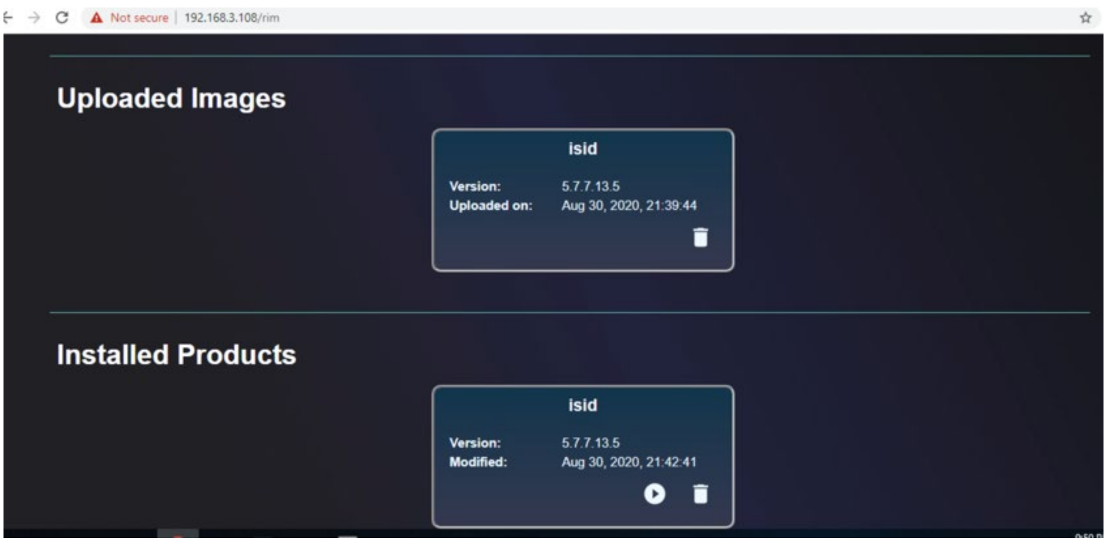
Note: If you configured the RIM server from step 6 above, then there is no need to reconfigure.



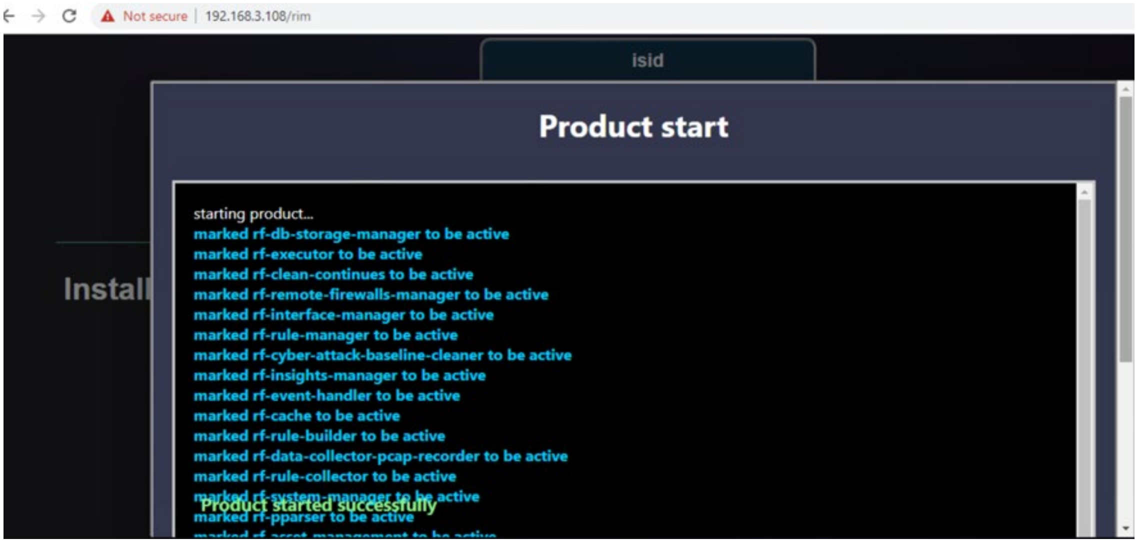
Product installation window:



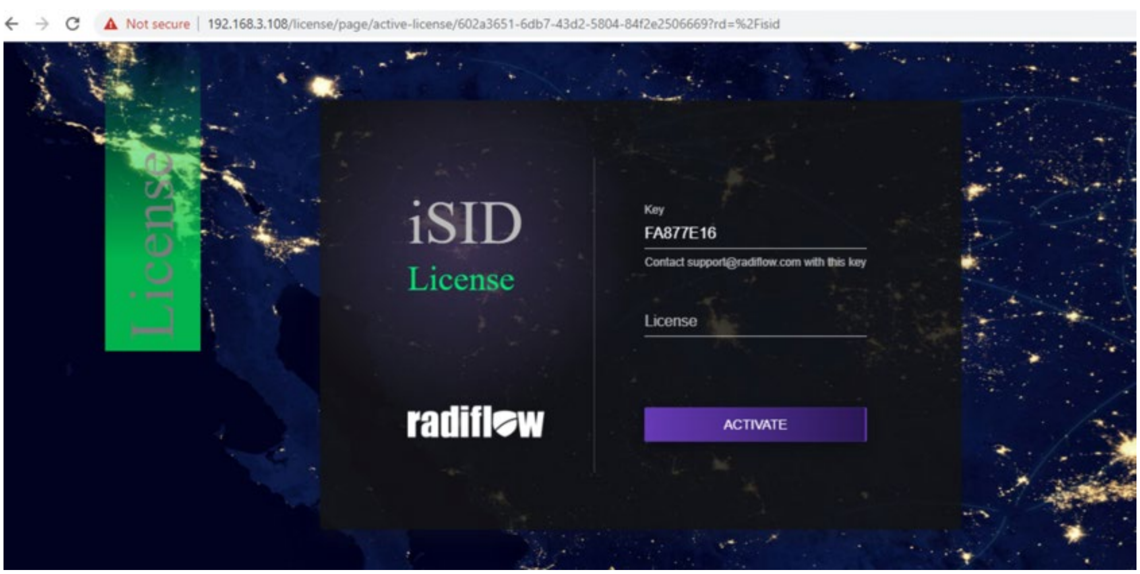
7. Once the installation is complete, the installed iSID image displays.



8. Run an installed iSID image, click **Finish** when it is complete.



9. Test the installed and running iSID.
10. Navigate to https://192.168.3.108/isid to enter the activation key:
11. Contact Radiflow to get the license and enter the license key and select Activate. We need to enter: **E7ICAMY8.**



12. Enter the following credentials for iSID:
- Username: **radiflow**
- Password: safe@Rad1flow

13. View the Radiflow iSID web application.

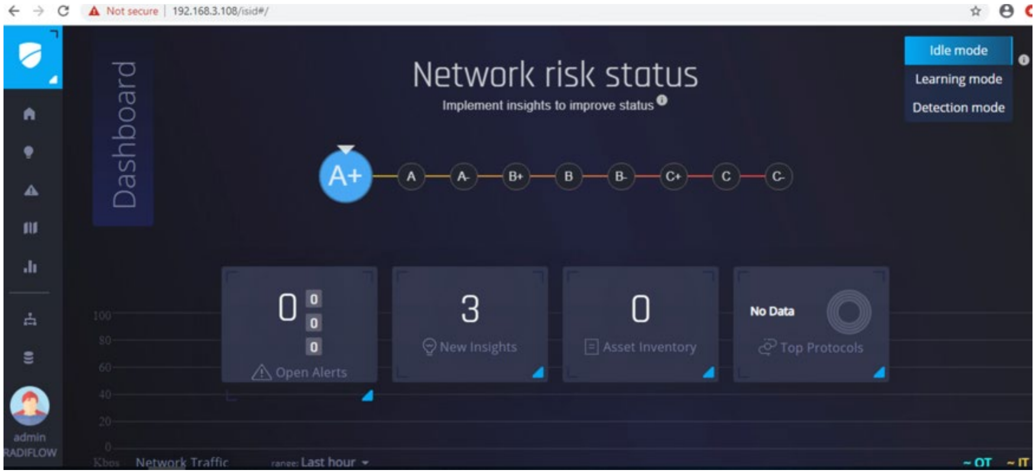
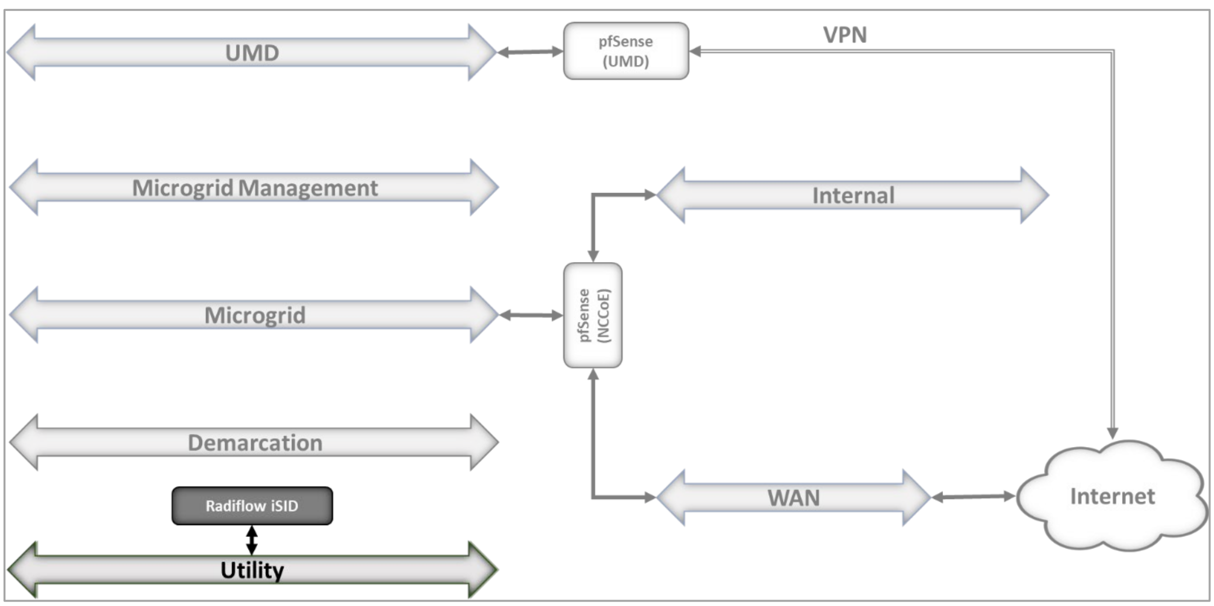


Figure 2-3 shows the location of Radiflow iSID in the example solution.

Figure 2-4 Radiflow iSID position in the example solution



2.5 Spherical Analytics Immutably ™

We implemented the command register element of the reference architecture using the Spherical Analytics Immutably service. Immutably receives records of information exchanges from the distribution ops systems, the front-end processor, and the microgrid master controller. It digitally signs the records, augments them with information from notaries providing time stamps and source information, and places them on a distributed ledger. This ledger provides an immutable audit trail of information exchanges between the utility and microgrid DER devices.

The records in the ledger are cryptographically chained together to provide tamper detection. The utility and all participating microgrid operators can read and verify the audit trail maintained by the Immutably distributed ledger.

2.5.1 Spherical Analytics Immutably Installation and Configuration

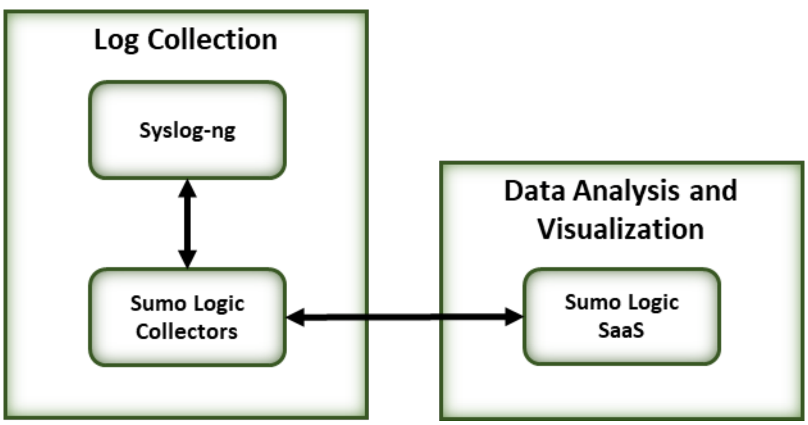
Immutably is a software-as-a-service product and no installation was required. We developed three pieces of software to send data to Immutably. The source for this software is provided in Appendix B.

The records are sent using an Immutably representational state transfer (REST) application programming interface.

2.6 Sumo Logic

Sumo Logic provides a cloud-based SIEM capability for analyzing and visualizing security information and events that implement the data analysis and visualization elements of the reference architecture. Sumo Logic data analytics and visualization are software-as-a-service products. No installation was required for the analytic and visualization services. Figure 2-5 shows Sumo Logic's role in the reference architecture.

Figure 2-5 Sumo Logic Role in the Example Solution

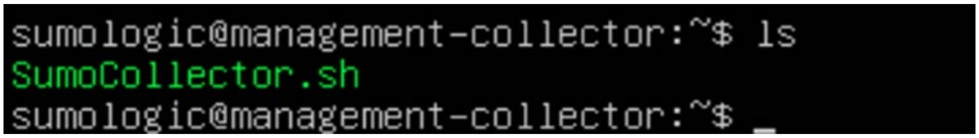


2.6.1 Sumo Logic syslog Collector Installation

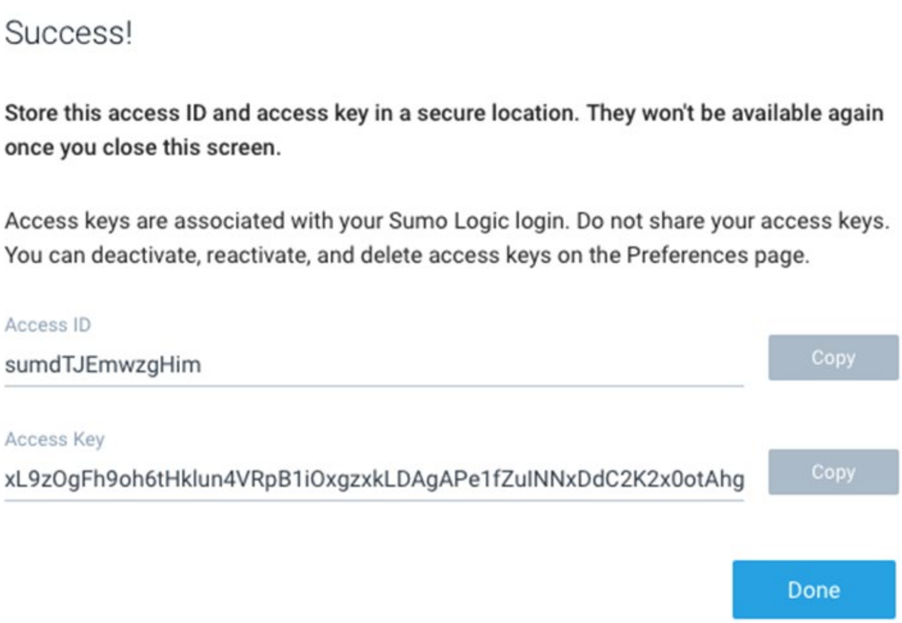
We installed the Sumo Logic syslog collector on a Linux system to send syslog data to Sumo Logic for analysis. The Sumo Logic collector provides one of the two parts that make up the log collection element of the reference architecture. We combined the Sumo Logic syslog collector with the open-source version of syslog ng to create the log collector element of the reference architecture.

1. We set up an Ubuntu Linux VM and installed the collector using a command provided by Sumo Logic:

    a. sudo wget "https://collectors.us2.sumologic.com/rest/download/linux/64" -O SumoCollector.sh && sudo chmod +x SumoCollector.sh && sudo ./SumoCollector.sh && chmod +x SumoCollector.sh



2. Next, an authentication method is required to get the access key and access ID or installation token strings from the Sumologic account, which will be used to register installed collectors. Navigate to Preferences from the menu options.
    a. Click **Add Access Key** and add a username for your collector.
    b. Click **Create Key** to see the access ID and Access Key you created.



3. Run the command:
    a. sudo ./SumoCollector.sh -q -Vsumo.accessid=<accessId> -Vsumo.accesskey=<accessKey> -Vsources=<filepath>

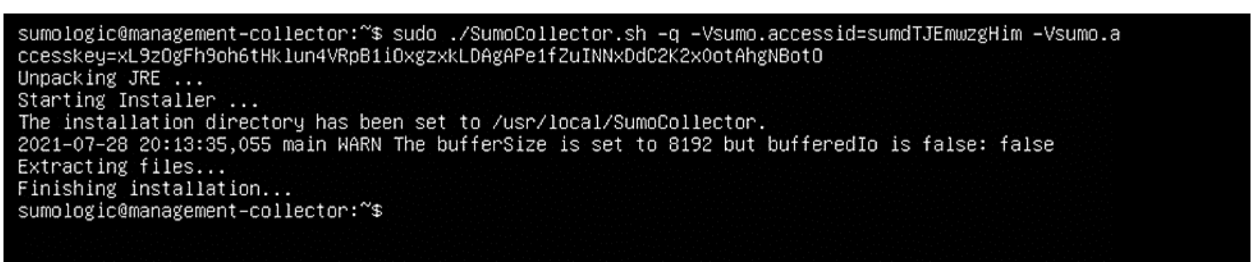
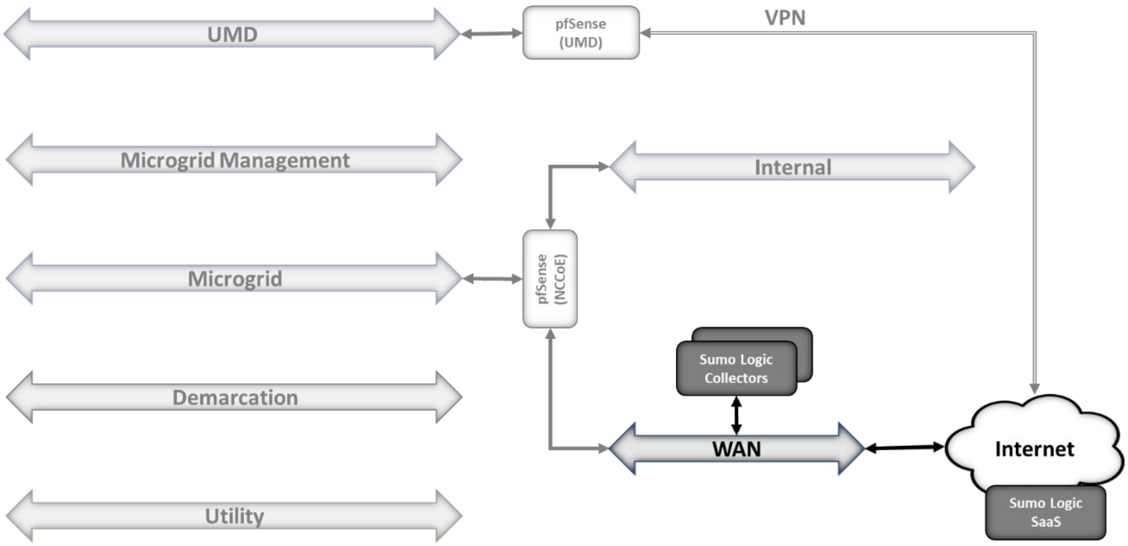


Figure 2-5 shows the location of Sumo Logic collectors and Sumo Logic SaaS in the example solution.

Figure 2-6 Sumo Logic Location in the Example Solution

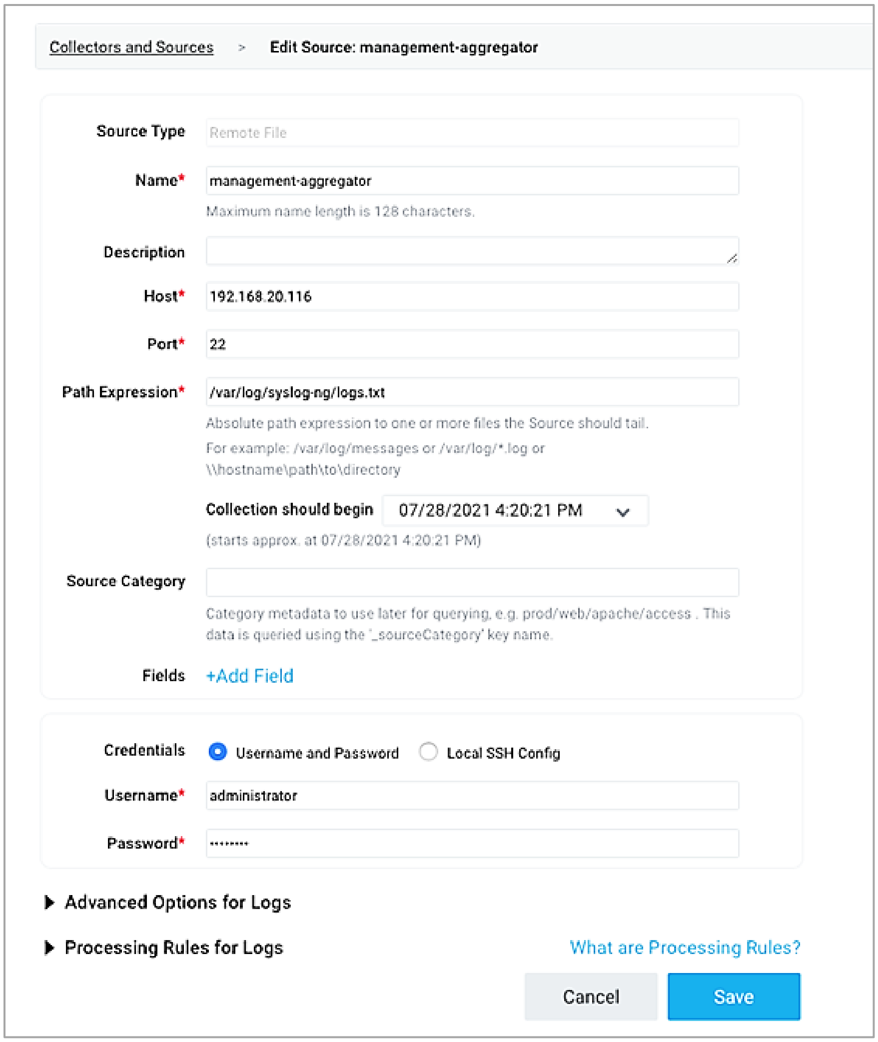


2.6.2 Configuring Sources for syslog Collectors

For each installed collector, we are using Syslog or remote file as our source type. Each product's log data goes to a syslog aggregator, implemented with Syslog ng, before reaching the Sumo Logic collector. Installation and configuration guide for Syslog-ng is described in section 2.10.

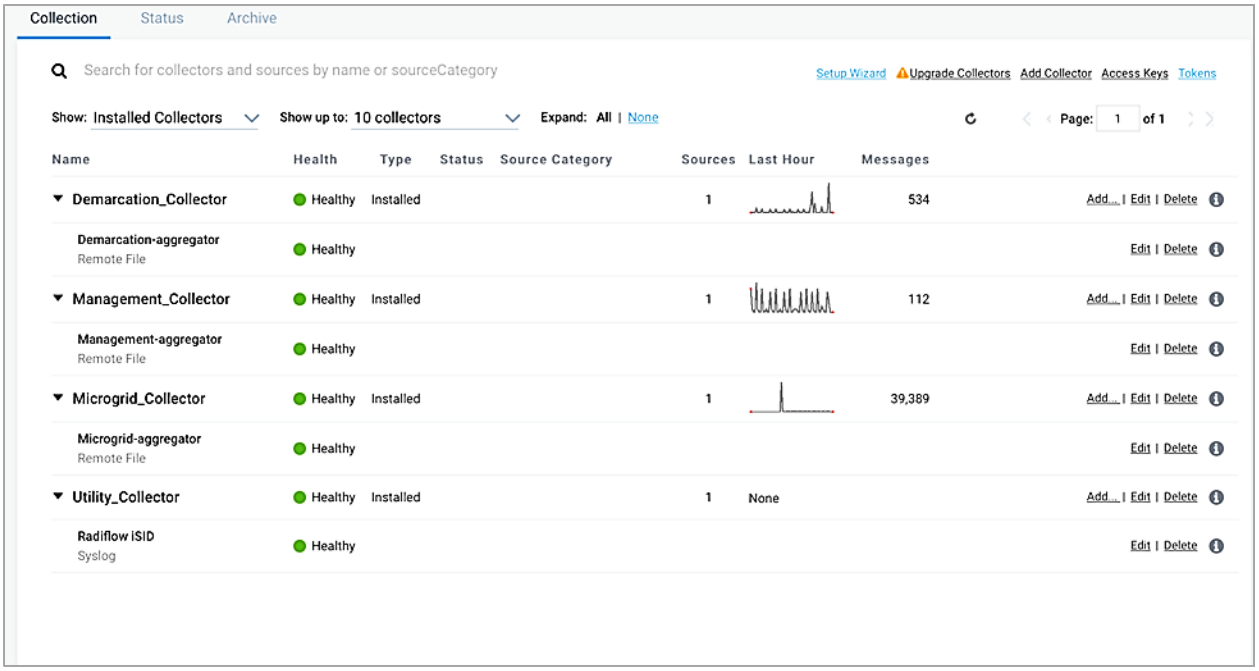
1. Navigate to **Manage Data > Collection** on the **Collector** menu.
2. Click **Add Source** for Collector management-collector.

3. Select the **Remote File** source and provide the following information for source and destination:
    a. Name: `management-aggregator`
    b. Host: `193.168.20.116`
    c. Port: `22`
    d. Path Expression: `cd /var/log/syslog-ng/logs.txt`



4. Click **Save.**

We configured four collectors, one for each of the eight networks used in the example solution, microgrid, microgrid management, demarcation, and utility. This configuration is shown below.



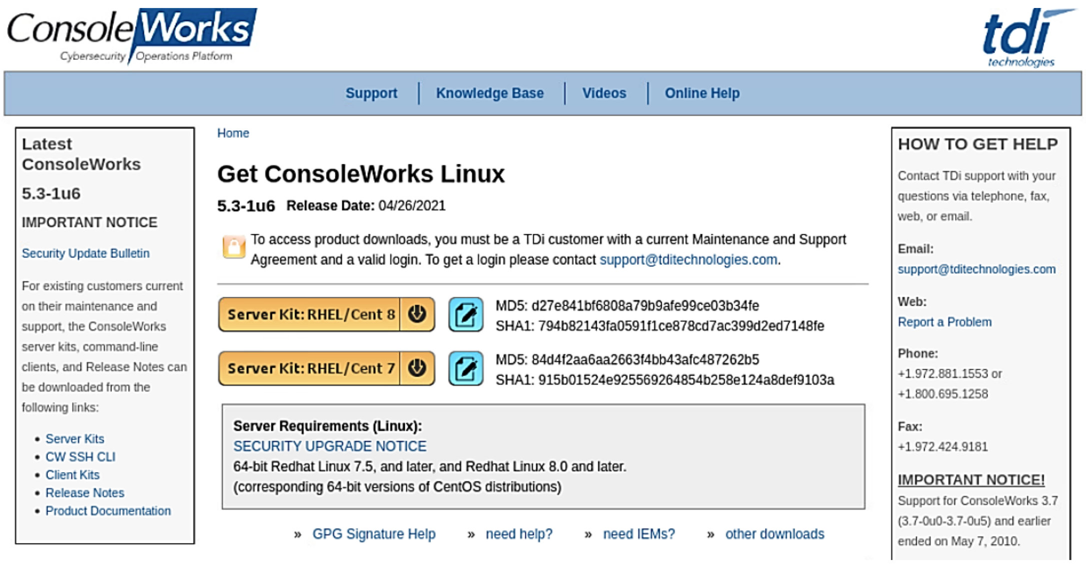
2.7 TDi Technologies ConsoleWorks

TDi Technologies ConsoleWorks serves as a ”jump box” to control privileged user access to the management interfaces of Cisco ISE and Cisco Cyber Vision. ConsoleWorks maintains the credentials used to access the dedicated management interfaces of these products. Privileged users have credentials that allow them to access ConsoleWorks. ConsoleWorks uses “user profiles” to define the management interfaces that each privileged user is allowed to access, and the credentials used to access that interface. ConsoleWorks authenticates authorized users to product management interfaces and records all privileged user actions in an audit trail.

2.7.1 Console Works Installation and Configuration

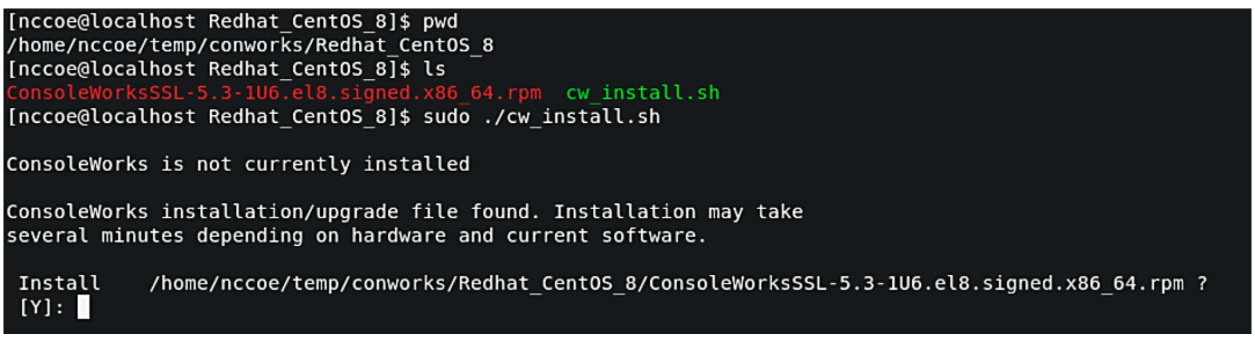
Create a virtual machine running Centos 7.5 with one network interface, dynamic host configuration protocol disabled, and an IP address `192.168.20.109`, then:

1. Download the installation kit from the Tdi website at http://support.tditechnologies.com. A username and password are required. Contact Tdi Support at support@tditechnologies.com to request a username and password. You will also need a unique link from Tdi Technologies for the ConsoleWorks License ZIP file. Download this file (do not unzip it) to your chosen directory.

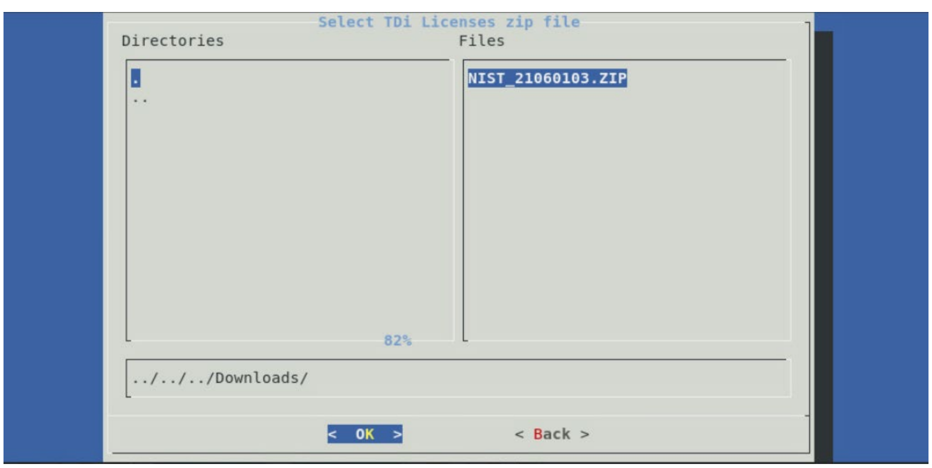


2. Create a directory to contain the ConsoleWorks installation files: `$mkdir -p temp/conworks`.

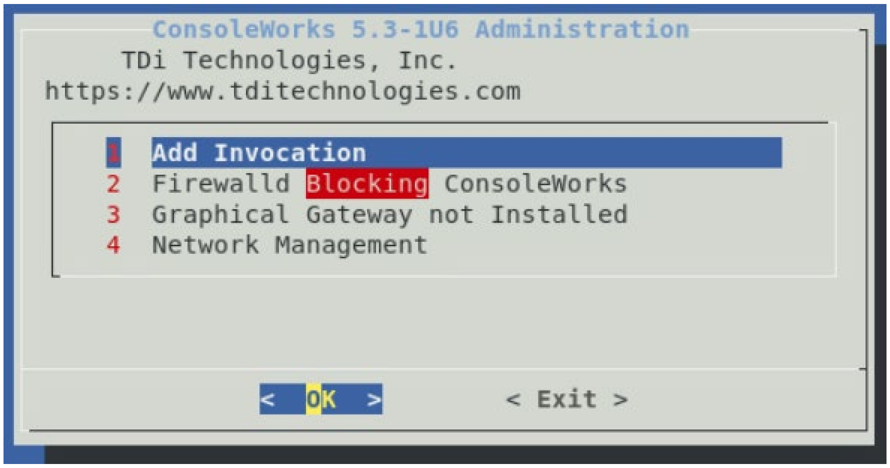
3. Inside the new directory, run the install script: `$sudo ./cw_install.sh`.

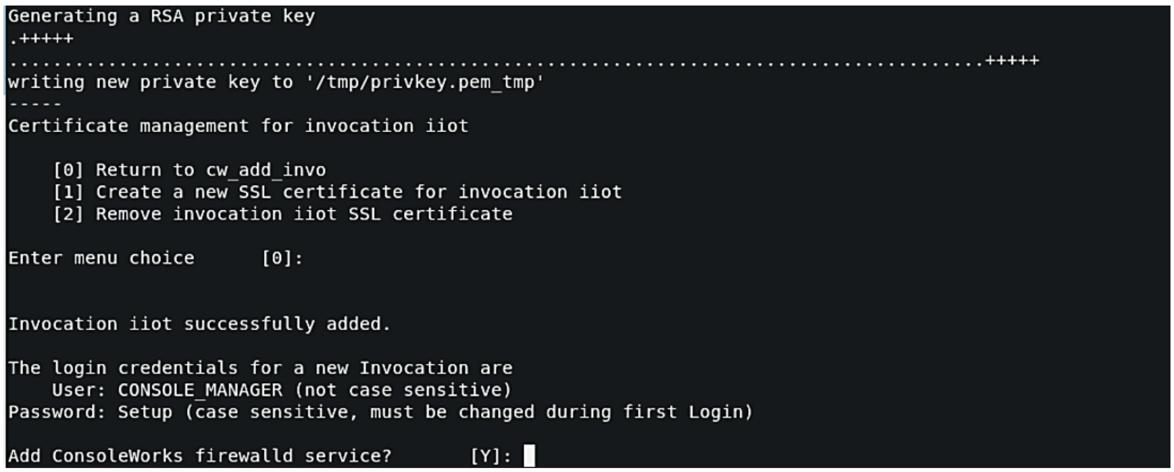


4. Follow the installer script to select the previously downloaded license file.

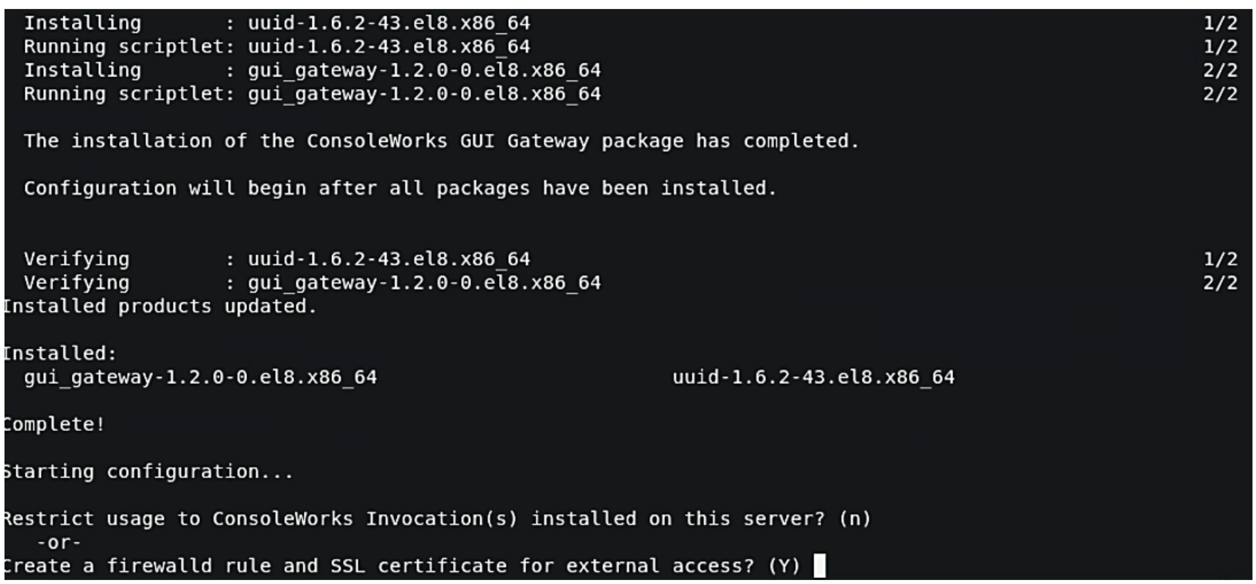


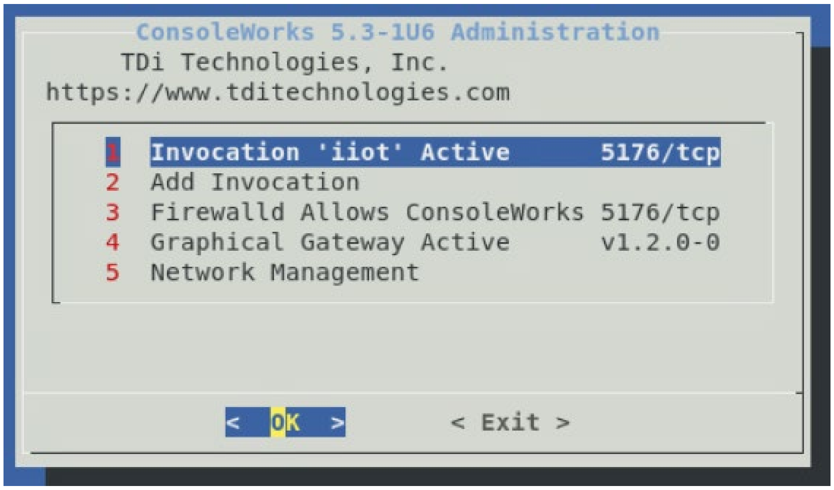
5. Follow the prompts to add an invocation, configure the firewall, install the Graphical Gateway, and any other network management settings.


ConsoleWorks 5.3-1U6 Administration
TDi Technologies, Inc.
https://www.tditechnologies.com
1 Add Invocation
2 Firewalld Blocking ConsoleWorks
3 Graphical Gateway not Installed
4 Network Management
< OK >
< Exit >


Generating a RSA private key
.+++++
....+++++
writing new private key to '/tmp/privkey.pem_tmp'

Certificate management for invocation iiot
[0] Return to cw_add_invo
[1] Create a new SSL certificate for invocation iiot
[2] Remove invocation iiot SSL certificate
Enter menu choice [0]:
Invocation iiot successfully added.
The login credentials for a new Invocation are
User: CONSOLE_MANAGER (not case sensitive)
Password: Setup (case sensitive, must be changed during first Login)
Add ConsoleWorks firewalld service? [Y]:

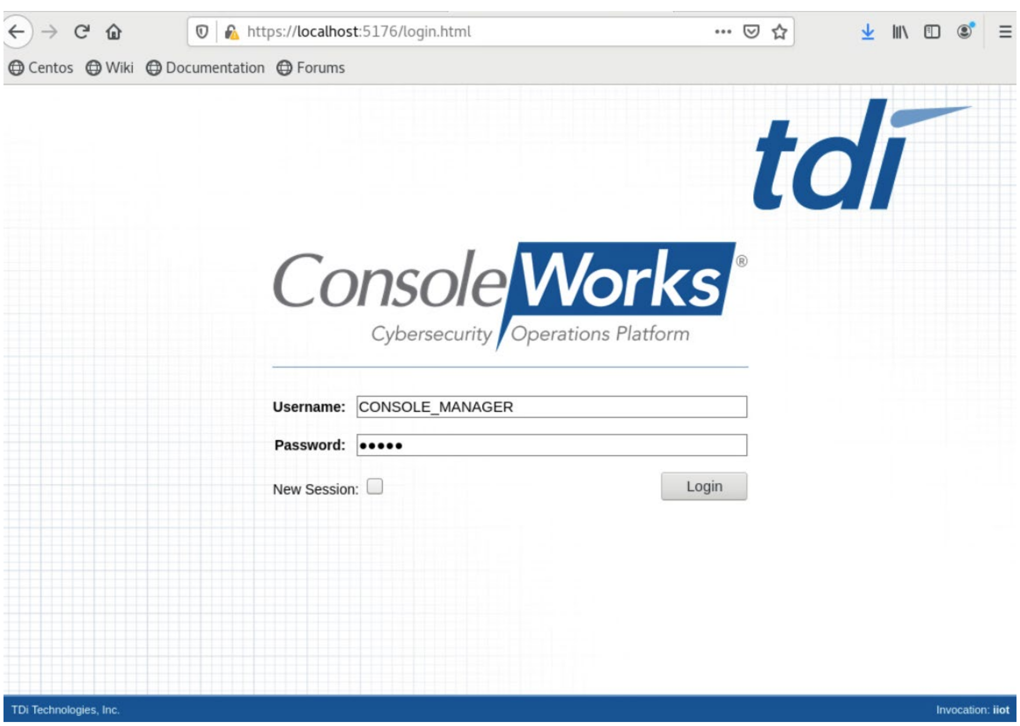

Installing : uuid-1.6.2-43.el8.x86_64 1/2
Running scriptlet: uuid-1.6.2-43.el8.x86_64 1/2
Installing : gui_gateway-1.2.0-0.el8.x86_64 2/2
Running scriptlet: gui_gateway-1.2.0-0.el8.x86_64 2/2
The installation of the ConsoleWorks GUI Gateway package has completed.
Configuration will begin after all packages have been installed.
Verifying : uuid-1.6.2-43.el8.x86_64 1/2
Verifying : gui_gateway-1.2.0-0.el8.x86_64 2/2
Installed products updated.
Installed:
gui_gateway-1.2.0-0.el8.x86_64 uuid-1.6.2-43.el8.x86_64
Complete!
Starting configuration...
Restrict usage to ConsoleWorks Invocation(s) installed on this server? (n)
-or-
Create a firewalld rule and SSL certificate for external access? (Y)



6. When the ConsoleWorks Administration script shows the details of the invocation and firewall settings, installation is complete. Select Exit to close the script.

7. If ConsoleWorks did not autostart, run the following command: `# /opt/ConsoleWorks/bin/cw_start <invocation name>`.

8. Log in to the ConsoleWorks local instance at `https://localhost:5176` (or a different port number if configured) with the username *CONSOLE_MANAGER* and the password "Setup". You will be required to set up a new password when complete.

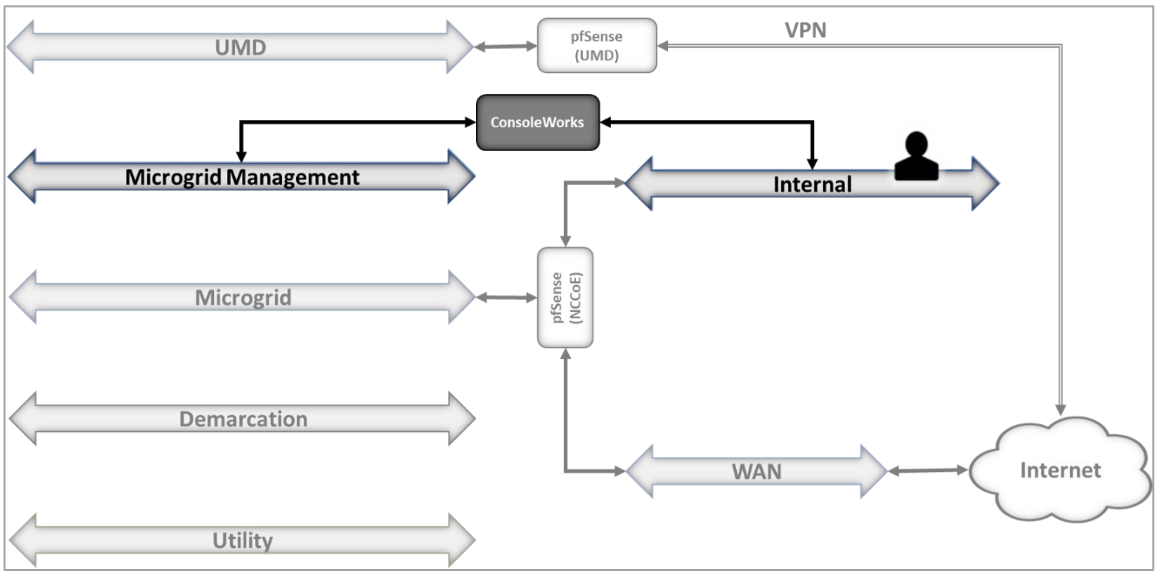


Three privileged users were defined in ConsoleWorks:

- One user has permission and credentials to access Cisco Cyber Vision
- One user has permission and credentials to access Cisco ISE
- One user has permission and credentials to access both Cisco Cyber Vision and Cisco ISE

Figure 2-7 shows ConsoleWorks position in the example solution.

Figure 2-7 ConsoleWorks Position in the Example Solution



2.8 Xage Security Fabric

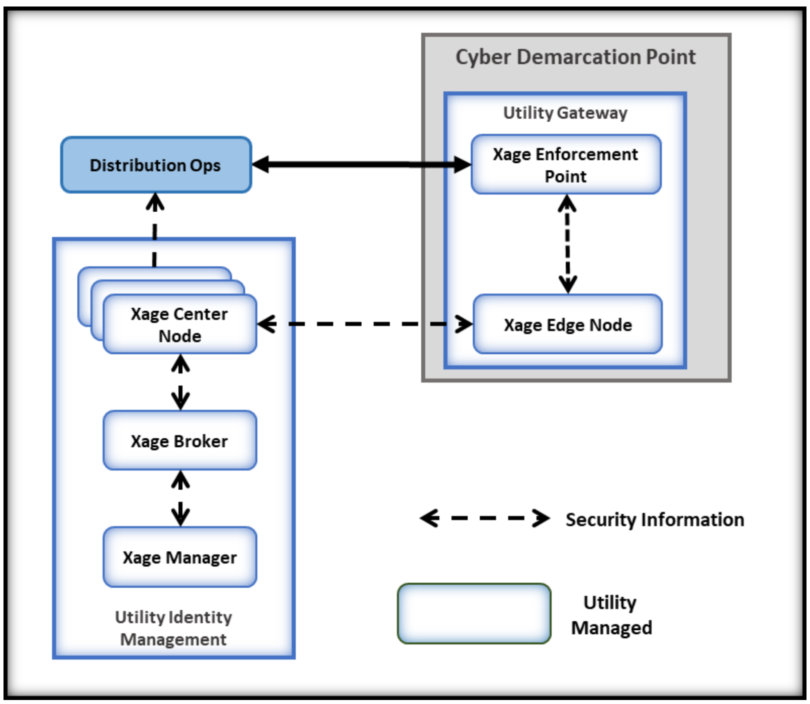
The Xage Security Fabric implements the utility identity management and utility GW elements of the reference architecture. The fabric consists of five services, the Xage Manager, Xage Broker, Xage Cener Fabric Node, the Xage Edge Node, and the Xage Enforcement Point. The Xage Manager, Xage Broker, and Xage Center Nodes combine to implement the utility identity management element. The Xage Edge Node and Xage Enforcement Point implement the utility GW.

- The Xage Manager configures users, devices, and access policies. The policies are then sent to Xage Broker. There is one Xage Manager operated by the utility and used to configure security policies for access to all DERs.
- The Xage Broker is a liaison between the Xage Manager and the Xage Center Nodes. The broker copies information such as identities and credentials from the Xage Manager to the Xage Edge nodes. In the NCCoE example solution, there is one Xage Broker operated by the utility to distribute access policies for all DERs via the distributed ledger operated on the Xage Center Nodes.
- The Xage Center Nodes use a distributed ledger to provide a geographically distributed information store that is tamperproof. The Xage Broker distributes policy information to the

Xage Center Nodes. This distributed information store provides policy information for the Xage Edge Nodes.

- A Xage Edge Node is in the cyber demarcation point at each microgrid operator site. The Xage Edge Node retrieves security information for its site from the Xage Center Nodes and stores it locally within the cyber demarcation point.
- The Xage Enforcement Point (XEP) in the cyber demarcation point uses the security information to allow or deny access to the front-end processor.

Figure 2-8 Xage Implementation of Reference Architecture Elements



2.8.1 Xage Installation and Configuration

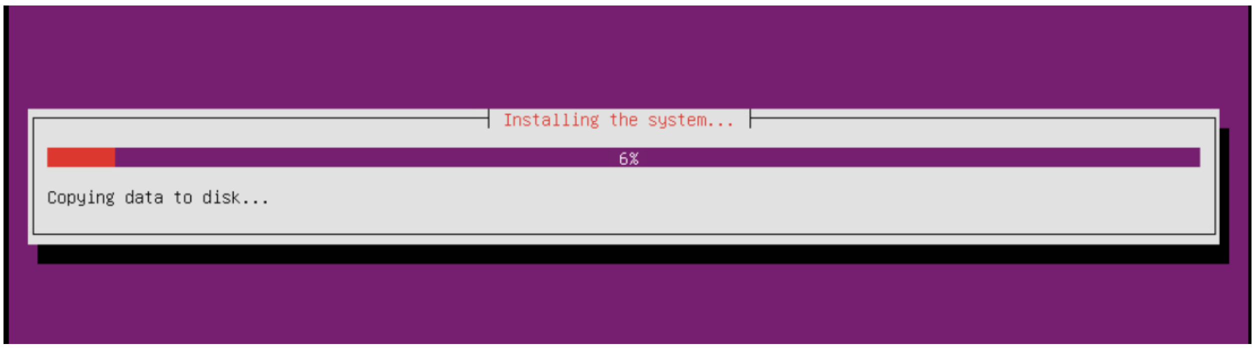
Xage provides a Linux ISO file configured with all the packages needed by the Xage services. We used this ISO to create all the VMs needed by the installation.

We followed the instructions in the XSG_Release_3.3_Install guide provided by Xage.

1. Starting on page 7 of the guide, we used Xage Built ISOs (2.1.1)
2. Starting on page 13, the install happens.
    a. We created the VM for the Xage Manager using the provided ISO
        i. The Xage Manager IP address id 192.168.3.102.
        ii. We then created three more VMs using the Xage-provided ISO, one each for
            1. Xage Broker

        2. Xage Center Fabric Node
        3. Xage Edge Node
    iii. During the install starting on page 13, we configure the Xage manager with the IP addresses of the three different VMs, and the Xage manager deploys the appropriate software to those other VMs.

3. Begin the install and follow the Custom ISO install guide: Create a VM with 2 cores in the CPU, 8Gb RAM, and 60Gb Hard Drive size. Load the Xage Custom ISO into the virtual CD Drive and start the installer. Once completed, continue with the install.

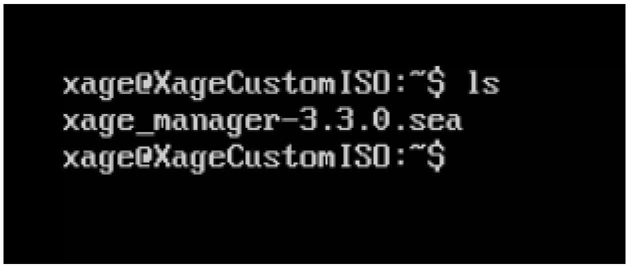


3. During the install, Xage creates a user that is used with the username **xage** and password **secret**. Log in to the VM using these credentials.

5. Type *sudo vi /etc/ssh/sshd_config* (or a different text editor) and ensure **PubkeyAuthentication** and **PasswordAuthentication** are uncommented and are set to **yes**. Then run *ifconfig* to get the IP address from the ethernet device.

```
# Don't read the user's ~/.rhosts and ~/.shosts files
IgnoreRhosts yes
# For this to work you will also need host keys in /etc/ssh_known_hosts
RhostsRSAAuthentication no
# similar for protocol version 2
HostbasedAuthentication no
# Uncomment if you don't trust ~/.ssh/known_hosts for RhostsRSAAuthentication
#IgnoreUserKnownHosts yes

# To enable empty passwords, change to yes (NOT RECOMMENDED)
PermitEmptyPasswords no

# Change to yes to enable challenge-response passwords (beware issues with
# some PAM modules and threads)
ChallengeResponseAuthentication no

# Change to no to disable tunnelled clear text passwords
PasswordAuthentication yes
"/etc/ssh/sshd_config" 88L, 2541C written
xage@XageCustomISO:~$ ifconfig
docker0   Link encap:Ethernet  HWaddr 02:42:f2:9e:25:24
          inet addr:172.17.0.1  Bcast:172.17.255.255  Mask:255.255.0.0
          UP BROADCAST MULTICAST  MTU:1500  Metric:1
          RX packets:0 errors:0 dropped:0 overruns:0 frame:0
          TX packets:0 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:0
          RX bytes:0 (0.0 B)  TX bytes:0 (0.0 B)

ens192    Link encap:Ethernet  HWaddr 00:50:56:ad:72:7b
          inet addr:192.168.20.112  Bcast:192.168.20.255  Mask:255.255.255.0
          inet6 addr: fe80::250:56ff:fead:727b/64 Scope:Link
          UP BROADCAST RUNNING MULTICAST  MTU:1500  Metric:1
          RX packets:43 errors:0 dropped:0 overruns:0 frame:0
          TX packets:56 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:1000
          RX bytes:19814 (19.8 KB)  TX bytes:5987 (5.9 KB)

lo        Link encap:Local Loopback
          inet addr:127.0.0.1  Mask:255.0.0.0
          inet6 addr: ::1/128 Scope:Host
          UP LOOPBACK RUNNING  MTU:65536  Metric:1
          RX packets:160 errors:0 dropped:0 overruns:0 frame:0
          TX packets:160 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:1
          RX bytes:11840 (11.8 KB)  TX bytes:11840 (11.8 KB)

xage@XageCustomISO:~$ _
```

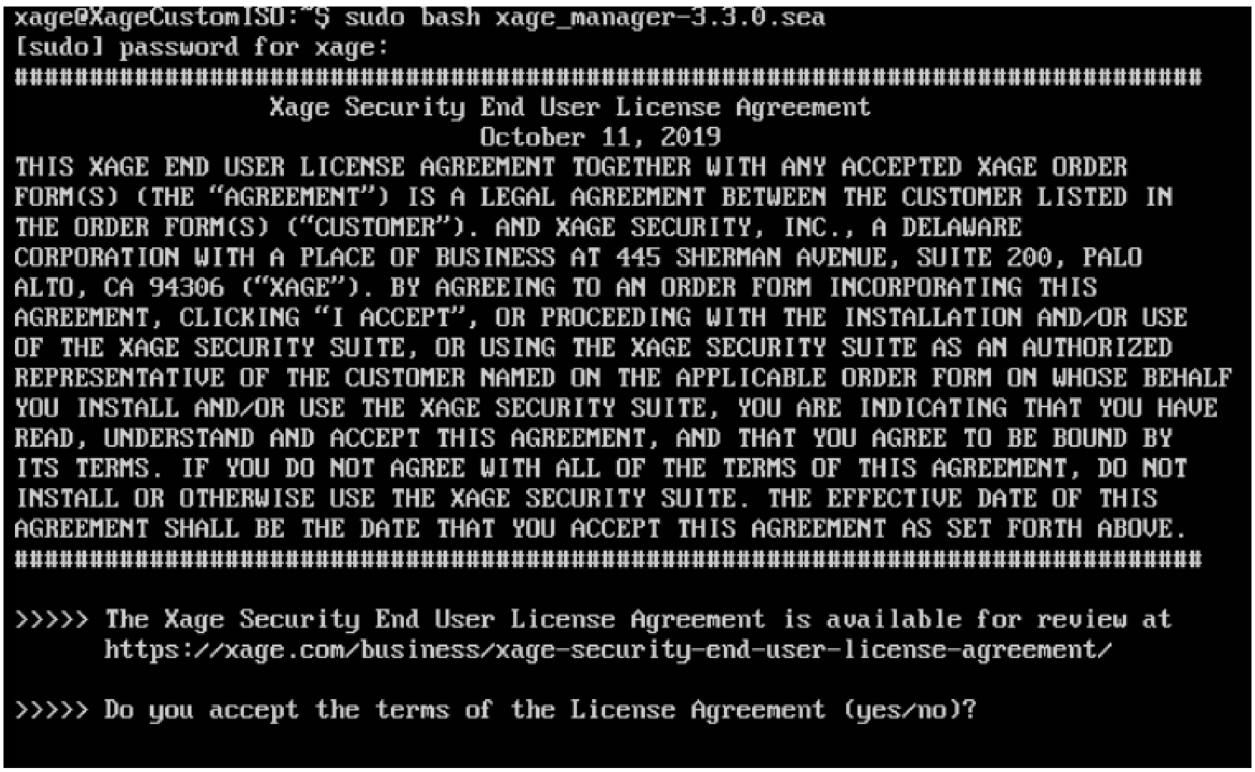
6. Using secure copy (SCP), copy the xage SEA file for installation to the Xage home drive.



```
xage@XageCustomISO:~$ ls
xage_manager-3.3.0.sea
xage@XageCustomISO:~$
```

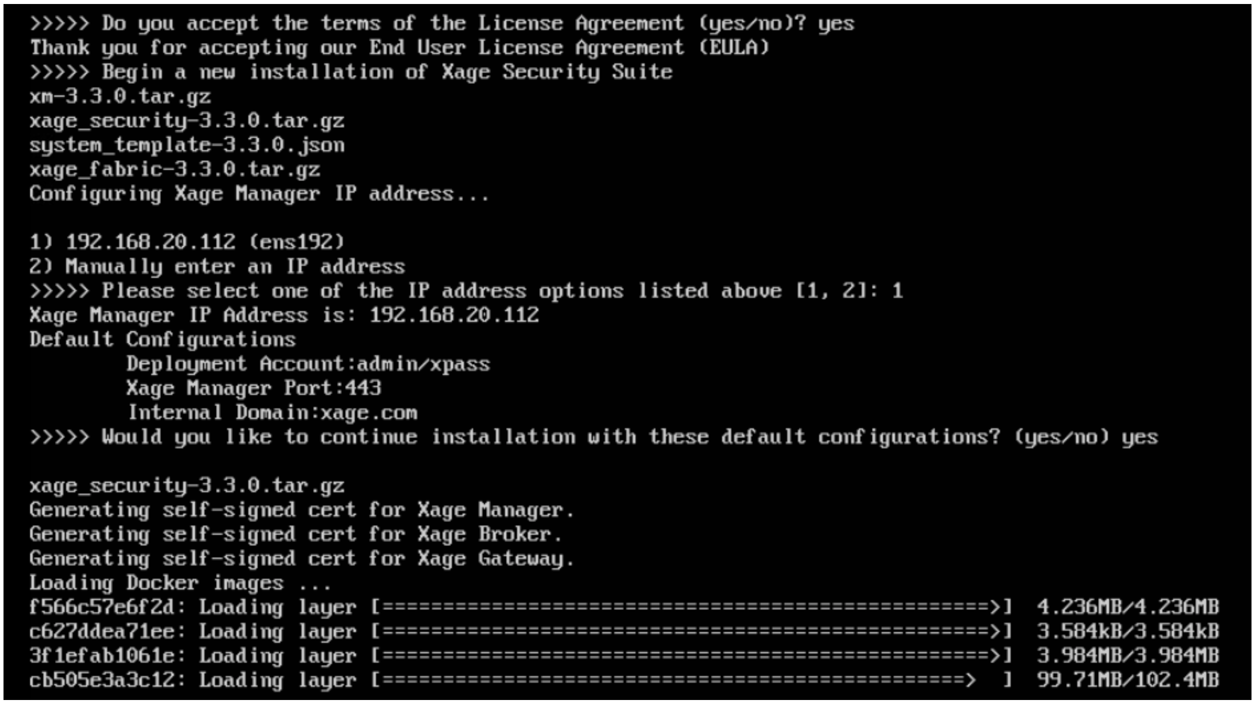
7. Beginning with the install guide, we opted to utilize Xage for managing users and user groups internally (as opposed to LDAP or Active Directory).

8. Begin installation by running *sudo bash xage_manager-3.3.0.sea* and accepting the EULA. Xage will then extract all the files.



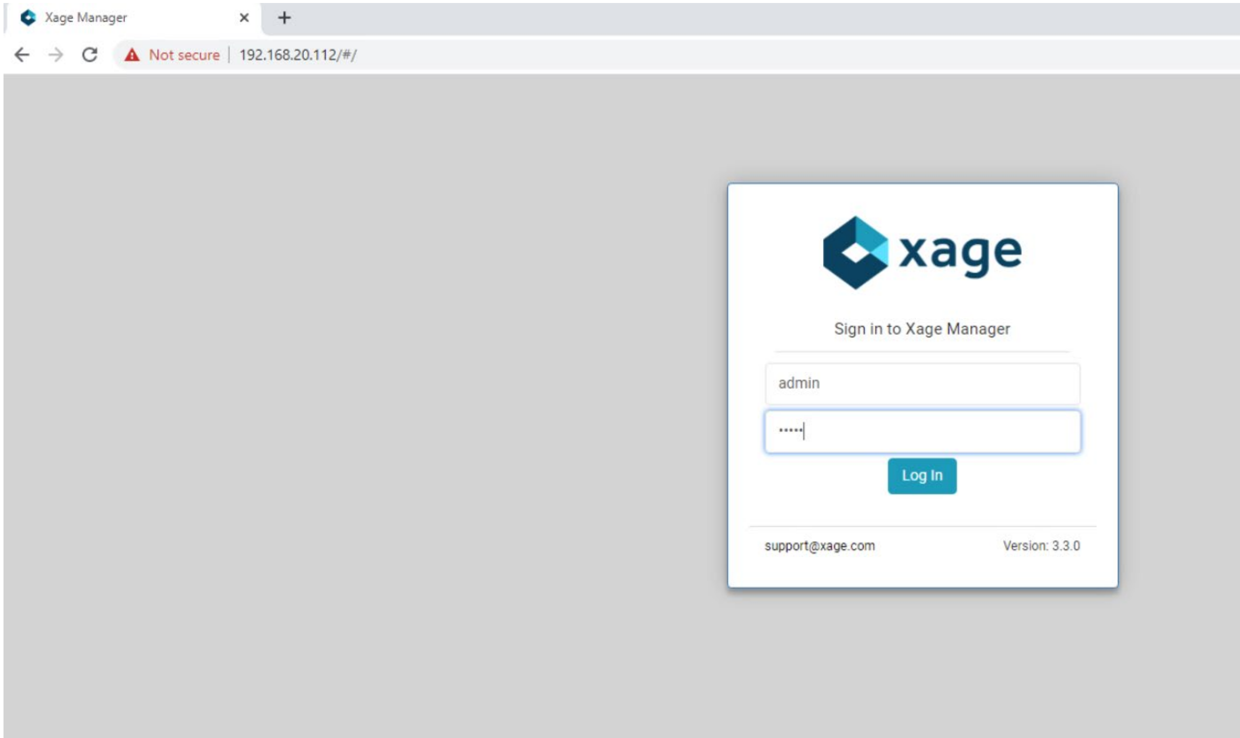
```
xage@XageCustomISO:~$ sudo bash xage_manager-3.3.0.sea
[sudo] password for xage:
################################################################################
                 Xage Security End User License Agreement
                              October 11, 2019
THIS XAGE END USER LICENSE AGREEMENT TOGETHER WITH ANY ACCEPTED XAGE ORDER
FORM(S) (THE "AGREEMENT") IS A LEGAL AGREEMENT BETWEEN THE CUSTOMER LISTED IN
THE ORDER FORM(S) ("CUSTOMER"). AND XAGE SECURITY, INC., A DELAWARE
CORPORATION WITH A PLACE OF BUSINESS AT 445 SHERMAN AVENUE, SUITE 200, PALO
ALTO, CA 94306 ("XAGE"). BY AGREEING TO AN ORDER FORM INCORPORATING THIS
AGREEMENT, CLICKING "I ACCEPT", OR PROCEEDING WITH THE INSTALLATION AND/OR USE
OF THE XAGE SECURITY SUITE, OR USING THE XAGE SECURITY SUITE AS AN AUTHORIZED
REPRESENTATIVE OF THE CUSTOMER NAMED ON THE APPLICABLE ORDER FORM ON WHOSE BEHALF
YOU INSTALL AND/OR USE THE XAGE SECURITY SUITE, YOU ARE INDICATING THAT YOU HAVE
READ, UNDERSTAND AND ACCEPT THIS AGREEMENT, AND THAT YOU AGREE TO BE BOUND BY
ITS TERMS. IF YOU DO NOT AGREE WITH ALL OF THE TERMS OF THIS AGREEMENT, DO NOT
INSTALL OR OTHERWISE USE THE XAGE SECURITY SUITE. THE EFFECTIVE DATE OF THIS
AGREEMENT SHALL BE THE DATE THAT YOU ACCEPT THIS AGREEMENT AS SET FORTH ABOVE.
################################################################################

>>>>> The Xage Security End User License Agreement is available for review at
      https://xage.com/business/xage-security-end-user-license-agreement/

>>>>> Do you accept the terms of the License Agreement (yes/no)?
```

9. The installer will then prompt for IP addresses. Select the default. Enter "yes" to accept the default configurations. Xage finishes the installation.



10. Once completed, Xage will give information on how to log in with a web server.

11. Log in to the web server at the IP address listed with the username and password listed.



12. After logging in, you will be prompted to add a Xage Broker, Xage Center Node, and Xage Edge Node. These need to be VMs installed in the environment, using the Xage Custom ISO. Following Step 3 of this section will install required base operating systems, then use those IP addresses for the individual installations.

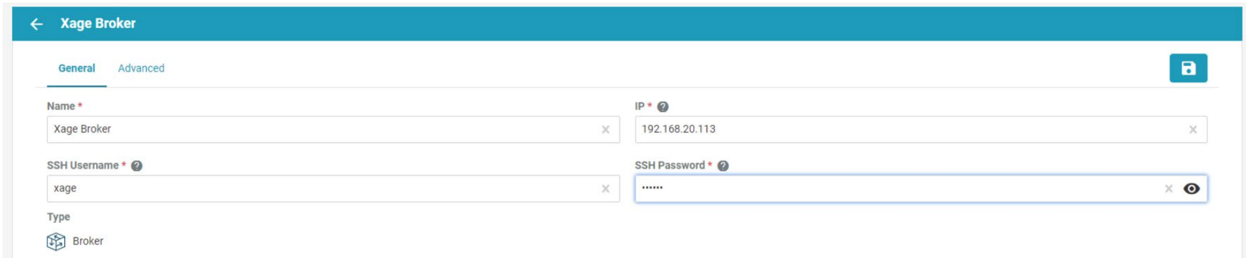
13. Gather the IP addresses of the devices that will be added. In this installation, the IP addresses are as follows:

    a. Broker: 192.168.20.113

    b. Center Nodes (four is the minimum): 192.168.20.114, 192.168.20.117, 192.168.20.118, 192.168.20.119

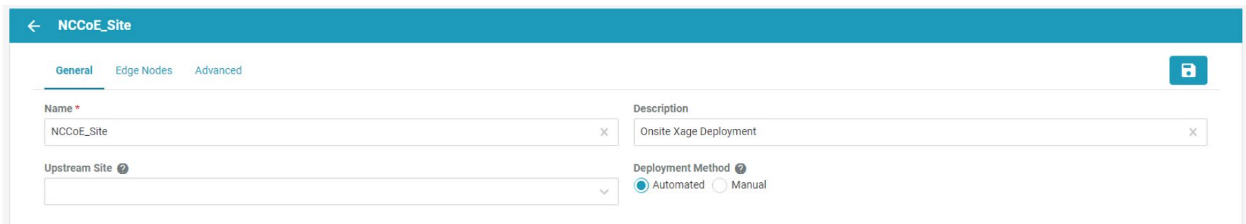
    c. Edge Node: 192.168.20.115

14. Starting with the Xage Broker, click **Add** on the far right of the **Broker** row. Fill in the required information and click the create icon in the top right of the frame.

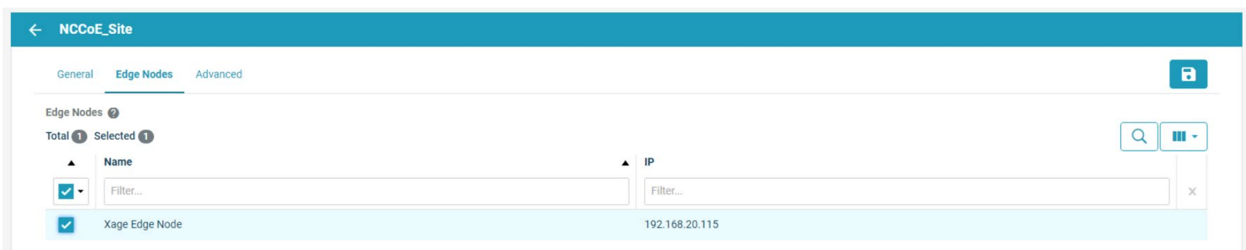


15. Repeat the previous step for Center Node and Edge Node.

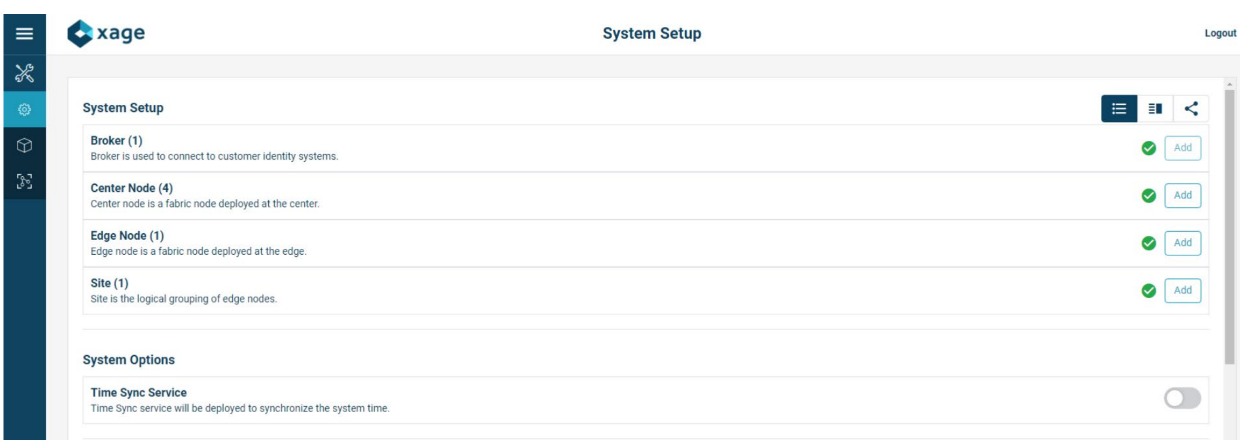
16. Click **Add** on the far right of the **Site** row to add a new site. The **General Configuration** screen opens. Fill in the information as needed.



17. Next, click **Edge Nodes** on the top bar and select the Xage Edge Node created earlier then, click **Create**.

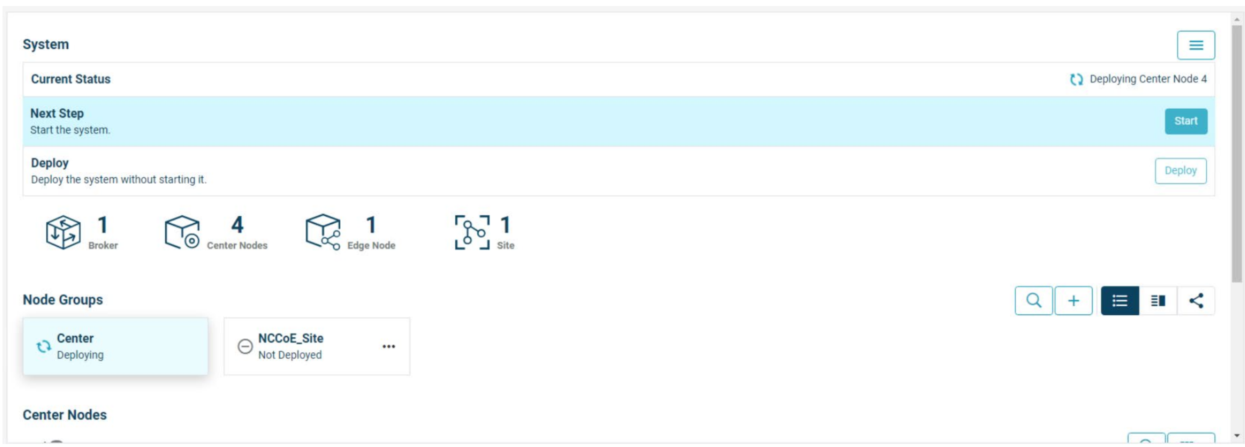


18. Once all devices are configured completely, the **System Setup** page displays all green checks.

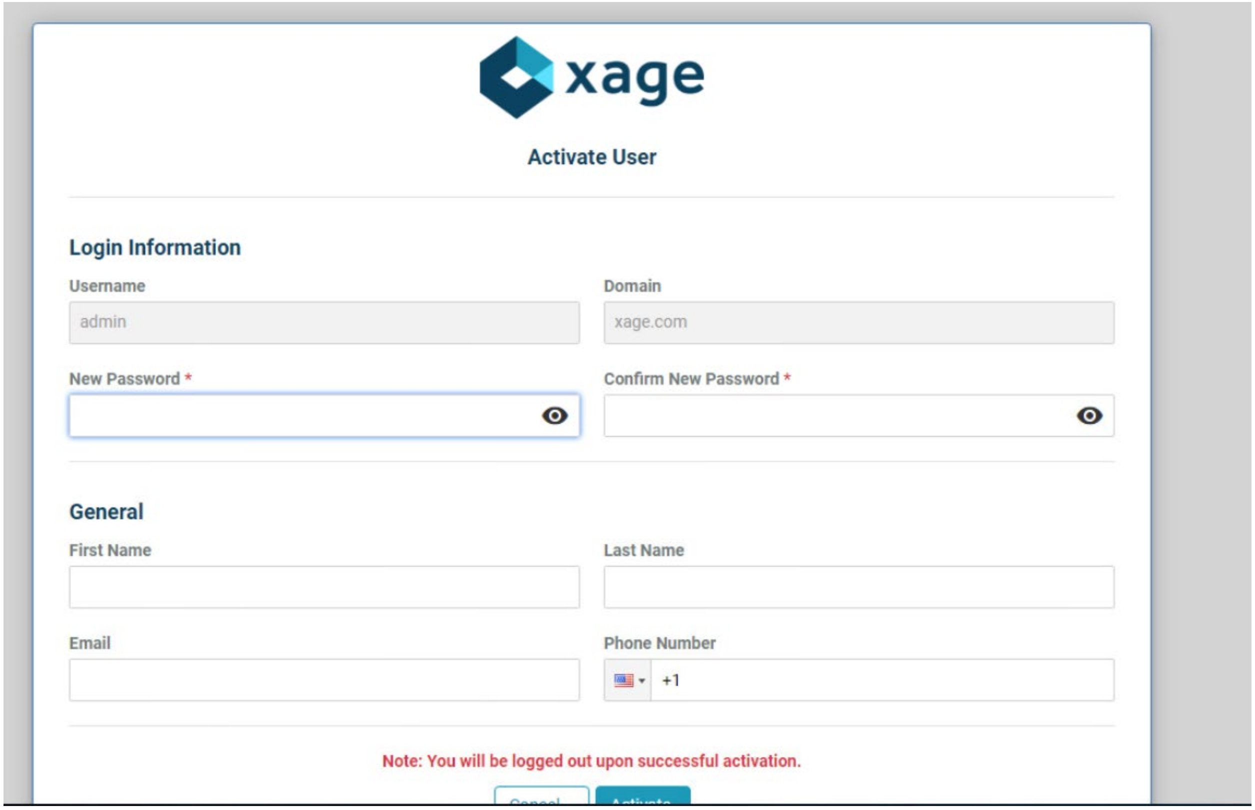


19. At the bottom of the screen, Click **Start** to start the system. Then click **Start** again to confirm.

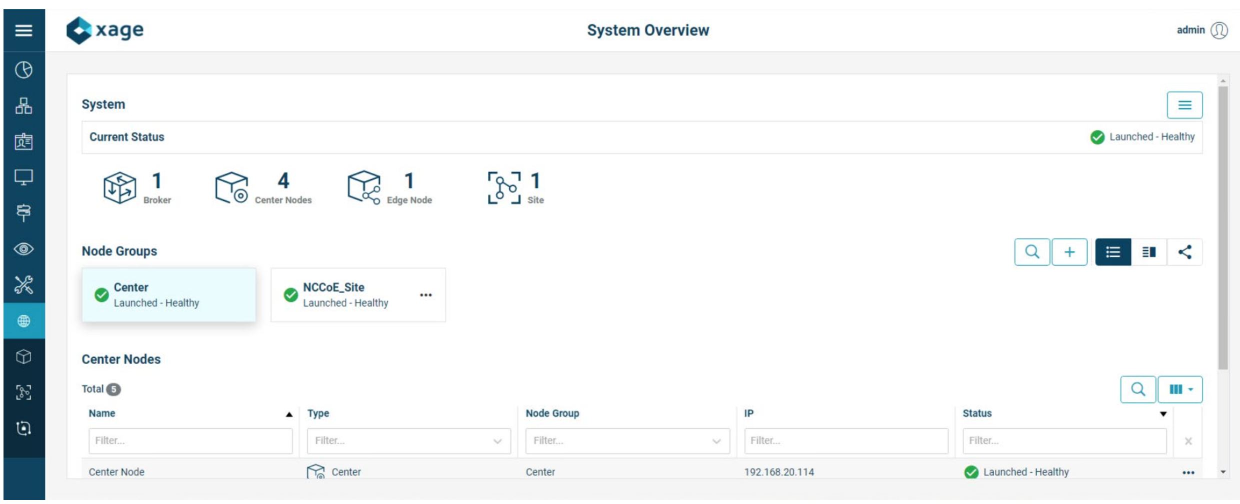
20. Starting will begin for the system, including deploying all nodes. **Current Status** will show what the system is currently doing.



21. After deployment is finished, you will have to login again and change your password to activate the manager.



22. Once logged back in, Xage will show a green check mark labeled **Launched – Healthy**.



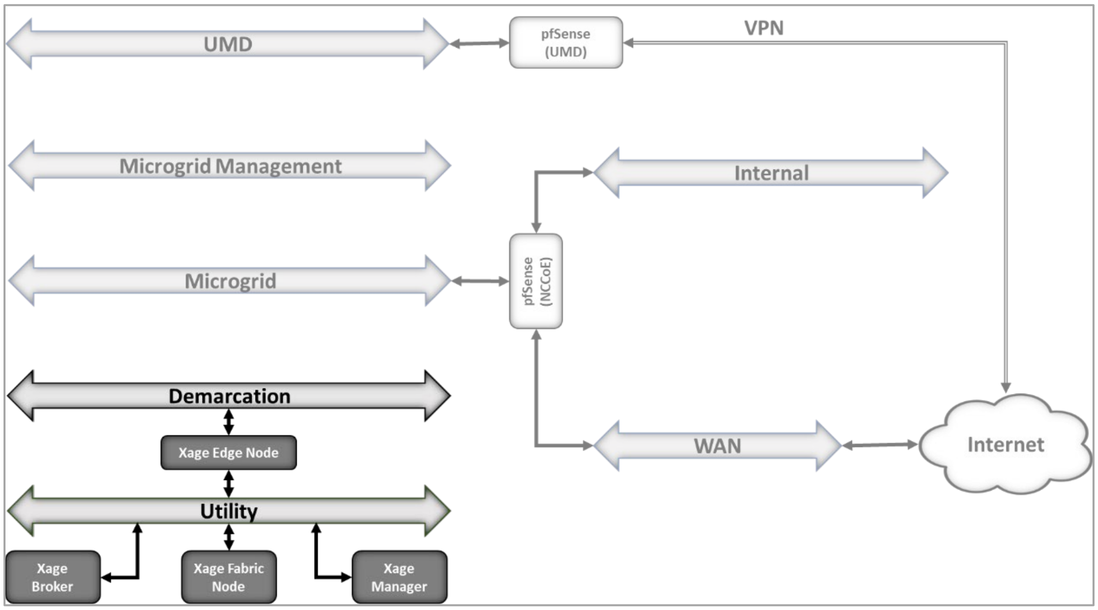
We configured three identities and two devices in the Xage Security Fabric using the Xage manager:

- One device was configured for each solar array at UMD.
- Three identities were configured:
  - One identity was given access to both UMD solar arrays.
  - One identity was given access to only one UMD solar array.

- One identity was given no access to the UMD solar arrays.

Figure 2-9 shows the location of the Xage components in the example solution.

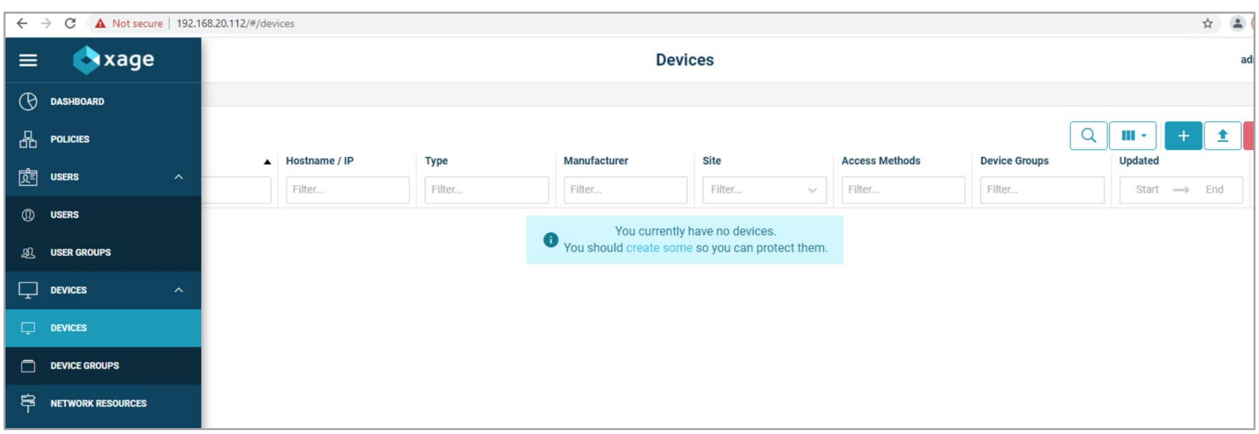
Figure 2-9 Xage Location in the Example Solution



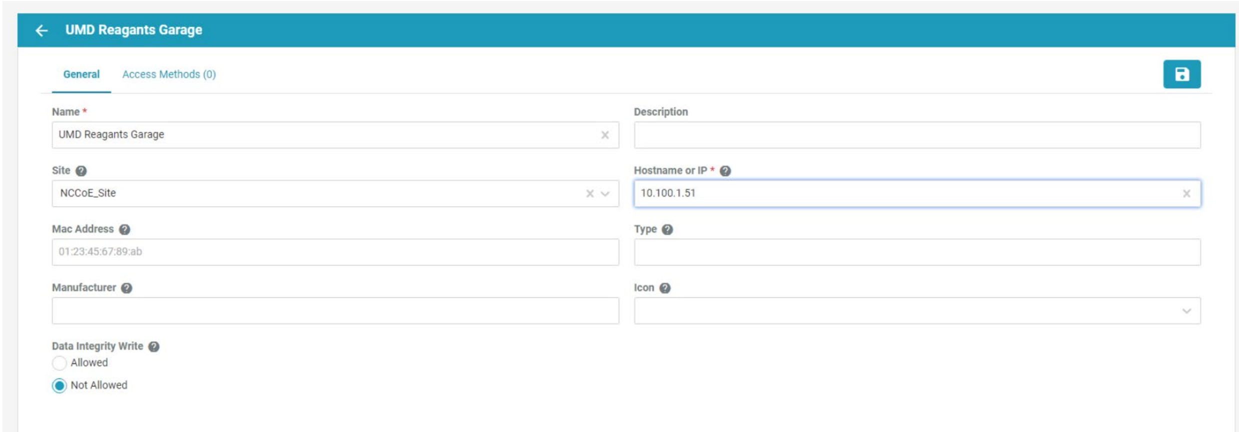
2.8.2 Configure Xage Devices

Follow these steps to configure Xage devices:

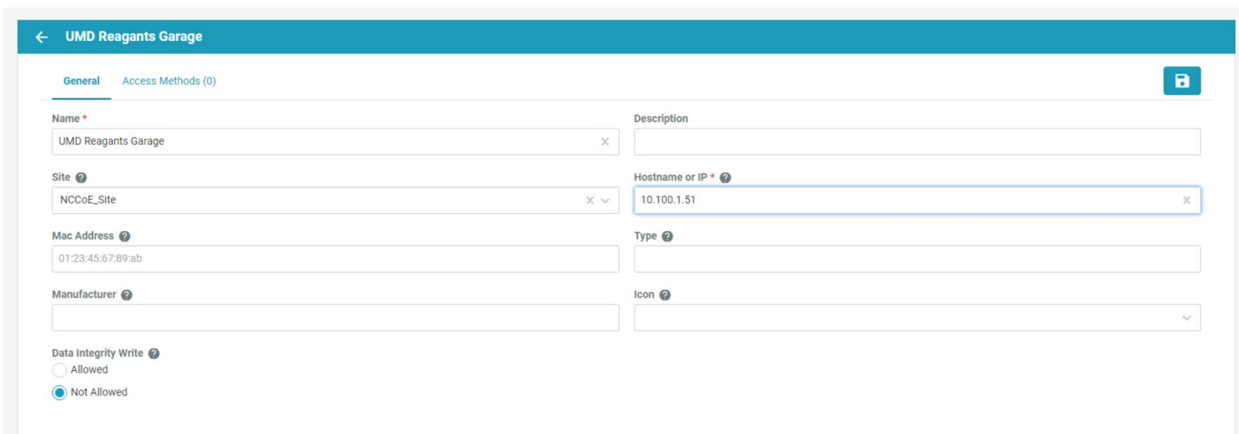
1. From the main Xage System Overview page, select **Devices > Devices** to create new devices for Xage.



2. Click the **+** to create a new device, then fill in the details for that device.



3. Click the **Access Methods** tab and fill in the details for an HTTP Proxy. Then click the **Create** button.

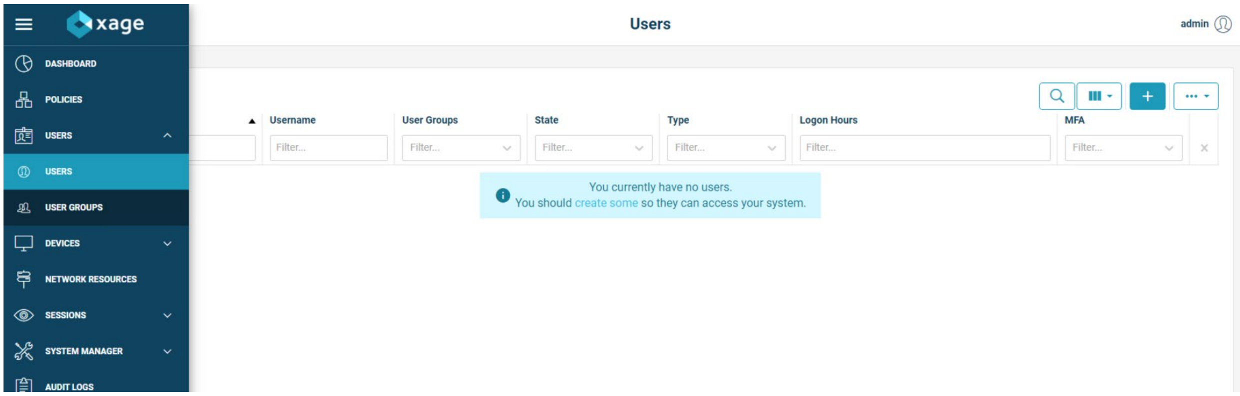


4. Repeat this method for the second device.

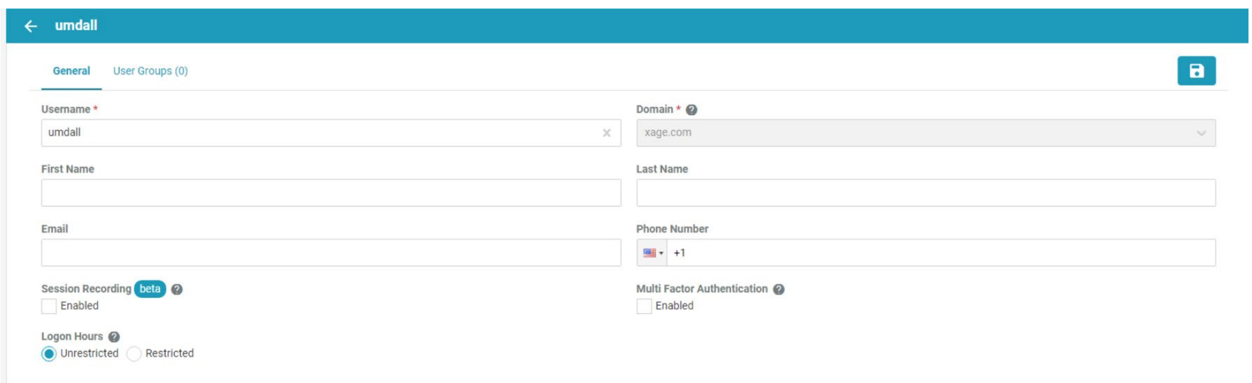
2.8.3 Configure Xage Identities

Follow these steps to configure Xage identities:

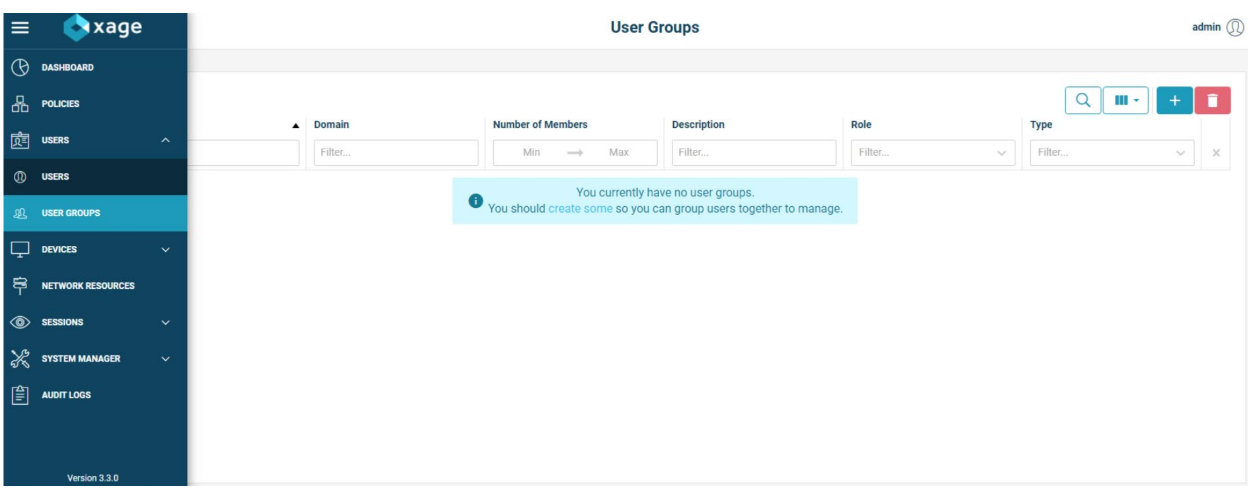
1. From the main Xage System Overview page, select **Users > Users** to create new identities for Xage.



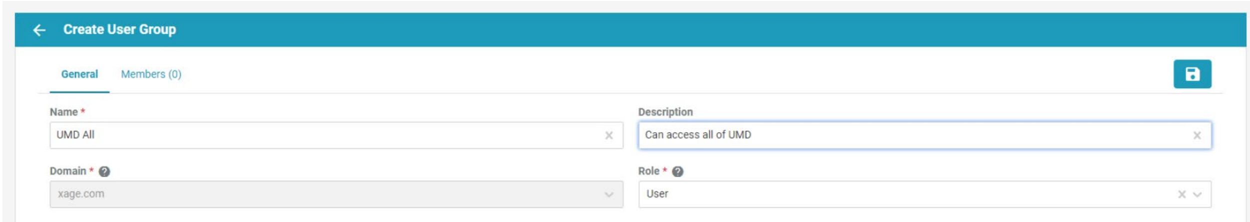
2. Click the **+** to create a new user, then fill in the details for that user. This example shows a user that does not use session recording and does not restrict logon hours. The user also does not use multi-factor authentication. When finished, click the **create** button.



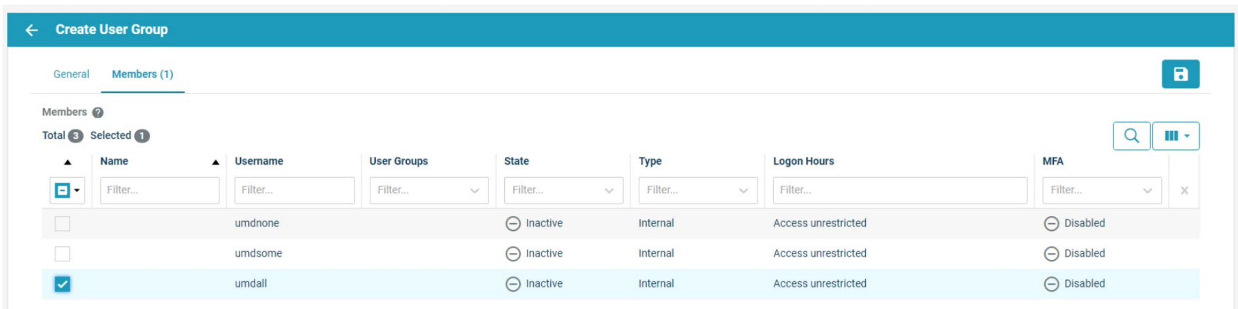
3. Add in other users as needed.
4. The next step is to create user groups for the users. Go to **Users > User Groups** and click the **+** sign.



5. Add in details for the **General** tab, then move to the **Members** tab.



6. Select users for addition to the current group, then click the create button. Repeat for all necessary groups.



2.9 pfSense Open-source Firewall

pfSense is an open-source firewall/router used to create a site-to-site VPN tunnel between the NCCoE lab and the UMD campus network.

We installed pfSense using the installation guide at https://docs.netgate.com/pfsense/en/latest/install/download-installer-image.html. We installed pfSense in a Linux virtual machine in our virtual lab using the ISO installation media option.

We used the instructions at https://docs.netgate.com/pfsense/en/latest/vpn/openvpn/index.html to configure the VPN.

2.10 Syslog-ng Open-Source Log Management

Syslog-ng is an open source log server (https://github.com/syslog-ng/syslog-ng). Syslog ng provides the second part of the log collector component of the reference architecture. Syslog ng serves as a syslog aggregator. Cisco ISE and Cisco Cyber Vision send their syslog data to syslog ng. Syslog ng then sends the aggregated data to the Sumo Logic syslog collector for transport to the Sumo Logic software-as-a-service analysis and visualization capabilities to process. Figure 8 shows syslog-ng implementing the reference architecture log aggregator element.

We used Linux Centos 8 VMs to host our syslog-ng instances -ng.

2.10.1 Installing Syslog-ng

Follow these steps to install Syslog-ng:

1. On a VM that will host syslog-ng, run the command `sudo apt-get install syslog-ng -y`.
2. When this completes, check the syslog-ng version with the command `syslog-ng –version`.
3. Verify syslog-ng is running with the command `syslog-ng status`.

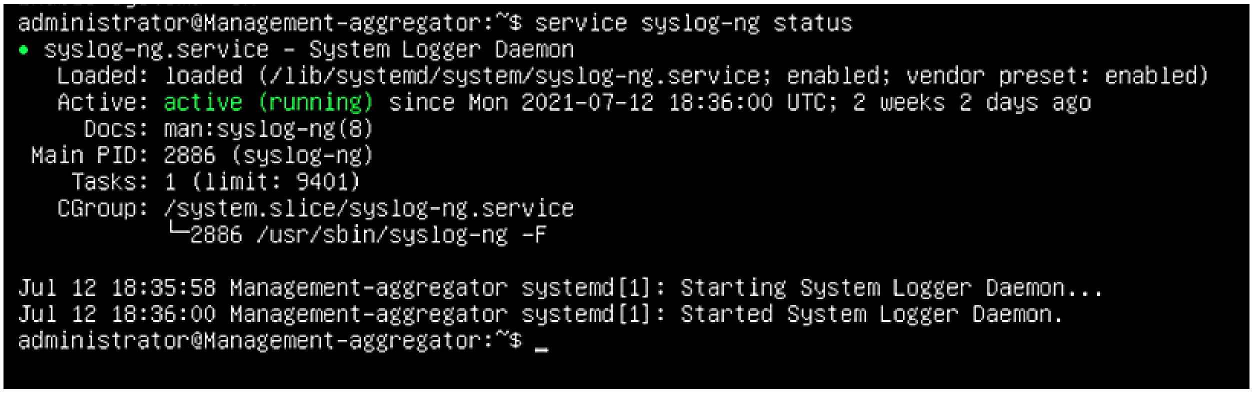
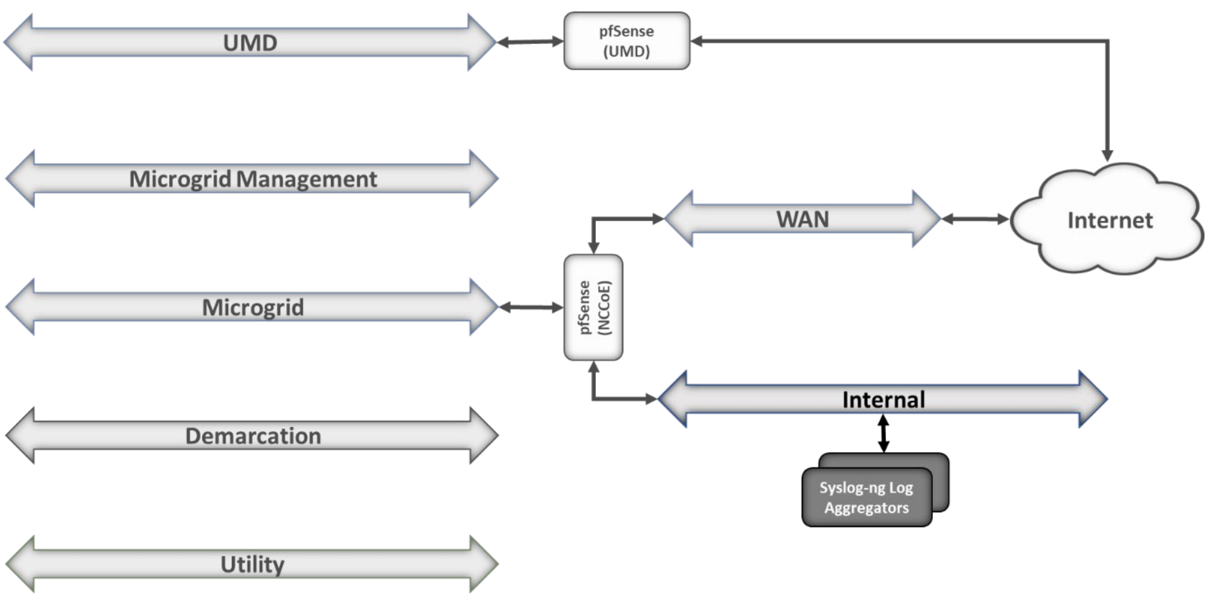


Figure 2-10 shows the location of the syslog-ng log aggregators in the example solution.

Figure 2-10 syslog-ng Location in the Example Solution

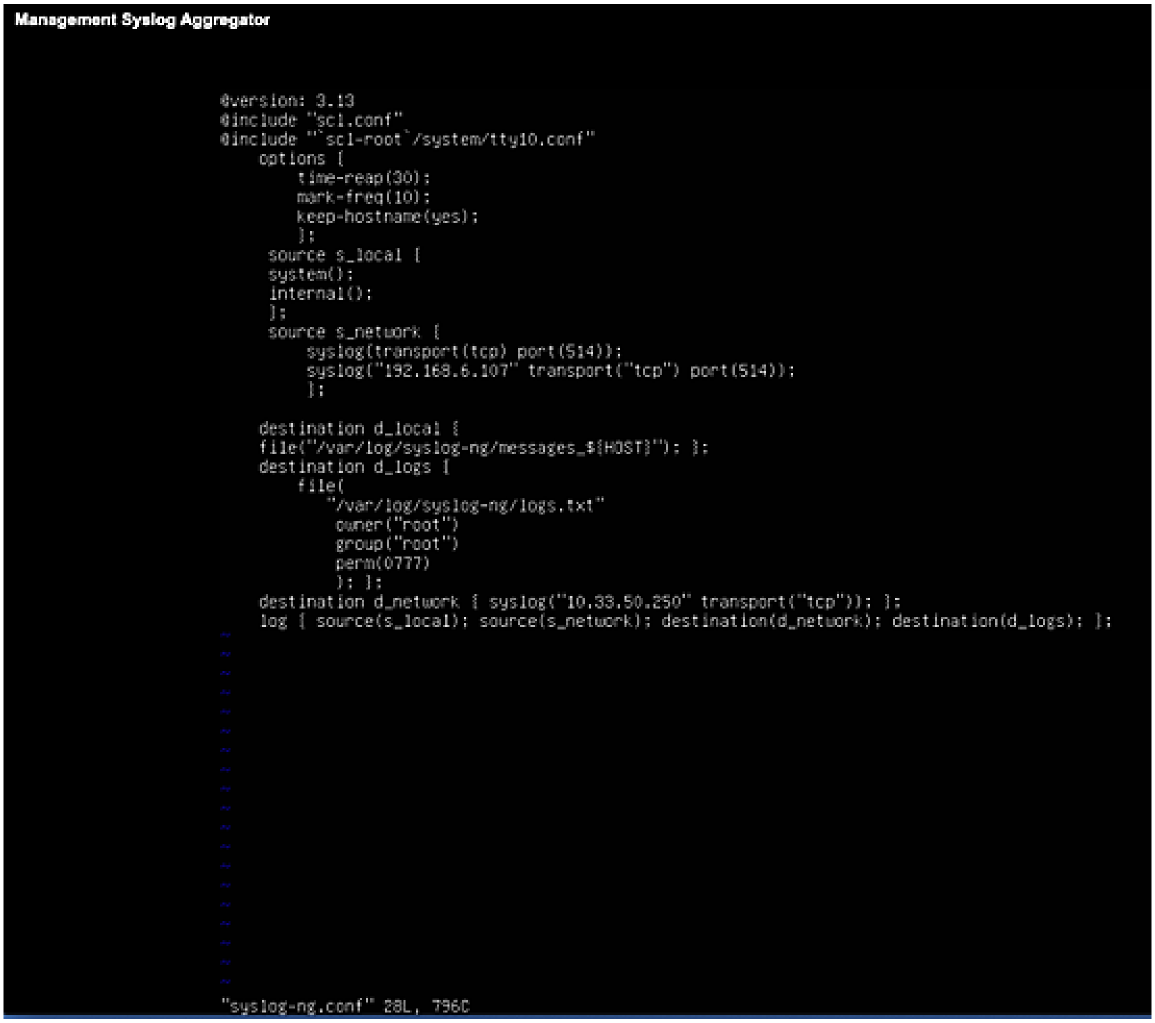


2.10.2 Configuring Syslog-ng

Follow these steps to configure Syslog-ng:

1. Navigate to the `/etc/syslog-ng` directory using the command `cd /etc/syslog-ng` and run the command `vim syslog-ng.conf` to configure `scl.conf.`

2. For each product that sends log data to syslog-ng, edit the source and destination configuration information to add the IP address, protocol, and port number.



Appendix A List of Acronyms

CA	Certificate Authority
DER	Distributed Energy Resource
GW	Gateway
IP	Internet Protocol
ISO	Optical disk image in International Standards Organization 9660 format
IT	Information Technology
LAN	Local Area Network
LTE	Long Term Evolution
NCCoE	National Cybersecurity Center of Excellence
NIST	National Institute of Standards and Technology
OT	Operational Technology
OVA	Open Virtualization Appliance
PV	Photovoltaic
SaaS	Software as a Service
SIEM	Security Information and Event Management
SP	Special Publication
TAC	Transport Access Control
vLAN	Virtual Local Area Network
VM	Virtual Machine
UMD	University of Maryland

Appendix B Software for Using Immutably

This appendix presents the software used to send records to the command register. This same software, with minor variations, is used in the distribution ops system, front end processor, and microgrid master controller.

```
import requests
import json
from requests_oauthlib import OAuth1, OAuth1Session
from pyModbusTCP.client import ModbusClient
from pyModbusTCP.server import ModbusServer, DataBank
from time import sleep


class Proofworks:

    def __init__(self):

        self.host = 'https://immutably.client.cxl.io/api'
        self.key = 'kXHeHvHnwEDeGFPOmjTs39Oest42WxmXz62y1LfJ'
        self.secret =
'GiXxoeWk26DnFUloSn3rQQ97tZHm7SGdK86au5bLqTJtIHuzrzK6nd0J4lqArYrI'
        self.realm = '74b8e784-242b-11e8-b467-0ed5f89f718b.0d091c52-2431-11e8-b467-
0ed5f89f718b.fee64f24-f8c5-4406-953e-3705cccd9c3c'
        self.project_id = 'b269de55-8c42-482f-a0cb-2077c3f9be9f'
        self.session = None

    def login(self):

        payload = json.dumps({
```

```
                "key": self.key,
                "secret": self.secret,
                "realm": self.realm
            })

            headers = {
                'Content-Type': 'application/vnd.io.cxl.credentials.consumer-key+json',
                'Authorization': 'OAuth
realm="realm",oauth_consumer_key="key",oauth_signature_method="HMAC-
SHA1",oauth_timestamp="1504127763",oauth_nonce="6ULC6xT4Fxi",oauth_version="1.0",
oauth_signature="%2BegGM2djZ032sy7MyTwpfnqByZg%3D"'
            }

            oauth = OAuth1(self.key, client_secret=self.secret)
            response = requests.request("POST", f"{self.host}/authc/login", auth=oauth,
headers=headers, data=payload)
            token = str(response.json()['access-token'])

            self.session = OAuth1Session(self.key, client_secret=self.secret,
resource_owner_key=token, realm=self.realm)

        def get_total_proofs_in_project(self):
            response = self.session.get(
                f"{self.host}/proofworks/projects/{self.project_id}/proofs", timeout=10,
            )
            r = response.json()
            return r.get('count')

        def create_proof(self, source, NetRealEnergy, V_LL, Current, Frequency):
```

```
        headers = {
            "Content-Type": "application/json"
        }

        proof = json.dumps([
         {"==": ["source: ", source]},
         {"==": ["Real Energy - Net: ", NetRealEnergy]},
         {"==": ["Voltage - L-L: ", V_LL]},
         {"==": ["Current: ", Current]},
         {"==": ["Frequency: ", Frequency]}
        ])

        response = self.session.post(
            f"{self.host}/proofworks/projects/{self.project_id}/proofs",
            data=proof,
            timeout=10,
            headers=headers,
        )
```

932 # Appendix C References

933 [1] Xage Security, Xage Security Fabric Installation Guide, Version 3.2.0, February 2021.