THE ROLE OF THE IEEE 2030.5 INTEROPERABILITY STANDARD IN DISTRIBUTED ENERGY RESOURCES INTEGRATION

White Paper

15 January 2025

MAIN AUTHORS Alexandre Lucas, Peter Nemcek, Matjaz B. Juric, Nikolaj Candellari, Jawad Younus, Ferdinando Bosco, Yashvi Baria, Marcantonio La Franca

EDITOR Elizaveta Kuzmina

CONTENT

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101096511. Disclaimer: The sole responsibility for any error or omissions lies with the editor. The content does not necessarily reflect the opinion of the European Commission. The European Commission is also not responsible for any use that may be made of the information contained herein.

EXECUTIVE SUMMARY

KEY FINDINGS

This White Paper explores the IEEE 2030.5 communication protocol and its vital role in integrating distributed energy resources (DERs) into the energy sector. The need for IEEE 2030.5 arises from the increasing penetration of DERs, decarbonization goals, smart grid development, energy storage, electrification of transport and heat sectors, and consumer participation.

Key capabilities of IEEE 2030.5 include secure and robust communication between DER devices and energy service providers, hierarchical control, interoperability, security, and scalability. The protocol has been adopted in several global markets, including the USA, Australia, and the EU, with regulatory frameworks mandating its use for DER communication and grid connection compliance.

The InterSTORE project has developed an enhanced version of IEEE 2030.5, featuring communication over the NATS messaging system and support for JSON formats, improving real-time data exchange and many-to-many integration of devices and systems. The project tested these advancements in seven use cases, demonstrating the protocol's capabilities in flexibility monetization, energy communities, grid-supporting BESS, hybrid storage performance, and EV charging clusters.

CHALLENGES

Interoperability is crucial for integrating DERs into the power grid, and IEEE 2030.5 ensures seamless communication, reducing integration complexity, data silos, and scalability issues. However, barriers to adoption include testing and certification gaps, regulatory alignment, high costs of upgrading legacy infrastructure, and lack of awareness and technical expertise.

RECOMMENDATIONS

The document concludes with recommendations for promoting IEEE 2030.5 adoption, including regulatory and standardization efforts, investments in infrastructure, robust governance, simplified certification processes, and alignment with industry needs. The IEEE 2030.5 communication protocol is essential for integrating DERs and supporting smart grid operations, driving the energy sector's transformation towards a more decentralized, efficient, and sustainable future.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101096511. Disclaimer: The sole responsibility for any error or omissions lies with the editor. The content does not necessarily reflect the opinion of the European Commission. The European Commission is also not responsible for any use that may be made of the information contained herein.

LIST OF ABBREVIATIONS

Figure Title	Page
IEEE	Institute of Electrical and Electronics Engineers
DER	Distributed Energy Resources
BESS	Battery Energy Storage System
EMS	Energy Management System
NATS	NATS Messaging System (originally "Neural Autonomic Transport System")
JSON	JavaScript Object Notation
XML	Extensible Markup Language
MQTT	Message Queuing Telemetry Transport
SCADA	Supervisory Control and Data Acquisition
DNP3	Distributed Network Protocol 3
IEC	International Electrotechnical Commission
TCP/IP	Transmission Control Protocol/Internet Protocol
PV	Photovoltaic
EV	Electric Vehicle
HESS	Hybrid Energy Storage System
LPC	Legacy Protocol Converter
EU	European Union
TSO	Transmission System Operator
DSO	Distribution System Operator
DOE	Dynamic Operating Envelope
CSIP	Common Smart Inverter Profile
CA-R21	California Rule 21
REF	Reference
GUI	Graphical User Interface
VPN	Virtual Private Network
TLS	Transport Layer Security
SSL	Secure Sockets Layer
AES	Advanced Encryption Standard
IPsec	Internet Protocol Security
CIM	Common Information Model
SMGW	Smart Meter Gateway
JAR	Java Archive
Docker	Docker (a platform for developing, shipping, and running applications)
GitHub	GitHub (a platform for version control and collaboration)
Docker Hub	Docker Hub (a cloud-based repository for Docker images)
FIWARE	FIWARE (an open-source platform for smart solutions)
HyDEMS	Hybrid Distributed Energy Management Systems
AFRR	Automatic Frequency Restoration Reserve
FCR	Frequency Containment Reserve
OEM	Original Equipment Manufacturer
PPP	Public-Private Partnership
AI	Artificial Intelligence
IoT	Internet of Things

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101096511. Disclaimer: The sole responsibility for any error or omissions lies with the editor. The content does not necessarily reflect the opinion of the European Commission. The European Commission is also not responsible for any use that may be made of the information contained herein.

INTRODUCTION

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101096511. Disclaimer: The sole responsibility for any error or omissions lies with the editor. The content does not necessarily reflect the opinion of the European Commission. The European Commission is also not responsible for any use that may be made of the information contained herein.

THE NEED FOR IEEE 2030.5 IN THE ENERGY DOMAIN

Today's energy sector is shaped by a dynamic convergence of multiple drivers, including ambitious energy targets, environmental concerns, and digitalization opportunities. These trends are brought together by a common theme: interoperability, which plays a crucial role in ensuring seamless integration across devices and systems. The key trends driving this transformation include:

- Increasing Penetration of Distributed Energy Resources (DERs): The global energy landscape is rapidly evolving, with an increasing share of DERs such as rooftop solar, batteries, wind power, and electric vehicles. These resources require advanced communication protocols to integrate effectively into the grid (Lund et al., 2020).

- De-carbonization and Renewable Energy Goals: Countries around the world are setting aggressive targets for reducing carbon emissions and increasing the share of renewable energy in their power mix, driving the need for smarter grid solutions (IEA, 2022).

- Smart Grid Development: The shift toward smart grids involves deploying advanced technologies and communication systems to improve grid resilience, reliability, and efficiency (Amin et al., 2021).

- Energy Storage and Management: As energy storage systems become more widespread, the need for protocols that can effectively manage charging and discharging cycles is growing (Doeff et al., 2020).

- Electrification of the Transport and Heat Sectors: It involves transitioning from fossil fuels to electric alternatives, aiming to reduce greenhouse gas emissions and improve energy efficiency. In transport, this includes the adoption of electric vehicles (EVs), supported by the development of charging infrastructure. In the heat sector, technologies like heat pumps are becoming popular, as they are more efficient than traditional heating systems (Pérez et al., 2018).

- Consumer Participation: The rise of the prosumer model, where consumers generate, store, and sell energy back to the grid, highlights the need for communication protocols that support greater consumer involvement in decentralized energy systems (von Appen et al., 2021).

In this white paper, we present the introduction, evolution, and global regulatory efforts surrounding the IEEE 2030.5 communication standard, comparing it to other existing protocols and standards in the energy domain. We will explore the unique capabilities of the enhanced version of IEEE 2030.5, developed under the InterSTORE Horizon Europe project, and how it aligns with these key energy trends.

Additionally, we will provide a set of use cases enabled by the adoption of IEEE 2030.5 InterSTORE, illustrating how it supports the energy sector's goals of decarbonization, grid modernization, and consumer engagement. Finally, we will discuss the barriers to widespread adoption of this protocol and offer a series of recommendations to promote its integration across industries and manufacturers, ensuring its role as a cornerstone of future energy systems.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101096511. Disclaimer: The sole responsibility for any error or omissions lies with the editor. The content does not necessarily reflect the opinion of the European Commission. The European Commission is also not responsible for any use that may be made of the information contained herein.

IEEE 2030.5: A PROTOCOL FOR A DECENTRALIZED ENERGY FUTURE

The IEEE 2030.5 (formerly SEP 2.0) communication protocol was developed to support smart grid operations, primarily in the realm of DER integration. It is an open communication standard that uses Internet Protocol (IP)-based networks to provide secure and robust communication between DER devices and energy service providers (Xie et al., 2018). The standard contains a dictionary, or data model, in which terms are defined for a common understanding. The protocol is flexible enough to handle both residential and commercial installations, enabling DERs to participate in various demand response programs, grid-support services, and emergency management protocols (Gungor et al., 2020).

One of the key features of IEEE 2030.5 is its support for hierarchical control. This is particularly important for managing a large number of DER systems geographically scattered across many voltage levels of the power grid. It allows for local DER control at the device level while also supporting global commands from aggregators and grid operators (Amin et al., 2021).

The adoption of IEEE 2030.5 is significant for a few reasons:

- Interoperability: It ensures that different DER systems from various manufacturers can communicate using a common language (Karnouskos et al., 2020).

- Security: IEEE 2030.5 mandates robust security protocols, including encryption and authentication, which are essential for preventing cyberattacks on the grid (Zhang et al., 2019).

- Scalability: As DER adoption increases, IEEE 2030.5's architecture can accommodate growing numbers of interconnected devices without compromising performance (von Appen et al., 2021).

GLOBAL RECOGNITION AND REGULATORY INTEGRATION OF IEEE 2030.5 FOR DER COMMUNICATION

The IEEE 2030.5 standard has gained traction in several global markets, such as Canada, the USA, Australia, Ireland, and the EU. These regions have either already adopted or are in the process of adopting IEEE 2030.5 as a go-to protocol for DER communication and data exchange among various entities. Figure 1 illustrates the number of devices in these locations, which are growing every year.

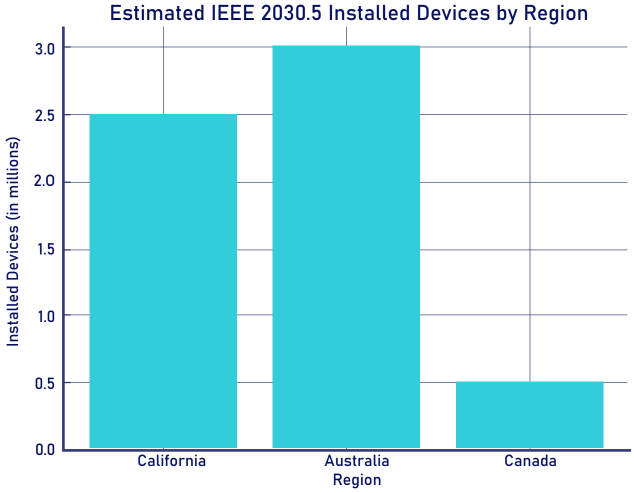

Figure 1 Number of installed devices in California, Australia and Canada (Statistics Quality Logics et al., 2023)

In the USA, regulatory frameworks such as California Rule 21 and IEEE 1547.1 grid connection compliance mandates play a crucial role. Similarly, in Australia, compliance with the AS/NZS 4777 grid code is required, alongside policies from the Australian Energy Market Operator (AEMO), such as Dynamic Operating Envelopes (DOE) and Dynamic Export Regulation (Gungor et al., 2020).

The adoption of Common Smart Inverter Profiles (CSIPs) is mandated as a standardized set of technical specifications. These specifications are designed to facilitate communication between Distributed Energy Resources (DERs), such as solar inverters and energy storage systems, and utility grid operators. Central to the CSIP requirements is the implementation of IEEE 2030.5, a communication protocol designed to standardize interactions between DERs and grid service providers (Xie et al., 2018)

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101096511. Disclaimer: The sole responsibility for any error or omissions lies with the editor. The content does not necessarily reflect the opinion of the European Commission. The European Commission is also not responsible for any use that may be made of the information contained herein.

THE BIRTH OF CSIP AND ROAD TO IEEE 2030.5: CALIFORNIA AS A PIONEER

CSIP was initially introduced in California under California Rule 21 (CA-R21). The state of California, which has been at the forefront of renewable energy integration, faced the challenge of ensuring that Distributed Energy Resources (DERs) could seamlessly interact with utility grids (Amin et al., 2021). As more households and businesses install solar panels and storage devices, maintaining grid stability and security became crucial (von Appen et al., 2021).

In this context, California Rule 21 provided the foundation for CSIP. The rule required DER inverters to conform to a set of technical standards to participate in grid services, and IEEE 2030.5 became the designated communication standard for implementing these requirements (Karnouskos et al., 2020). This protocol is essential for both static and dynamic command-and-control operations. It facilitates secure and standardized data exchange between Distributed Energy Resource Management Systems (DERMS) and DER inverters using a client-server model.

CSIP, as defined in CA-R21, is now a regulatory necessity for any inverter wishing to interconnect with California's grid. The IEEE 2030.5 protocol allows inverters to respond dynamically to grid service requests, including voltage regulation, frequency control, and energy export limits.

CSIP-AUS: ADAPTING CSIP TO THE AUSTRALIAN CONTEXT WITH IEEE 2030.5

Australia, which has one of the highest penetrations of rooftop solar in the world, has adopted a version of CSIP known as CSIP-AUS. While CSIP-AUS retains the core framework of the California model, there are significant regional adaptations to address the unique challenges of Australia's energy grid (Elliston et al., 2019).
A key component of CSIP-AUS is the use of the IEEE 2030.5 communication protocol, which standardizes secure, interoperable interactions between Distributed Energy Resource (DER) systems and utility grid operators. IEEE 2030.5 ensures seamless communication for both static and dynamic commands, playing a vital role in the effective management of DERs across the grid.

The most notable distinction in CSIP-AUS is the inclusion of Dynamic Operating Envelope (DOE) commands, enabled through IEEE 2030.5. DOEs allow network service providers to dynamically adjust the export or import limits of DER systems based on real-time grid conditions. This feature is particularly important in Australia, where local grid stability is a concern due to the large volume of distributed solar energy.

In addition to the DOE feature, the Dynamic Export Regulation, also supported by IEEE 2030.5, allows for more granular control over energy export by DERs. It enables network operators to adjust export limits dynamically based on grid demand and supply conditions. This real-time regulation ensures grid stability during high solar generation and prevents DER systems from overloading the grid with excess power. When grid capacity allows, DERs can export more energy (Zhang et al., 2019).

The Australian Energy Market Operator (AEMO) mandates DOE policy, and South Australian DNSPs (DSOs) impose Dynamic Export Regulation as critical tools to manage grid stability. This ensures DER systems can be constrained or enabled in real time, preventing voltage fluctuations and maintaining grid integrity during fluctuating energy demand and supply (Elliston et al., 2019).

By integrating these features through IEEE 2030.5, CSIP-AUS ensures that DERs like solar PV and energy storage systems operate in harmony with the grid's capacity, providing stability, security, and efficiency in Australia's decentralized energy landscape.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101096511. Disclaimer: The sole responsibility for any error or omissions lies with the editor. The content does not necessarily reflect the opinion of the European Commission. The European Commission is also not responsible for any use that may be made of the information contained herein.

THE EU'S UPCOMING REGULATORY WORKS FOR DER INTEROPERABILITY AND THE PROPOSALS FOR ADOPTING IEEE 2030.5

The European Union is in the advent of an explosion of Distributed Energy Resources integration with the grid. Notably, the new DIRECTIVE (EU) 2024/1711 of 13 June 2024 amends Directives (EU) 2018/2001 and (EU) 2019/944 to enhance the Union's electricity system. Alongside this, the Electricity Directive (Directive (EU) 2019/944) and the Regulation on the Internal Market for Electricity (Regulation (EU) 2019/943) promote a flexible, market-based approach to grid management and design. Additionally, **the EU Data Act** aims to establish a clear legal framework for sharing and accessing data across sectors, including energy, supporting the ongoing digitalization of the energy sector. One of the key developments in this effort is the preparation of **the Network Code on Demand Response (NC-DR)**. This Network Code, part of the broader set of EU Network Codes governing grid connection, operation, and electricity markets, aims to facilitate the market integration of demand response and other flexibility resources. The NC DR builds upon existing EU regulations that mandate market-based procurement of system operator's ancillary services such as congestion management, voltage control, and balancing, all critical for the reliable operation of a highly DER in-fluxed grid.

Under the upcoming **Implementing Act on Interoperability Requirements and Non-Discriminatory and Transparent Procedures for Access to Data required for demand response**, the EU is also pushing forward with enhanced digital standards. In this context, IEEE 2030.5 is proposed as a key standard for enabling seamless communication between DERs and grid operators. IEEE 2030.5 is particularly well-suited for supporting interoperability in DER use cases, ensuring that distributed resources like solar panels and energy storage systems can effectively participate in grid operations while maintaining secure and efficient communication with system operators.

This strategic move aligns with the EU's vision of a flexible, de-carbonized energy system, where DERs play a critical role in balancing supply and demand in real time, all supported by robust digital infrastructure and the capability of coordinating multiple distributed energy resources will enable a robust and a flexible grid, its optimization and increased resilience.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101096511. Disclaimer: The sole responsibility for any error or omissions lies with the editor. The content does not necessarily reflect the opinion of the European Commission. The European Commission is also not responsible for any use that may be made of the information contained herein.

THE EVOLUTION FROM IEEE 2030.5-2018/23 REST BASED TO IEEE 2030.5 OVER NATS

InterSTORE is a Horizon Europe funded project focused on developing, deploying and demonstrating a suite of interoperable Open-Source tools aimed at integrating Distributed Energy Storage and Distributed Energy Resources (DER). Its goal is to enhance the hybridization, utilization, and monetization of storage flexibility within real-world environments, enabling more efficient and dynamic energy systems.

As part of the InterSTORE project, an enhanced version of the IEEE 2030.5-2018/23 protocol evolved and was made more efficient to address the bottlenecks of IEEE 2030.5, featuring two key innovations:

1. Communication over NATS messaging system: This shift from the traditional REST API-based communication to NATS messaging improves real-time data exchange, many-to-many interaction and scalability, making it more suitable for energy applications.
2. Support for JSON formats: In addition to XML, the enhanced IEEE 2030.5 version now supports JSON, a more versatile and widely adopted format for message exchange across various energy assets, improving integration and interoperability in diverse energy systems.

These advancements help unlock greater flexibility and efficiency in managing DERs and energy storage systems, ensuring smoother communication and data exchange in the evolving energy landscape.

The adoption of NATS messaging over traditional REST API-based messaging in the implementation of the IEEE 2030.5 standard for smart grids offers several key advantages, particularly for real-time communication, many-to-many interaction, scalability, and resilience. NATS's low-latency, high-throughput capabilities make it ideal for the real-time demands of grid monitoring and control, ensuring timely and efficient data transmission. Its publisher/subscriber model supports the many-to-many communication required by the updated standard, allowing for more flexible and modular system designs. NATS also enhances scalability and resilience with built-in redundancy, fault tolerance, and horizontal scaling, ensuring continuous operation even under varying loads and failures. Additionally, NATS's asynchronous communication reduces overhead and optimizes resource utilization, making it more efficient than synchronous REST APIs. This is particularly beneficial in resource-constrained environments typical of smart grids. The system's support for event-driven architecture and real-time event processing aligns well with smart grid applications such as dynamic demand response, predictive maintenance, and distributed energy resource management. Overall, NATS provides a robust, efficient, and scalable messaging framework that significantly enhances the performance and reliability of smart grid communications.

Regarding the file formats, incorporating JSON file formats alongside XML in the IEEE 2030.5 standard enhances performance, interoperability, and usability. JSON format is becoming more popular in energy systems and is more lightweight and efficient, leading to faster parsing and reduced transmission overhead, which is crucial for real-time smart grid applications. JSON's less verbose structure also results in lower bandwidth usage, benefiting resource-constrained environments. From an interoperability perspective, JSON is widely used in web technologies and is natively supported by most modern programming languages, facilitating easier integration with various systems and platforms. This broad compatibility can accelerate development and deployment processes. Additionally, JSON's readability and simplicity make it easier for developers to work with, reducing the learning curve and potential for errors. It also enhances the flexibility of data representation, allowing for a more straightforward handling of complex data structures compared to XML.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101096511. Disclaimer: The sole responsibility for any error or omissions lies with the editor. The content does not necessarily reflect the opinion of the European Commission. The European Commission is also not responsible for any use that may be made of the information contained herein.

LANDSCAPE AND GAPS

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101096511. Disclaimer: The sole responsibility for any error or omissions lies with the editor. The content does not necessarily reflect the opinion of the European Commission. The European Commission is also not responsible for any use that may be made of the information contained herein.

OVERVIEW OF CURRENT SMART GRID PROTOCOLS AND INFORMATION EXCHANGE MODELS

In this section of the white paper, we present the differences between the IEEE 2030.5 and other existing protocols and standards, highlighting the capabilities of the new version of the IEEE 2030.5. It also provides a set of use cases enabled by the IEEE 2030.5 adoption aligned with the targets and trends seen in the energy market. It will then discuss the barriers to its adoption and provide a set of recommendations to promote its integration in industry and manufacturers.

The purpose of this section in to provide an overview of the main protocols found in smart grid and to identify the main strengths while contextualizing the IEEE 2030.5 considering the developments performed in the InterSTORE project. Various protocols are utilized in smart grid systems to ensure efficient, reliable, and secure communication and data exchange among the diverse components of the grid. The most used protocols in smart grids can be broadly categorized based on their application areas, such as communication, data management, and interoperability and can be found below.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101096511. Disclaimer: The sole responsibility for any error or omissions lies with the editor. The content does not necessarily reflect the opinion of the European Commission. The European Commission is also not responsible for any use that may be made of the information contained herein.

IEEE 2030.5 (2018/23) AND IEEE 2030.5 (INTERSTORE)

The IEEE 2030.5 (2018/23) and the enhanced IEEE 2030.5 (InterSTORE) both excel in scalability for connecting not only behind-the-meter assets but also in-front-of-the-meter assets. The ability of IEEE 2030.5 (InterSTORE) to use NATS over REST enables it to offer high-speed, many-to-many connectivity. This makes it one of the most interoperable, versatile, and scalable protocols for DERs, aggregators and utility-scale DER integration, while also ensuring strong regulatory compliance and dedicated security suit.

EEBUS:

EEBus is a communication standard for energy management systems, focusing mainly on behind the meter assets on optimizing energy consumption across various devices in smart homes and buildings. It facilitates demand-side management and ensures efficient energy use by connecting appliances, electric vehicles, and renewable energy sources. Though EEBus offers no direct utility cloud connection in its current stage as it is built to be a local bus. Despite that specially in Europe EEBus is getting known for its focus on interoperability and compatibility with multiple smart grid platforms specially in Germany's Smart Meter Gateway (SMGW) topic.

ZIGBEE:

Zigbee is a low-power, wireless communication protocol designed for home automation, smart metering, and sensor networks. It supports mesh networking, enabling devices to communicate over long distances through intermediary devices. Zigbee is popular in smart grid applications for its simplicity, energy efficiency, and widespread adoption in smart meters and home energy devices. A gateway is needed for a direct utility cloud connection.

MODBUS TCP:

Modbus TCP is a widely used open protocol for industrial automation and energy management systems, allowing devices like sensors, controllers, and actuators to communicate over TCP/IP networks. It is known for its simplicity and robustness, making it a common choice in supervisory control and data acquisition (SCADA) systems and distributed energy resource (DER) integration.

MODBUS SUNSPEC:

Modbus SunSpec is a version of Modbus that adheres to the SunSpec Alliance's standards for photovoltaic (PV) and energy storage systems. It enables standardized communication between solar inverters, batteries, and other renewable energy devices, ensuring interoperability and simplifying integration with energy management systems and utility networks.

IEEE 1815 OR DNP3 (DISTRIBUTED NETWORK PROTOCOL):

Zigbee is a low-power, wireless communication protocol designed for home automation, smart metering, and sensor networks. It supports mesh networking, enabling devices to communicate over long distances through intermediary devices. Zigbee is popular in smart grid applications for its simplicity, energy efficiency, and widespread adoption in smart meters and home energy devices. A gateway is needed for a direct utility cloud connection.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101096511. Disclaimer: The sole responsibility for any error or omissions lies with the editor. The content does not necessarily reflect the opinion of the European Commission. The European Commission is also not responsible for any use that may be made of the information contained herein.

IEC 61850:

IEC 61850 is an international standard for communication within electrical substations and smart grids. It defines communication protocols for automation, protection, and control systems in power utility environments. The protocol supports high-speed data transfer, interoperability, and real-time communication between intelligent electronic devices (IEDs) in substations.

IEC 61850-7-420 extends the IEC 61850 framework to include DERs, providing the information models and protocols necessary for integrating renewable energy systems and energy storage into the grid infrastructure. This is the same data exchange model, which is also used by DNP3, Sunspec Modbus and IEEE 2030.5 which makes the mentioned protocol as interoperable.

IEC 60870-5-104:

IEC 60870-5-104 is an extension of IEC 60870-5-101, used for communication in SCADA systems, primarily in energy and power sectors. It allows for the transmission of real-time data between control centers and field devices over TCP/IP networks. IEC 104 is valued for its use in remote control, monitoring, and automation of substations and power distribution systems. When it comes to interoperability IEC 104 is compatible with European CIM data exchange models.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101096511. Disclaimer: The sole responsibility for any error or omissions lies with the editor. The content does not necessarily reflect the opinion of the European Commission. The European Commission is also not responsible for any use that may be made of the information contained herein.

COMPARISON TABLE OF THE MENTIONED PROTOCOLS

The following comparison table, presents an assessment of a sample of wide adopted protocols across 9 different categories and includes the IEEE 2030.5 developed in InterSTORE:

Table 1 – Common Smart Grid Protocol Comparison

Protocols	Flexibility	Connectivity	Scalability	Regulative	Security	Maturity
IEEE 2030.5 (2018) IEEE 2030.5 (InterSTORE)	High; supports a wide range of DER (solar, storage, EVs).	IP-based, well-suited for utility-to-DER communication. IEEE 2030.5 (2018) uses REST. IEEE 2030.5 (interSTORE) uses NATs.	High; supports large-scale utility networks and DERs. Can be used for both behind the meter and in front of the meter for direct utility interfaces.	Strong in U.S. (California Rule 21), AUS growing globally.	Strong (TLS encryption, role-based access control).	HMature in the U.S. Canada and AUS, growing in international markets.
EEBUS	High; designed for energy management systems, appliances, EVs.	IP-based, commonly used in home/building energy management.	Moderate; suitable for home/building energy systems Limited to behind the meter assets only, no direct utility cloud connection.	Strong in Europe, aligned with European smart home standards.	Strong (TLS encryption, device authentication).	Mature in Europe, growing in smart home energy management.
Zigbee	Moderate; mainly for device-level communication, IoT, smart home.	Low-power, wireless mesh network, typically for short-range.	Limited; best for home energy and IoT device networks. No direct utility cloud connection possible.	Compliant with Zigbee Alliance, used in smart home applications.	Moderate (AES encryption, low-power IoT standards).	MMature in IoT, used widely in smart home energy systems.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101096511. Disclaimer: The sole responsibility for any error or omissions lies with the editor. The content does not necessarily reflect the opinion of the European Commission. The European Commission is also not responsible for any use that may be made of the information contained herein.

Protocols	Flexibility	Connectivity	Scalability	Regulative	Security	Maturity
Modbus TCP	Low; mainly used for simple, industrial data exchange.	Ethernet-based, used in industrial control systems.	Limited; best suited for small to medium-sized industrial setups. No direct utility cloud connection possible.	No direct compliance with energy regulations.	Weak; no native security (external solutions like VPNs required).	Mature in industrial automation.
Modbus SunSpec	Moderate; designed for solar PV and energy storage devices.	Ethernet-based, optimized for SunSpec Alliance standards.	Moderate; used in small to medium solar and DER deployments. No direct utility cloud connection possible. A gateway is required.	Aligned with SunSpec Alliance, accepted in the solar industry.	Weak; no inherent security, external security needed.	Growing maturity in solar and energy storage sectors.
DNP3	High; designed for SCADA and industrial control systems.	Serial, Ethernet, and IP-based connectivity.	High; scalable for large industrial and utility networks. No direct connection to Behind the meter home assets. Requires a gateway.	Strong; NERC-CIP compliant (U.S.), widely used in utilities.	Strong (Secure DNP3 supports encryption and authentication).	Very mature in utility and industrial control systems.
IEC 61850	Very high; designed for substation automation and smart grids.	Ethernet-based, supports real-time communication.	Very high; ideal for large-scale substation and utility applications. No direct connection to Behind the meter home assets. Requires a gateway.	Strong global compliance for utility and substation automation.	Strong (supports TLS/SSL, authentication, encryption).	Very mature, industry standard for smart grid and substation automation.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101096511. Disclaimer: The sole responsibility for any error or omissions lies with the editor. The content does not necessarily reflect the opinion of the European Commission. The European Commission is also not responsible for any use that may be made of the information contained herein.

Protocols	Flexibility	Connectivity	Scalability	Regulative	Security	Maturity
IECi 104	Moderate; used in SCADA and power system automation.	IP-based, suited for long-distance communication.	High; commonly used in large SCADA systems. No direct connection to Behind the meter home assets.	Compliant with European SCADA/grid communication standards.	Weak; relies on external security measures (VPN, IPsec).	Mature in European SCADA and utility communication .

From the table we can see that IEEE 2030.5 (2018/23) and the recently enhanced IEEE 2030.5 (InterSTORE) stand out for their scalability in connecting both behind-the-meter and in-front-of-the-meter assets, with InterSTORE offering high-speed, many-to-many connectivity using NATS over REST, making it highly interoperable and secure for aggregators, EMS and utility-scale DER integration. EEBUS is more suited for local home or building energy management in Europe, while Zigbee is ideal for small-scale, low-power IoT applications. DNP3 is robust for SCADA and industrial use, but lacks scalability for non-SCADA applications, and both DNP3 and IEEE 61850 are limited in grid edge device connectivity. Modbus is widely used in industrial settings but lacks regulatory alignment and security for large-scale DER systems. In the end it all comes down to the exact use case and here we can see for the use case of DERs IEEE 2030.5 (InterSTORE) stands out as an interoperable, versatile, and scalable protocol.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101096511. Disclaimer: The sole responsibility for any error or omissions lies with the editor. The content does not necessarily reflect the opinion of the European Commission. The European Commission is also not responsible for any use that may be made of the information contained herein.

THE IMPORTANCE OF IEEE 2030.5 INTEROPERABILITY AND THE ROLE OF LPC AND CLIENT/SERVER

The IEEE 2030.5 enables seamless communication within smart grid environments. This standard is crucial for facilitating the integration of distributed energy resources (DERs), such as solar panels, wind turbines, and energy storage systems, into the power grid. Interoperability ensures that devices and systems from different manufacturers can effectively exchange data and interact with each other, promoting efficiency, reliability, and grid modernization.

The lack of interoperability can lead to several challenges, such as:

- Integration Complexity: Connecting devices and systems using different communication protocols, requires custom integration solutions, increasing complexity and development costs.
- Data Silos: Without standardized communication, data from different devices and systems may be trapped in silos, limiting the ability to gain comprehensive insights into grid operations.
- Limited Scalability: Proprietary or incompatible communication protocols can hinder the scalability of smart grid deployments, making it difficult to accommodate a growing number of DERs.

To address these challenges, the InterSTORE project developed two key software components:

1. **Legacy Systems Protocol Converter (LPC):** The LPC acts as a middleware, translating between legacy communication protocols (like Modbus and MQTT) and the modern IEEE 2030.5 standard over the NATS messaging system.

2. **Interoperable Client/Server:** The client/server provides a standardized framework for devices and Energy Management Systems (EMS) to communicate using IEEE 2030.5 messages over NATS.

LPC and the Interoperable Client/Server are envisioned to have the following impact:

- **Bridging Legacy Systems:** Many existing devices in the energy sector use legacy protocols like Modbus and MQTT. The LPC enables these devices to communicate with modern IEEE 2030.5-compliant EMS systems, ensuring a smooth transition to the new standard.

- **Facilitating Standardized Communication:** Both the LPC and the client/server promote the adoption of the IEEE 2030.5 standard, providing a common communication framework for devices and EMS systems. This simplifies integration efforts and fosters interoperability.

- **Leveraging NATS for Enhanced Performance:** NATS, a high-performance messaging system, is used as the underlying communication protocol for both components. This enables a message-driven, loosely coupled architecture, enhancing scalability and flexibility.

- **Open-Source Collaboration:** Both the LPC and the client/server are open-source projects available on GitHub and Docker hub, encouraging community collaboration and wider adoption of these technologies.

By developing these open-source tools, the InterSTORE project aims to lower the barriers and costs for adopting the IEEE 2030.5 standard and fostering interoperability in the smart grid domain. This will lead to a more efficient, reliable, and sustainable energy ecosystem.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101096511. Disclaimer: The sole responsibility for any error or omissions lies with the editor. The content does not necessarily reflect the opinion of the European Commission. The European Commission is also not responsible for any use that may be made of the information contained herein.

TECHNICAL ADVANCEMENTS ACHIEVED

The InterSTORE project has made significant advancements in promoting IEEE 2030.5 interoperability by developing the LPC and the Interoperable Client/Server. The use of NATS messaging, support for multiple message exchange patterns, asynchronous communication, and dual format compatibility with IEEE 2030.5 (XML and JSON) are key achievements that contribute to a more interconnected, efficient, and flexible smart grid ecosystem. These achievements are crucial for facilitating the integration of DERs and enabling a more sustainable energy future.

1. Communication over NATS and Support for Multiple Message Exchange Patterns:

- **NATS as the Foundation:** Both the Legacy Protocol Converter (LPC) and the Interoperable Client/Server utilize NATS as the underlying messaging system. NATS, known for its high performance, scalability, and reliability, is well-suited for distributed systems and cloud-native applications, making it an ideal choice for modern smart grid communication.

- **Flexibility in Message Exchange:** The LPC's architecture enables support for various message exchange patterns, including one-to-one, one-to-many, and many-to-many communication. This versatility allows for diverse integration scenarios within the smart grid, accommodating the communication needs of various devices and systems.

- **Example of Many-to-Many Communication:** LPC can subscribe to messages from multiple incoming connections (e.g., devices using Modbus and MQTT) and then publish transformed messages to multiple outgoing connections (e.g., EMS systems using IEEE 2030.5 over NATS). This demonstrates a many-to-many communication pattern, showcasing the flexibility of the LPC in handling complex integration scenarios.

2. Support for Asynchronous Communication:

- **NATS and Asynchronous Messaging:** The use of NATS as the communication backbone inherently enables asynchronous communication. This means that senders and receivers of messages do not need to be online or synchronized at the same time for communication to occur.

- **Benefits of Asynchronous Communication:** Asynchronous communication enhances system resilience and scalability. Devices and systems can send and receive messages independently, without blocking or waiting for responses, leading to improved efficiency and responsiveness in the smart grid.

3. Support for IEEE 2030.5 in XML and JSON Format:

- **Dual Format Compatibility:** Both the LPC and the Interoperable Client/Server are designed to handle IEEE 2030.5 messages in both XML and JSON formats. This dual format support ensures compatibility with a wider range of devices and systems, promoting interoperability within the smart grid.

- **Simplified Integration for Developers:** The ability to choose between XML and JSON simplifies integration for developers, as they can select the format that best suits their application and existing infrastructure.

- **Examples of Transformation:** LPC can transform messages between JSON and XML formats, adhering to the IEEE 2030.5 standard. This demonstrates the LPC's capability in handling different data representations while ensuring compliance with the standard.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101096511. Disclaimer: The sole responsibility for any error or omissions lies with the editor. The content does not necessarily reflect the opinion of the European Commission. The European Commission is also not responsible for any use that may be made of the information contained herein.

LEGACY SYSTEMS PROTOCOL CONVERTER

The Legacy Systems Protocol Converter (LPC) plays a crucial role in enabling interoperability by addressing the challenge of disparate communication protocols prevalent in the energy sector. LPC key ability is to translate messages between legacy protocols commonly used by devices, such as Modbus and MQTT, and the modern IEEE 2030.5 standard, which is widely adopted by EMS systems. This translation capability enables seamless communication between devices and EMS systems that would otherwise be unable to exchange data effectively.

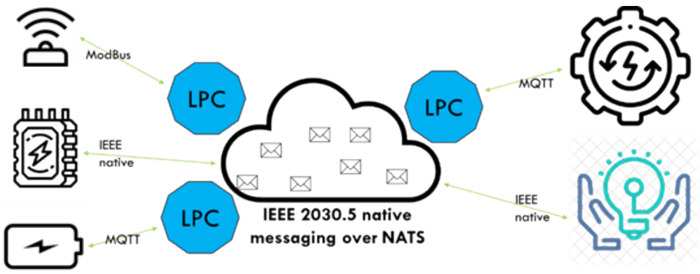

Figure 2 Architecture of NATS implementation with LPC

The Legacy Protocol Converter (LPC) acts as middleware, facilitating communication between devices using various protocols and Energy Management Systems (EMS) operating on the IEEE 2030.5 standard.

The LPC offers several key features that enhance its usability and flexibility:

- **Built-in Transformation Framework:** Users can define mappings and transformations for converting messages between different formats and structures.
- **Configuration File:** The LPC utilizes a configuration file to specify connection details for NATS, MQTT, and Modbus devices, simplifying setup and management.
- **Flexibility:** The LPC supports multiple transformations, each with distinct incoming and outgoing connections, message formats, and structures, catering to diverse integration scenarios.
- **Deployment Options:** The LPC can be deployed in various ways, including Docker containers, JAR files, or integrated into custom projects, offering deployment flexibility.

To simplify the configuration, there is an UI provided, which is accessible at:
https://sunesis.si/interstore/lpc/

The LPC can be deployed on various platforms, including:

- **Docker containers:** Pre-built images are available on Docker Hub for easy deployment.
- **JAR files:** The LPC can be run on any system with OpenJDK Java Runtime Environment using a JAR file.
- **Custom builds:** Users can compile and build the LPC from source code for tailored implementations.

The LPC's flexible architecture enables various use cases, including integrating legacy devices with modern EMS systems and facilitating data exchange in smart grid environments.

GitHub repository is accessible here:
https://github.com/Horizont-Europe-Interstore/Legacy-Protocol-Converter

Docker Hub image repository is accessible here:
https://hub.docker.com/r/interstore/legacy-protocol-converter

Future development efforts for the LPC focus on:

- **Enhanced security:** Implementing robust security measures, including authentication, authorization, and TLS/SSL support.
- **Improved scalability and resilience:** Enhancing the LPC's architecture for horizontal scalability and fault tolerance, ensuring high availability and resilience.
- **Integration with Data Spaces Framework:** Enabling seamless integration with data spaces for improved data interoperability.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101096511. Disclaimer: The sole responsibility for any error or omissions lies with the editor. The content does not necessarily reflect the opinion of the European Commission. The European Commission is also not responsible for any use that may be made of the information contained herein.

INTEROPERABLE CLIENT/SERVER SOFTWARE LIBRARY

Another important deliverable of InterSTORE is the interoperable client/server software library. The interoperable client/server software library also aims to simplify the integration of IEEE 2030.5 devices and EMS systems by providing a standardized communication framework built on the NATS messaging system. This open-source approach encourages wider adoption of the IEEE 2030.5 standard within the smart grid domain and helps organization to implement IEEE 2030.5 protocol natively in devices and EMS systems:

- **Provide open-source, out-of-the-box support for IEEE 2030.5 communication between devices and EMS systems:** The client/server enables devices and EMS systems to exchange IEEE 2030.5 messages using either the original XML format or the JSON format. This facilitates seamless communication between devices and EMS systems, regardless of their specific implementation details.
- **Provide support for next-generation NATS messaging:** The client/server utilizes NATS as the communication protocol between devices and EMS systems. NATS is a high-performance messaging system designed for distributed systems, microservices, IoT devices, and cloud-native applications. NATS offers advantages over traditional communication methods like REST over HTTP, enabling a message-driven, loosely coupled, and scalable communication platform.
- **Provide a reference implementation as an open-source project available on GitHub:** The source code for the client/server is publicly available on GitHub. This allows developers to use, modify, and contribute to the project, promoting the adoption of the IEEE 2030.5 standard and encouraging community collaboration.

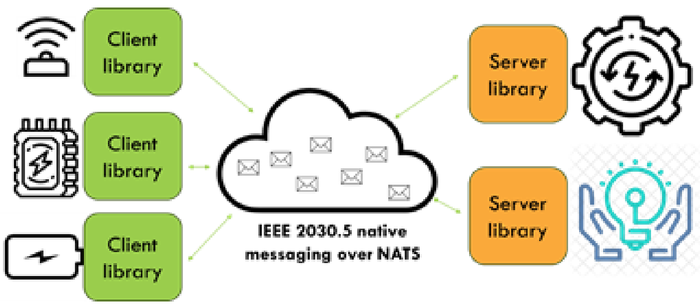

Figure 3 Architecture of NATS implementation with Client/Server

The client/server architecture shown in Figure 3, specifically designed for handling IEEE 2030.5 messages over the NATS messaging system, is instrumental in facilitating interoperability between devices and Energy Management Systems (EMS).

The point of interest is NATS Messaging for Enhanced Performance and Scalability. The client/server leverages NATS messaging, a high-performance, cloud-native system designed for distributed environments. This choice of communication protocol offers several advantages over traditional methods like REST over HTTP. NATS enables a message-driven, loosely coupled communication model, where devices and EMS systems can interact asynchronously without being tightly integrated. This promotes scalability and flexibility in system design. The inherent scalability of NATS allows the client/server architecture to handle a growing number of devices and EMS systems, making it well-suited for large-scale smart grid deployments.

The open-source nature of the client/server software, available on GitHub, encourages community collaboration and wider adoption of the IEEE 2030.5 standard. Developers can use, adapt, and contribute to the project, fostering innovation and improvement.

The client/server comprises three primary modules:

- **Client Module:** Handles communication from the device side, sending IEEE 2030.5 messages over NATS to the server.
- **Server Module:** Handles communication from the EMS side, receiving and processing IEEE 2030.5 messages from clients over NATS.
- **Client-Server-Common Module:** Shared functionality for both client and server, including generating Java classes from XML Schema Definition (XSD) and handling the serialization and deserialization of IEEE 2030.5 data types.

The source code for the interoperable client/server is publicly available on GitHub, fostering community collaboration and wider adoption of the IEEE 2030.5 standard.
GitHub access link:
https://github.com/Horizont-Europe-Interstore/Client-Server

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101096511. Disclaimer: The sole responsibility for any error or omissions lies with the editor. The content does not necessarily reflect the opinion of the European Commission. The European Commission is also not responsible for any use that may be made of the information contained herein.

AUTOMATED TESTING FOR IEEE 2030.5 COMPLIANCE: ENSURING INTEROPERABILITY AND RELIABILITY

The successful implementation of the IEEE 2030.5 standard for smart grid communication relies heavily on rigorous testing to ensure that devices and systems adhere to the standard's specifications and interoperate seamlessly. Automated testing procedures play a crucial role in this process, streamlining test execution, improving accuracy, and reducing the time and effort required for comprehensive validation.

INTERSTORE'S APPROACH TO AUTOMATED TESTING

The InterSTORE project has recognized the importance of automated testing for IEEE 2030.5 compliance and has developed a dedicated software tool, referred to as the "Test Software," to facilitate this process. The Test Software incorporates the SunSpec testing procedures, adapting them to leverage the efficiency and flexibility of the NATS messaging system. This approach ensures compatibility with established testing methodologies while modernizing the process for enhanced efficiency.

ARCHITECTURE AND COMPONENTS OF THE TEST SOFTWARE

The Test Software is designed with a modular architecture, comprising several key components that interact to execute tests, collect results, and provide comprehensive reports. These components, illustrated in Figure 4, include:

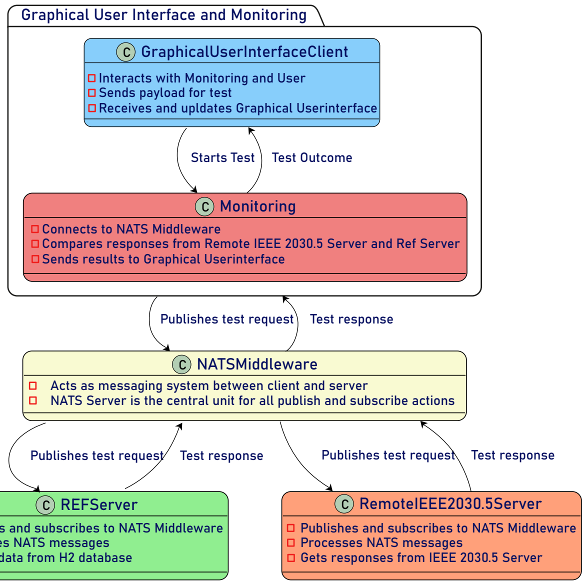

Figure 4 Testing Procedures Flow Chart

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101096511. Disclaimer: The sole responsibility for any error or omissions lies with the editor. The content does not necessarily reflect the opinion of the European Commission. The European Commission is also not responsible for any use that may be made of the information contained herein.

KEY COMPONENTS:

- **Graphical User Interface (GUI):** The GUI provides a user-friendly interface for initiating tests, providing input parameters, and visualizing test results. Users can select specific tests from a list, fill out relevant forms if required, and view reports that indicate whether tests passed or failed, along with actual and expected responses.

- **Monitoring Module:** This module encompasses a worker module and a control channel. The worker module establishes communication with the remote IEEE 2030.5 server (the server under test) using NATS. The control channel initiates communication with the REF Server (reference server) also via NATS.

- **NATS Middleware:** NATS serves as the communication backbone, facilitating message exchange between the monitoring module, REF Server, and the remote IEEE 2030.5 server.

- **REF Server:** The REF Server is a crucial component that implements IEEE 2030.5 resources according to the standard's specifications. It provides standard responses for comparison with the responses from the server under test. The REF Server uses an embedded database to persist resources, ensuring consistency throughout testing.

- **Remote IEEE 2030.5 Server:** This is the server being tested. It's typically connected to Distributed Energy Resources (DERs) that support the IEEE 2030.5 protocol. The remote server receives test messages via NATS and responds based on its implementation of the standard.

TEST EXECUTION PROCESS:

1. **Test Initiation:** The user selects a test from the GUI, providing input parameters as needed.

2. **Message Transmission:** The monitoring module sends the test message to the remote IEEE 2030.5 server via NATS.

3. **Server Response:** The remote server processes the message and sends a response back to the monitoring module via NATS.

4. **REF Server Interaction:** The monitoring module also sends the same test message to the REF Server, which generates a standard response based on the IEEE 2030.5 specifications.

5. **Response Comparison and Reporting:** The monitoring module compares the responses from the remote server and the REF Server. The GUI displays the test results, indicating whether the test passed or failed. The report includes actual and expected responses for detailed analysis.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101096511. Disclaimer: The sole responsibility for any error or omissions lies with the editor. The content does not necessarily reflect the opinion of the European Commission. The European Commission is also not responsible for any use that may be made of the information contained herein.

BENEFITS OF AUTOMATED TESTING APPROACH

Benefits of InterSTORE's Automated Testing Approach are numerous. **Efficiency and Automation:** The Test Software significantly reduces the time and effort required for testing by automating the test execution process, handling message transmission, response collection, and comparison. **Increased Accuracy:** Automation minimizes the potential for human error during testing, leading to more accurate and reliable test results. **Enhanced Modularity and Adaptability:** The modular design of the Test Software allows for easy expansion of test cases and integration with different testing environments. **User-Friendliness:** The intuitive GUI simplifies test execution and reporting, making the testing process accessible to a wider range of users.

The InterSTORE project outlines plans for further enhancing the Test Software:

- **Expanding Test Case Coverage:** Adding more test cases to the GUI will ensure more comprehensive validation of IEEE 2030.5 implementations.

- **Remote Server Integration:** Integrating the Test Software with remote IEEE 2030.5 servers in real-world deployments will facilitate testing in actual operating environments.

- **Performance Optimization:** Continuous efforts to optimize the performance of the Test Software will further improve testing efficiency.

The development of the automated Test Software is a significant achievement of the InterSTORE project, providing a valuable tool for ensuring the interoperability and reliability of IEEE 2030.5 implementations. The Test Software's modular design, NATS-based communication, and user-friendly interface contribute to a robust and adaptable testing framework. Continued enhancements will further strengthen the Test Software's capabilities, supporting the widespread adoption of the IEEE 2030.5 standard and driving progress towards a truly interoperable smart grid ecosystem.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101096511. Disclaimer: The sole responsibility for any error or omissions lies with the editor. The content does not necessarily reflect the opinion of the European Commission. The European Commission is also not responsible for any use that may be made of the information contained herein.

IEEE 2030.5 ENABLING THE ENERGY SYSTEM TRANSFORMATION

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101096511. Disclaimer: The sole responsibility for any error or omissions lies with the editor. The content does not necessarily reflect the opinion of the European Commission. The European Commission is also not responsible for any use that may be made of the information contained herein.

THE IEEE 2030.5 USE CASES AND DEMONSTRATIONS IN INTERSTORE

The new developments to the IEEE 2030.5 were tested within the Horizon Europe InterSTORE project. Seven use cases tackled the deployment and demonstration of the IEEE 2030.5 from different perspectives. These demonstrations had the goal of verifying the new functionalities, the well-functioning of the deployment, monitoring and control performance using the IEEE 2030.5. Moreover, it analysed the time of the deployment itself, using the protocol with different number of DER assets and EMS, and evaluate the performance in terms of data exchange speed, highlighting the use of the NATS messaging system and the use of Data Spaces. Due to the diversity of platforms and configurations within the pilots, the demonstrations provided the ability to use the Legacy Protocol Converter from MQTT or Modbus TCP and also to use the native client/server library in a Flexibility Aggregation platform. Below the architectures followed in the demonstrations, with the IEEE 2030.5 integration and short description of the pilot demonstrations.

FLEXIBILITY MONETIZATION AND ENERGY COMMUNITY USE CASES

The flexibility monetization and energy community use cases apply a new generation of the flexibility aggregation platform CyberNoc (developed by CyberGrid) is applied, enhanced with the developed interoperability toolkit, an option for integrating BESS, its hybridization feature, Market Arbitrage tool, Energy Community software tools and Open data space connection integration. In this demonstration the client / server library will be used in the CyberNoc platform.

The objective of the flexibility monetization use case is to offer its customers the possibility to generate flexibility revenues. To technically achieve this, the Aggregator deploys and operates a Flexibility Management Platform – an ICT system, which aggregates and manages flexibility from diverse sources. The flexibility will be provided mostly through power curtailment set points sent to DER in real time and their hybridization with other flexibility sources (loads, RES, DG, etc.) into marketable products. The IEEE 2030.5 in this regard plays a uniforming role due to the potential high diversity of assets. It will autonomously bid the hybrid flexibility products to the most appropriate markets (balancing, TSO and DSO balancing services, intraday, etc.) and executes the provision of the flexibility.

In the energy community use case on the other hand, the CyberNoc platform will be upgraded to suit the specific case of energy communities. The reason for this additional development lies in the fact that energy communities could generate flows of real time data from electricity meters placed at renewable electricity sources, consumption sites, battery energy storage systems, heat pumps, etc. Most of these could provide some electric flexibility which can be utilized either locally, within the community supporting self-sufficiency mode or at different electricity markets, like helping balance the transmission grid, improving voltage levels at distribution grid or taping into price opportunities of intraday markets.

Altogether, CyberGrid will demonstrate both use cases within a residential pilot. This means that each DER will be connected, monitored and controlled by CyberNoc via the novel protocol IEEE 2030.5 over NATS. The controlling will be done so that self-consumption is maximised, and additional flexibility is monetised on appropriate markets.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101096511. Disclaimer: The sole responsibility for any error or omissions lies with the editor. The content does not necessarily reflect the opinion of the European Commission. The European Commission is also not responsible for any use that may be made of the information contained herein.

GRID SUPPORTING BESS USE CASE

A novel feature introduced by this pilot, is the integration of the IEEE 2030.5 with a FIWARE platform. The integration of the tools developed in the InterSTORE project will facilitate the integration of additional storage units in the FZJ campus. The novelty of this use case will be the integration with a FIWARE platform, an open-source framework providing components and standard architectures for smart solutions in different domains. This middleware allows the integration of various field devices, thanks to the support of numerous standard IoT protocols (e.g., Modbus). Nevertheless, at the moment, IEEE 2030.5 is not supported, yet, and thus the ICT platform can benefit from the integration of the tools developed in InterSTORE.

In this use case, a series of commissioning tests will be performed to verify the effective interoperability of the communication interface, considering 2 battery systems.

For the demonstration, in order to deploy IEEE 2030.5 with the LPC, the following devices are used:

- Riello battery system (DER, 1500 kW/500 kWh, Native communication based on Modbus TCP/IP).
- Tesla battery system (DER, 500 kW/2.5 MWh, Native communication based on Modbus TCP/IP).
- Photovoltaic system (DER, 1.1MWp, Native communication based on Modbus TCP/IP).
- Heat pump (DER, avg. 200 kW, Native communication based on MQTT).
- Raspberry Pi 4b (RPi), to deploy the LPC and the NATS server in docker containers.
- MQTT broker.

HYBRID STORAGE PERFORMANCE EVALUATION AND FLEXIBILITY PROVISION USE CASE

This use case makes use of a HESS installed in a building basement. The HESS is composed by two batteries: one of vanadium Redox flow, with 10kW and 40kWh and the other is a set of second life lithium batteries with 100kW and 92 kWh. These batteries are connected to their inverters and are operated according to an EMS installed in a local PC. The HESS is connected to the building, 'behind the meter'. The building has also a PV system of 100kW installed on the rooftop. In the present UC, HESS operation strategies are demonstrated, that aim to optimize two minimization functions (cost and emissions), comparing Hybrid systems to single battery systems dispatch. The UC will also analyse the integration of the IEEE 2030.5 in the BMS, to showcase the interoperable solution of the InterSTORE project, applied to distributed resources.

Based on the benefits and limitations of the presented options, this demo runs a parallel communication based on the IEEE 2030.5 with the already current installation based on ModBus. It follows the local server to deploy the software and convert MobBus to IEEE 2030.5 and again ModBus.

- Single point deployment (one EMS – one inverter).
- There is no need for asset aggregation to a shared NATS cloud.
- Existing infrastructure does not support the IEEE 2030.5 natively hence the LPC is required.
- Both the EMS and inverter are located in the same physical space.
- The installed PC is flexible enough for the installation of the LPC without the need of additional hardware.
- Resource Efficiency: By deploying the Legacy Protocol Converter (LPC) and NATS on a local server, we reduce the resource burden on individual energy devices. This ensures that additional devices do not need to support Docker, Java, or NATS, which can be resource intensive.
- Optimized Communication: The converter and EMS are located within the same machine, allowing for faster communication compared to cloud-based solutions. Deploying the NATS server locally ensures lower latency and better performance, reducing deployment complexity.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101096511. Disclaimer: The sole responsibility for any error or omissions lies with the editor. The content does not necessarily reflect the opinion of the European Commission. The European Commission is also not responsible for any use that may be made of the information contained herein.

FREQUENCY SERVICES AND ADAPTIVE BESS MANAGEMENT FOR AUTONOMOUS GRID OPERATION USE CASES

The primary aim of these use cases is to enable the flexible use of HESS across diverse applications, leveraging beyond-the-state-of-the-art methods to hybridize and utilize storage flexibility using the IEEE 2030.5, while ensuring data space standardization. This laboratory use case also aims at evaluating the performance of using the NATS communication in Grid services such as Fast Peak Shaving and Frequency regulation. The specific topics include:

- **Demonstration of High-Impact Use Cases**: The focus on frequency and inertia services, and HESS management systems for autonomous operation across different modes.
- **Integration of different Distributed Energy Resources (DER):** seeks to integrate different DERs to enable the hybridization and utilization of storage flexibility within real-life environments. This integration fosters the optimal utilization of diverse storage technologies, maximizing their synergies and extending the performance of energy storage solutions.
- **Hybrid Energy Storage Solutions:** Embracing a hybrid approach, this demonstration explores the combination of various storage technologies to expand possibilities and enhance performance. By leveraging the strengths of different technologies, a hybrid solution mitigates oversizing issues, reducing both capital and operational expenditures.
- **Development of Hybrid Distributed Energy Management Systems (HyDEMS):** This demonstration aims to show an innovative DEMS capable of hybridizing and virtualizing distributed energy resources to optimize seamless performance. These cloud-based software control platforms feature advanced asset modelling, optimal operation, hybridization algorithms, and state-of-function virtualization layers.
- **Enhanced Interoperability and Functionality:** Through the integration of DEMS, the pilot seeks to maximize interoperability and functionality, translating technical parameters into actionable insights for multiple grid services. This approach facilitates real-time control and operation of aggregated energy storage systems, ensuring reliability and robustness.

MANAGEMENT OF EV CHARGING CLUSTERS AS HESS

In this demonstration, two roles/actors come into play. The balancing service provider (BSP) supporting the DSO/TSO in managing the distributed power flexibility and use the flexibility to provide grid services, in order to solve problems on the distribution grid (Low Voltage / Medium Voltage) grid. The main **scope** of the use case is experimenting an entire end-to-end process to simulate an aggregate different sites supplying local flexibility service to the DSO grid.

This use case will make use of a Flexibility platform to allow a set of different sites/assets to participate as a portfolio in flexibility market services. This Use Case identifies and analyses how different type of storage technologies can contribute in a unique cluster to provide flexibility and grid services.

A Gateway will be used to host Legacy Protocol Converter software. The LPC will be configured to operate protocol conversion from Modbus protocol to IEEE 2030.5 protocol, and from IEEE 2030.5 to MQTT. Most of the assets have implemented the IEEE 2030.5 protocol, for those assets, the LPC operate just the conversion to MQTT protocol to route the signals to ICT platforms. The protocol used will be Modbus and IEEE 2030.5 at asset level and MQTT and openADR at Digital platform Level.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101096511. Disclaimer: The sole responsibility for any error or omissions lies with the editor. The content does not necessarily reflect the opinion of the European Commission. The European Commission is also not responsible for any use that may be made of the information contained herein.

OTHER EXAMPLES OF USE CASES IN THE ENERGY SECTOR

The architecture and specifications of the IEEE 2030.5 native client/server library and Legacy protocol converter are described in detail in Deliverable D1.3 (InterSTORE, 2024) in InterSTORE. The IEEE 2030.5 new developments solidify on the following strengths:

1. Many-to-many communications enable multiple devices and systems to seamlessly interact with each other, promoting a more flexible and scalable network architecture.
2. NATS enabling features introduce lightweight messaging capabilities that support distributed communication and enhance real-time data exchange across various assets.
3. The use of JSON file formats simplifies data structuring and exchange, making the protocol more accessible for integration and ensuring easier interoperability with modern software platforms.
4. Asset discovery capabilities provide an efficient method for automatically identifying and integrating new devices into the network, reducing configuration overhead and enhancing system scalability.

Together, these features contribute to making IEEE 2030.5 a robust and adaptable protocol for managing distributed energy resources and smart grid applications.

Such developments already released in open source, will enable the effective provision of different services. Some identified use cases are the following:

Real-Time Demand Response (DR) Coordination: System operators can dynamically adjust demand response strategies based on real-time data from various assets and participants, including residential, commercial, and industrial users. This is possible due to the asset discovery feature.

Distributed Energy Resource Management (DERM): Effective management of a diverse array of DERs, including solar panels, wind turbines, and battery storage, to ensure grid stability, orchestrating optimization strategies by coordination different local EMS.

Fault Detection and Isolation: Rapid detection and isolation of faults through communication between multiple grid assets, enhancing overall grid reliability.

Peer-to-Peer (P2P) Energy Trading: Consumers and prosumers can trade energy directly with each other, facilitated by the many-to-many communication capabilities.

Direct Load Control (DLC) by several systems: An asset may have a dedicated Energy Management System for monitoring and control, which may be controlled and monitored by an Aggregator's system or a System Operator's system for flexibility provision remotely shutting down or reducing a customer's load or appliance.

Microgrid Coordination: Multiple microgrids can communicate and coordinate with each other and the main grid. This is particularly important for island capable grids and renewable energy communities. Seamless transition between islanded and grid-connected modes based on real-time data from interconnected assets.

Real-Time Energy Consumption Feedback: If applied to the AMI advanced metering infrastructure, the NATS messaging would provide consumers with real-time data on their energy usage and production, enabling more informed decisions and energy-saving actions.

Energy Storage Coordination: Effective use of energy storage systems and hybrid systems to not only balance supply and demand, but also to provide services to the grid FCR, AFRR and even lower time response requirements such as inertia provision.

Coordination between EMS: Different dedicated energy management systems, building energy management systems, battery management systems would be able to communicate in an interoperable way and share information about their asset's state and coordinate management strategies and back each other in case of faults. This can contribute to self-healing systems triggering reconfiguration of the network to quickly respond to faults and minimize outages.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101096511. Disclaimer: The sole responsibility for any error or omissions lies with the editor. The content does not necessarily reflect the opinion of the European Commission. The European Commission is also not responsible for any use that may be made of the information contained herein.

IEEE 2030.5 ENABLING DIGITALIZATION

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101096511. Disclaimer: The sole responsibility for any error or omissions lies with the editor. The content does not necessarily reflect the opinion of the European Commission. The European Commission is also not responsible for any use that may be made of the information contained herein.

THE IEEE 2030.5 AND DIGITALIZATION

The energy sector is undergoing a rapid transformation, driven by the integration of distributed energy resources (DERs) such as solar photovoltaics, electric vehicles, and energy storage systems. This shift, largely influenced by digitalization, demands more sophisticated communication, automation, and flexibility in energy systems. A key enabler of these capabilities is the IEEE 2030.5 standard, designed to facilitate seamless communication between devices, systems, and stakeholders across the energy value chain (Liu et al., 2021).

THE NEED FOR INTEROPERABILITY, DIGITALIZATION AND THE LINK TO IEEE 2030.5

Digitalization is revolutionizing energy systems by enhancing efficiency, integrating renewable resources, and improving resilience. As energy systems grow more complex, the need for interoperability among devices becomes paramount. IEEE 2030.5, was created to address this need, enabling many-to-many communication between devices for effective coordination and data exchange (Pérez-Donsión et al., 2022). Interoperability is essential for distributed energy systems, enabling real-time monitoring, remote control, and automation to create smart grids that are more agile and responsive to market and grid conditions.

INNOVATION IN COMMUNICATION MODELS AND OPTIMIZATION THROUGH IEEE 2030.5

The many-to-many communication model supported by IEEE 2030.5 plays a key role in managing DERs and energy storage systems. By allowing direct communication between multiple devices—such as solar panels, batteries, and smart appliances—the energy system can optimize operations without centralized control, improving efficiency and flexibility (Bovet et al., 2020).

IEEE 2030.5 supports both client-server and peer-to-peer communication models. In client-server systems, devices communicate through a central server, which allows centralized management and monitoring, ideal for OEMs and software developers. This model is beneficial for large-scale energy platforms that require a central control point for device management and updates (Simm et al., 2021). Peer-to-peer models, however, are increasingly relevant as energy systems decentralize, allowing direct communication between devices. This model is crucial for system integrators who deal with decentralized microgrids, where local communication between generation, storage, and consumption systems is key to real-time optimization (Wang et al., 2021).

WHO BENEFITS FROM IEEE 2030.5

The adoption of IEEE 2030.5 benefits various stakeholders across the energy industry. For **Original Equipment Manufacturers (OEMs)**, it ensures product compatibility with broader energy systems, enhancing market access. For example, smart inverters and home energy management systems need to meet IEEE 2030.5 requirements to integrate with existing infrastructure (Brandt et al., 2021).

Software developers benefit by being able to create interoperable applications that can be integrated with hardware solutions, offering innovation in demand response and energy management services (Zhao et al., 2019).

System integrators, who face challenges integrating new technologies with legacy systems—gain the advantage of IEEE 2030.5's common communication framework. This reduces complexity in multi-vendor environments and ensures smoother deployments (Wang et al., 2021).

Utilities and grid operators, on the other hand, benefit from the ability to integrate DERs and distributed energy management systems (DERMS) more effectively, maintaining grid stability and optimizing energy flow (Popovska et al., 2020).

Consumers benefit from IEEE 2030.5's integration with energy devices, which enables smart home systems to optimize energy usage, reduce costs, and sell excess energy to the grid. This interoperability-driven flexibility allows homeowners to participate more actively in energy markets (Rasheed & Hossain, 2020).

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101096511. Disclaimer: The sole responsibility for any error or omissions lies with the editor. The content does not necessarily reflect the opinion of the European Commission. The European Commission is also not responsible for any use that may be made of the information contained herein.

THE ROLE OF INTEROPERABILITY IN THE ENERGY VALUE CHAIN

The benefits of IEEE 2030.5 extend across the entire energy value chain:

- **Generation:** IEEE 2030.5 allows renewable energy sources like wind and solar to communicate with storage systems, aggregators and grid operators. This enables real-time supply-demand balancing, which is critical as the share of intermittent renewable energy in the grid increases (Lewis & Willis, 2019).
- **Distribution:** In energy distribution, IEEE 2030.5 helps enhance control over energy flows by enabling real-time communication between aggregators, grid operators, sensors, and DERs. This improves demand forecasting, load management, and ultimately grid reliability (Liu et al., 2021).
- **Consumption:** End-users, such as households or businesses, benefit from greater control over energy consumption through smart devices. Real-time monitoring, dynamic pricing, and automation are made possible by IEEE 2030.5-compliant systems, improving energy efficiency and cost savings (Zhao et al., 2019).

IEEE 2030.5 & DATA SPACES INTEGRATION

Integrating **Energy Data Spaces** with the **IEEE 2030.5** standard presents a compelling opportunity for optimizing and enhancing smart grid and energy management systems and empower the integration of DES, while promoting a trustworthy environment for data sharing, hence boosting digitalization:

Data spaces, allow for secure and scalable data sharing across platforms and organizations, thus enhancing the interoperability of energy systems using IEEE 2030.5. By integrating the data space, different energy stakeholders (e.g., utilities, grid operators, consumers) can access, exchange, and share data more effectively, creating a harmonized data ecosystem.

Benefits of Integrating IEEE 2030.5, Data Space, and NATS

- **Scalability:** NATS handles millions of messages per second, enabling the system to scale as more IEEE 2030.5 devices are added.
- **Real-Time Data Sharing:** NATS' low-latency messaging ensures that data from devices reaches stakeholders in near real-time, critical for time-sensitive grid operations.
- **Secure and Governed Access:** The data space ensures that only authorized entities can access the data, maintaining data sovereignty and regulatory compliance.
- **Interoperability:** Using NATS as a broker allows for flexible integration between heterogeneous systems (IEEE 2030.5 devices, grid management systems, analytics platforms, etc.).

By integrating IEEE 2030.5 devices with the Energy Data Space via NATS, energy data becomes accessible, actionable, and secure in a distributed environment, improving grid efficiency and DER management.

DATA-DRIVEN DECISION MAKING

With the inclusion of data spaces, advanced analytics can be applied to the large datasets generated by smart grids. These analytics can improve grid operations by enabling predictive maintenance, real-time demand forecasting, and energy optimization. Utilities and grid operators can make more informed decisions based on high-quality, shared data from different systems and participants.

IMPROVED CUSTOMER ENGAGEMENT AND ENERGY EFFICIENCY

Consumers and businesses can access and share real-time energy usage data through a data space that supports IEEE 2030.5. This creates opportunities for personalized energy management solutions, better demand response participation, and improved energy efficiency. Consumers can actively monitor their usage patterns and adjust behaviors to reduce energy costs.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101096511. Disclaimer: The sole responsibility for any error or omissions lies with the editor. The content does not necessarily reflect the opinion of the European Commission. The European Commission is also not responsible for any use that may be made of the information contained herein.

INTEGRATING ENERGY DATA SPACE WITH IEEE 2030.5

Example Use Cases:
Complementing the high-level use cases described in the **Blueprint of the Common European Energy Data Space (Int:net, 2024)** the integration of the IEEE 2030.5 InterSTORE version, unleashes new applications such as:

- **Microgrid Management:** A data space integrated with IEEE 2030.5 can enable multiple DERs (solar, batteries, EVs) within a microgrid to securely share data with utilities and grid operators. This optimizes the balance between generation and consumption, improving reliability.
- **Electric Vehicle (EV) Integration:** As EVs become more common, IEEE 2030.5 enables them to communicate with the grid for smart charging. Data spaces would allow utilities to dynamically adjust charging patterns based on grid demands, while respecting user privacy.
- **Dynamic Pricing and Demand Response:** With data sharing through a secure data space, utilities can provide dynamic pricing based on current grid conditions, and consumers can respond to price signals, adjusting their energy usage for cost savings.

The integration of Energy data space with IEEE 2030.5 opens a world of possibilities for secure, interoperable, and intelligent energy management. By leveraging the benefits of both technologies, utilities, grid operators, and consumers can achieve higher efficiency, better grid stability, and a more sustainable energy future.

Integration with Smart Cities and IoT

Data spaces allow for seamless integration with Internet of Things (IoT) devices and smart city infrastructures. As IEEE 2030.5 enables communication between energy devices, connecting these devices within a larger IoT framework via a data space can further extend smart city functionalities, such as managing electric vehicle charging, building automation, or integrating renewable energy sources.

This paragraph analyses and describes a potential integration of an Energy Data Space with the IEEE 2030.5 protocol using a NATS server.
Integrating data space with an IEEE 2030.5 interface device via a NATS server combines several key technology components:

IEEE 2030.5 Interface component: A device that implements the IEEE 2030.5 protocol, enabling communication with energy resources such as smart meters, electric vehicles, or solar panels.

1. Energy Data Space Framework: A platform designed for Energy sector to facilitate secure and governed data sharing across stakeholders while maintaining data sovereignty.
2. NATS Server: A lightweight, high-performance messaging system that enables real-time communication between distributed systems using a publish-subscribe model.

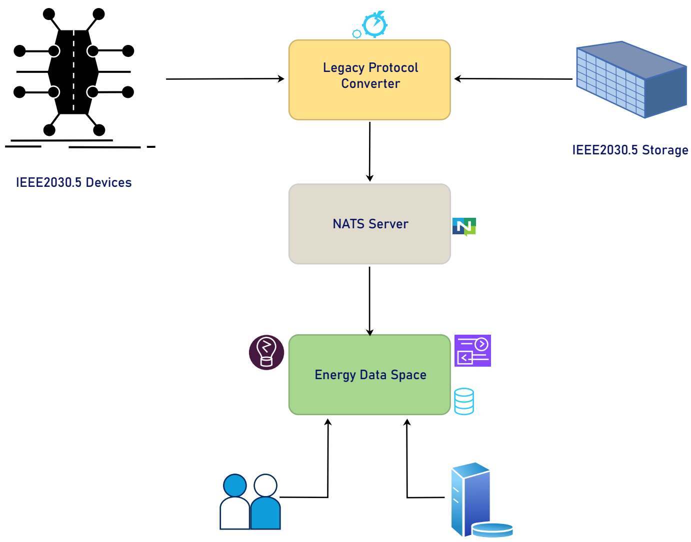

Figure 5 Data Space - IEEE 2030.5 integration diagram

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101096511. Disclaimer: The sole responsibility for any error or omissions lies with the editor. The content does not necessarily reflect the opinion of the European Commission. The European Commission is also not responsible for any use that may be made of the information contained herein.

KEY CHALLENGES ADOPTING THE IEEE 2030.5 IN EUROPE

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101096511. Disclaimer: The sole responsibility for any error or omissions lies with the editor. The content does not necessarily reflect the opinion of the European Commission. The European Commission is also not responsible for any use that may be made of the information contained herein.

BARRIERS AND ENABLERS

The adoption of the IEEE 2030.5 standard across Europe, while promising for the future of smart energy systems, faces both barriers and enablers. This standard has the potential to drive the interoperability and integration of distributed energy resources (DERs) and smart grid technologies, but several factors must be addressed to ensure widespread implementation. Following are the barriers and enablers towards widespread adoption of IEEE 2030.5 in Europe.

BARRIERS

Testing and Certification Gaps

One of the key barriers to the adoption of IEEE 2030.5 in Europe is the limited availability of testing and certification entities. These organizations play a critical role in ensuring that products comply with the standard and can be integrated into existing energy systems. Currently, Europe lacks a well-established network of certification bodies specializing in IEEE 2030.5, which slows the process of standardizing products and services across the region. Without a clear framework for testing and certification, manufacturers may hesitate to develop IEEE 2030.5-compliant products, further hindering adoption (Brandt et al., 2021).

Industry Adoption

Adoption by industry stakeholders is another significant challenge. Many energy companies and manufacturers are hesitant to implement IEEE 2030.5 due to the high costs of upgrading legacy infrastructure. Existing systems, particularly in older grids, may not be compatible with IEEE 2030.5, requiring significant investment to modernize equipment. Additionally, the presence of competing communication standards within Europe, such as IEC 61850, can create fragmentation, making it difficult for companies to decide which standard to adopt (Liu et al., 2021).

Regulatory Alignment and Policy Support

The lack of harmonized regulatory frameworks across European countries poses another barrier to the adoption of IEEE 2030.5. Energy markets in Europe vary widely in terms of grid infrastructure, policy objectives, and regulatory support for smart grid technologies. For example, Germany has made significant strides in smart grid development, with regulations supporting digitalization and DER integration, aligning well with IEEE 2030.5 standards (Federal Ministry for Economic Affairs and Energy, 2020). In contrast, Italy and Spain have been slower to adopt such frameworks, focusing more on traditional grid infrastructure and lagging in regulatory support for advanced communication standards (JRC Smart Grid Report, 2021). This fragmented regulatory environment makes it challenging to create a uniform approach to adopting the IEEE 2030.5 standard across Europe (Lewis & Willis, 2019).

Maintaining IEEE 2030.5 and Future Developments

One of the key enablers for the long-term success of IEEE 2030.5 in Europe is the active involvement of European stakeholders in maintaining and evolving the standard. Given the rapid pace of innovation in the energy sector, IEEE 2030.5 must adapt to new technological advancements, such as artificial intelligence, blockchain for energy trading, and advancements in energy storage technologies (Bovet et al., 2020).

Awareness and Expertise

A final barrier is the lack of awareness and technical expertise among stakeholders about the benefits and functionality of IEEE 2030.5. Without sufficient knowledge of how the standard can improve system interoperability and enable new digital services, many companies may continue to rely on existing technologies or choose other standards that they are more familiar with (Simm et al., 2021).

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101096511. Disclaimer: The sole responsibility for any error or omissions lies with the editor. The content does not necessarily reflect the opinion of the European Commission. The European Commission is also not responsible for any use that may be made of the information contained herein.

ENABLERS

Regulatory and Policy Support

A key enabler for the adoption of IEEE 2030.5 is the growing regulatory and policy support from the European Union (EU). With initiatives like the Clean Energy for All Europeans package and the European Green Deal, the EU is creating a policy environment that promotes the modernization and digitalization of energy systems. Central to this topic are the Digital Services ACT, the EU Data Act and Data Governance Act. These initiatives provide strong incentives for adopting standards that enhance interoperability, such as IEEE 2030.5, particularly in managing distributed energy resources and smart grids. The regulatory push toward de-carbonization, energy efficiency, and grid flexibility aligns well with the capabilities of IEEE 2030.5, making it an appealing choice for energy stakeholders (Pérez-Donsión et al., 2022).

Growing Demand for Interoperability

The rising need for interoperability between different energy devices and systems is another enabler for the adoption of IEEE 2030.5. As energy systems become more decentralized and DERs become more widespread, utilities, grid operators, and energy service providers are recognizing the importance of seamless communication between devices. IEEE 2030.5's ability to support many-to-many communication is particularly valuable in this context, enabling efficient integration of renewable energy sources, storage systems, and smart devices. The demand for smart energy management and automation is pushing more companies to adopt this standard (Lewis & Willis, 2019).

Support from Industry Leaders

Several large industry players, including original equipment manufacturers (OEMs) and technology companies, have recognized the value of IEEE 2030.5 and are actively supporting its adoption. Companies like Schneider Electric and Siemens have integrated IEEE 2030.5-compliant communication protocols into their energy management and smart grid solutions, allowing for easier interoperability between distributed energy resources (DERs) and grid systems.
For example, Schneider Electric's EcoStruxure Grid platform includes compatibility with IEEE 2030.5 to manage DER integration and optimize grid efficiency (Schneider Electric, 2020). Similarly, Siemens has incorporated IEEE 2030.5 in its Spectrum Power grid management software, which enables utilities to manage both traditional grid operations and DERs seamlessly (Siemens, 2021).
Technology companies such as Enphase Energy, a leader in solar energy solutions, have also adopted IEEE 2030.5 for their Enphase Ensemble energy management systems. This enables solar panels, storage, and inverters to communicate effectively with utility grids, enhancing grid reliability and making DERs easier to manage (Enphase Energy, 2021). By embedding this standard into their products, these industry leaders are driving wider adoption and creating an ecosystem of IEEE 2030.5-compliant devices.
As more products become available and certified to work with IEEE 2030.5, the standard's adoption becomes easier for other stakeholders, including utilities and system integrators. This support from key industry leaders ensures that the standard is gaining traction in the European energy market (Bovet et al., 2020).

Technological Advancements

The development of smart grid technologies and the increasing digitalization in the energy sector have significantly enabled IEEE 2030.5 adoption. For instance, ABB's Ability Smart Grid solutions integrate real-time grid monitoring and demand response, making use of IEEE 2030.5 to ensure seamless communication between distributed energy resources (ABB, 2020). Similarly, General Electric's Grid Solutions platform incorporates IEEE 2030.5 for managing DERs and improving grid resilience through advanced energy management systems (GE Grid Solutions, 2021). As these technologies continue to evolve, IEEE 2030.5's role as a secure, efficient communication protocol is increasingly recognized.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101096511. Disclaimer: The sole responsibility for any error or omissions lies with the editor. The content does not necessarily reflect the opinion of the European Commission. The European Commission is also not responsible for any use that may be made of the information contained herein.

POLICY AND REGULATION RECOMMENDATION

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101096511. Disclaimer: The sole responsibility for any error or omissions lies with the editor. The content does not necessarily reflect the opinion of the European Commission. The European Commission is also not responsible for any use that may be made of the information contained herein.

The IEEE 2030.5 standard, known for facilitating smart grid interoperability, has evolved to incorporate new technological and regulatory demands. The InterSTORE project is playing a pivotal role in advancing these developments, aligning with contemporary European Union (EU) policies and energy strategies. To ensure the new version of IEEE 2030.5, it supports effective energy management with many-to-many communication and scalable integration across Europe, essential recommendations are needed, focusing on regulatory and standardization efforts, investments in infrastructure, governance, certification, and alignment with industry needs.

To foster a comprehensive and secure energy ecosystem, regulatory bodies must strengthen cross-border standardization efforts with guidance documents. EU member states should engage in coordinated dialogues involving the EU Commission, IEEE working groups, and standardization entities like CENELEC. This collaborative approach would help create legislative frameworks that mandate IEEE 2030.5's adoption in smart grid projects, potentially through an implementation act aligned with the Data Act and Digital Markets Act. Such regulatory alignment would promote data sharing and interoperability across borders. Furthermore, the open-source nature of developing and adapting IEEE 2030.5 versions should be incentivized through policy measures, such as funding initiatives within Horizon Europe, to encourage widespread participation. Aligning with EU programs like the Data 4 Energy within the Smart Energy Expert Group will further support these standardization efforts.

Investments in infrastructure are critical for the adoption of IEEE 2030.5. Governments and regulatory bodies must prioritize modernization of grid infrastructure by directing investments toward integrating IEEE 2030.5-compliant technologies. Public-Private Partnerships (PPPs) can be utilized to share the financial burden and implement pilot projects demonstrating the standard's efficacy.

Support for technological ecosystems is also vital, with financial incentives and grants directed at start-ups and SMEs that focus on smart grid technologies and related innovations. Training and education programs should be funded to develop a skilled workforce capable of deploying and maintaining IEEE 2030.5 infrastructure.

Managing the evolution of IEEE 2030.5, especially in an open-source context, presents governance challenges. To address these, a coordinated governance framework is necessary. One initiative could be launched within the Linux Foundation for Energy to promote and guide IEEE 2030.5's development with which the InterSTORE will make a connection, for user engagement and community creation. This initiative would foster community engagement, manage development directions, and include a steering committee with representatives from regulatory bodies, certification agencies, industry leaders, and open-source contributors. Transparent protocols should be established for managing code submissions and updates, with a focus on maintaining compatibility across versions. Creating a feedback loop between developers, certification bodies, and users will support continuous improvements and adherence to industry standards.

Certification is another cornerstone of promoting IEEE 2030.5 adoption. Early involvement of European certification entities is essential to develop and validate testing procedures especially when integrating the legacy protocol converter for existing equipment. Simplifying the certification process with automated tools will reduce costs and time, encouraging smaller companies to adopt the standard. The core tools have been made available open-source by the InterSTORE consortium in the project's GitHub and DockerHub repositories. Accreditation programs for third-party labs should be introduced to expand compliance testing capabilities. Regular review cycles and feedback mechanisms will ensure that certification processes evolve in tandem with updates to IEEE 2030.5.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101096511. Disclaimer: The sole responsibility for any error or omissions lies with the editor. The content does not necessarily reflect the opinion of the European Commission. The European Commission is also not responsible for any use that may be made of the information contained herein.

Maintaining alignment with industry needs and the original developments of IEEE 2030.5 is also a piece in an open-governance scenario. Industry relevance can be sustained by engaging with energy companies, technology developers, OEMs and smart appliance manufacturers for input. The standard must adapt to technological advances such as IoT and AI to maintain applicability. Protocols should be established to manage forks and ensure backward compatibility across versions, preventing fragmentation and ensuring an unified development path.

To achieve broader recognition and support, the IEEE 2030.5 standard should be formally adopted through an implementation act that promotes its use across energy infrastructures. This approach supports EU data-sharing policies under the Data Act and aligns with efforts such as the JRC ESA (Energy Smart Appliances) code of conduct. Collaboration with public policy initiatives like Data 4 Energy will help synchronize IEEE 2030.5 with broader policy design efforts and best practices. Other initiatives to be aligned with are SmartEn association, and the Network Code for Demand Response as a target guide in terms of requirements.

In conclusion, the evolution and adoption of IEEE 2030.5 within the European energy framework require strategic regulatory support, investment in infrastructure, robust governance, certification processes, and alignment with industry needs. By promoting these measures, the standard can be effectively integrated to enhance energy efficiency and interoperability, benefiting stakeholders across Europe. The cooperation of regulatory bodies, industry players, and the open-source community will be vital in realizing these objectives.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101096511. Disclaimer: The sole responsibility for any error or omissions lies with the editor. The content does not necessarily reflect the opinion of the European Commission. The European Commission is also not responsible for any use that may be made of the information contained herein.

REFERENCES

1. Amin, M., & Wollenberg, B. (2021). Toward a Smart Grid: Power Delivery for the 21st Century. IEEE Power and Energy Magazine, 8(6), 34–41.

2. Brandt, A., Simm, W., & Koehler, J. (2021). Interoperability in smart grid ecosystems: The role of digital standards in distributed energy systems. Energy Policy, 154, 112-125.

3. Bovet, G., Li, Z., & Brunelli, D. (2020). Interoperability challenges in distributed energy systems: The case for digital standards. Energy Reports, 6, 511-523.

4. Doeff, M. M., & Rains, R. M. (2020). Energy Storage for Grid Resilience. Journal of Energy Storage, 28, 101-113.

5. Elliston, B., MacGill, I., & Riesz, J. (2019). Managing High Penetrations of Variable Renewable Energy in Australia's NEM. Energy Policy, 132, 1303–1315.

6. Enphase Energy, "Ensemble Energy Management Systems: Adopting IEEE 2030.5 for reliable grid communication and DER management," 2021. [Online]. Available: https://support.enphase.com/s/article/Ensemble-Energy-Management-Technology .

7. Federal Ministry for Economic Affairs and Energy, "Germany's Digitalization Strategy for the Energy Transition," 2020. [Online]. Available: https://www.bmwi.de/Redaktion/EN/Dossier/energy-transition.html.

8. GE Grid Solutions, "Grid Solutions Platform: Managing Distributed Energy Resources (DERs) with IEEE 2030.5 for improved grid resilience," 2021. [Online]. Available: https://www.gegridsolutions.com.

9. International Energy Agency (IEA). (2022). Renewables 2022: Analysis and Forecast to 2027. Paris: IEA Publications.

10. Gungor, V. C., Sahin, D., & Kocak, T. (2020). A Survey on Smart Grid Potential Applications and Communication Requirements. IEEE Transactions on Industrial Informatics, 9(1), 28–42.

11. Joint Research Centre (JRC) , "Smart Grids and Beyond: An EU Research and Innovation Perspective," European Commission, 2021. [Online]. Available: https://joint-research-centre.ec.europa.eu/jrc-news-and-updates/smart-grids-and-beyond-2021-12-17_en

12. Karnouskos, S., & de Holanda, T. N. (2020). Secure Smart Grid Protocols: An Overview. Journal of Systems and Software, 136, 133–144.

13. Lewis, J. W., & Willis, R. (2019). Managing grid resilience with distributed energy resources: A case for IEEE2030.5. Journal of Energy Engineering, 145(2), 58-66.

14. Liu, H., Wang, L., & Yao, Y. (2021). A review of digitalization and its role in smart grid integration: Focusing on IEEE2030.5 and other communication standards. IEEE Transactions on Power Systems, 36(3), 1873-1881.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101096511. Disclaimer: The sole responsibility for any error or omissions lies with the editor. The content does not necessarily reflect the opinion of the European Commission. The European Commission is also not responsible for any use that may be made of the information contained herein.

15. Lund, H., Østergaard, P. A., & Connolly, D. (2020). Smart Energy Systems and 4th Generation District Heating. Energy, 167, 111-125.

16. Pérez-Donsión, M., Simoes, M. G., & García, O. (2022). Energy digitalization: Trends, challenges, and opportunities in smart grids and distributed energy systems. Renewable and Sustainable Energy Reviews, 148, 111-125.

17. Pérez, R., Bailey, B. G., & Hoff, T. E. (2018). PV Grid Integration in a Decarbonized Electric Grid. Solar Energy, 174, 27–40.

18. Popovska, N., Thakur, R., & Andersen, L. (2020). Smart home energy management and digitalization: Interoperability challenges and opportunities in smart grids. IEEE Transactions on Smart Grid, 11(3), 2339-2347.

19. QualityLogic Inc., "IEEE 2030.5 Takes Off," 2021. [Online]. Available: https://www.qualitylogic.com/knowledge-center/ieee-2030-5-takes-off/ and https://esdnews.com.au/ieee-2030-5-connect-to-the-wide-world-of-distributed-energy-resources/.

20. Rasheed, A., & Hossain, S. (2020). Home energy management systems: The role of digital standards in advancing smart home technologies. Energy Research & Social Science, 65, 101-116.

21. Schneider Electric, "Schneider Electric Announces IEEE 2030.5 Certification of EcoStruxure DERMS and ADMS," 2022. [Online]. Available: https://smartgrid.schneider-electric.com/s/blog-article/a051R00001r3o8fQAA/schneider-electric-announces-ieee-20305-certification-of-ecostruxure-derms.

22. Simm, W., Brandt, A., & Koehler, J. (2021). Digital communication standards in smart energy systems: A comprehensive review of IEEE2030.5 applications. Journal of Energy Systems, 12(4), 165-183.

23. von Appen, J., Stetz, T., & Braun, M. (2021). Prosumers in the Smart Grid: Challenges and Opportunities. Renewable Energy, 165, 535-548.

24. Wang, T., Li, X., & Zhuang, H. (2021). Peer-to-peer communication and decentralized energy management in smart microgrids. IEEE Access, 9, 103571-103582.

25. Xie, L., Carvalho, P. M. S., & Ferreira, L. A. (2018). Smart Grid Interoperability: Challenges and Opportunities. Renewable and Sustainable Energy Reviews, 78, 1393–1402.

26. Zhao, C., Yang, Q., & Li, Z. (2019). Digital energy services in the smart grid: The role of software and communication standards. Renewable Energy, 140, 482-491.

27. Zhang, X., & He, X. (2019). Cybersecurity in Smart Grid Communication Protocols. Journal of Information Security and Applications, 47, 102–116.

28. InterSTORE, "Resources," 2024. [Online]. Available: https://interstore-project.eu/resources/ .

29. Int:net. "Blueprint of the Common European Energy Data Space," July 2024. Version 2.0. [Online] Available: https://enershare.eu/wp-content/uploads/Blueprint_CEEDS_v2.pdf.

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101096511. Disclaimer: The sole responsibility for any error or omissions lies with the editor. The content does not necessarily reflect the opinion of the European Commission. The European Commission is also not responsible for any use that may be made of the information contained herein.

LIST OF TABLES

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101096511. Disclaimer: The sole responsibility for any error or omissions lies with the editor. The content does not necessarily reflect the opinion of the European Commission. The European Commission is also not responsible for any use that may be made of the information contained herein.

LIST OF FIGURES

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101096511. Disclaimer: The sole responsibility for any error or omissions lies with the editor. The content does not necessarily reflect the opinion of the European Commission. The European Commission is also not responsible for any use that may be made of the information contained herein.

interstore

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101096511. Disclaimer: The sole responsibility for any error or omissions lies with the editor. The content does not necessarily reflect the opinion of the European Commission. The European Commission is also not responsible for any use that may be made of the information contained herein.