# DEVELOPMENT AND DEPLOYMENT OF A REALTIME INTERFACE CUSTOMER ENDPOINT FOR ENHANCING GRID STABILITY AND CONGESTION MANAGEMENT IN THE DUTCH ENERGY SECTOR

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## Abstract
The rapid energy transition in the Netherlands has intensified challenges related to grid stability and congestion management. To address these, Netbeheer Nederland, in collaboration with Dutch Distribution System Operators (DSOs) and market players, developed the Realtime Interface (RTI), a standardised communication system enabling real-time data exchange and dynamic power control between DSOs and Distributed Energy Resources (DERs) at the Point of Common Coupling (PoCC).
This paper details the design, development, and validation of the Teleport Gateway, the first RTI-compliant customer endpoint. It translates DSO setpoints into actionable commands for DERs such as photovoltaic systems, wind turbines, and battery energy storage systems. It leverages the IEC 61850 protocol for communication and integrates market signals for grid balancing and congestion management. Field trials with Enexis and other DSOs demonstrated the Teleport's scalability, reliability, and compliance with regulatory standards. The RTI and Teleport highlights the importance of standardised protocols, collaborative stakeholder involvement, and cybersecurity in addressing energy transition challenges.

## 1 Introduction

*1.1 Context and relevance*
The ongoing energy transition in the Netherlands is driving a rapid increase in decentralised, weather-dependent energy systems that introduced substantial challenges, particularly in grid stability and congestion management.

To connect more Distributed Energy Resources (DERs) and manage limited transport capacity while awaiting grid reinforcements - or to potentially avoid them -, Distribution System Operators (DSOs) may implement congestion management or alternative capacity management strategies. However, secure and efficient management of available capacity requires DSOs to access metering data for monitoring and to communicate real-time operating constraints to DERs owners [1].

Historically, communication between DSOs and DERs relied primarily on on/off control mechanisms. While effective in immediate crises, those methods lack the necessary granularity and scalability for modern grid demands. Furthermore, the absence of standardised communication protocols has led to a fragmented approach. Recognising these challenges, Netbeheer Nederland initiated a project in 2020, involving Dutch DSOs and market stakeholders, to develop the Realtime Interface.

*1.2 The Realtime Interface*

*1.2.1 Definition and regulatory context:* The Realtime Interface (RTI) is a system combining hardware and communication protocols to enable real-time setpoint communication between DSOs and DERs at the Point of Common Coupling (PoCC). The setpoint allows DSOs to direct the adjustment of an electricity production unit, consumption unit, electricity storage unit, or a combination thereof [2].

The RTI is rooted in European Union legislation [3] and the Dutch Electricity Grid Code [4], mandating an interface for power modulation in Type B systems (1MW-50MW capacity). Since January 2024, all new or upgraded feed-in connections within this range must comply with RTI requirements.

*1.2.2 Functionality and architecture:* The primary function of the RTI is to provide DSOs with direct control capabilities over the power output of connected DERs, particularly during periods of acute grid congestion. Key functionalities include:

- Real-time data exchange: Continuous monitoring of active power, reactive power, voltage, and current measurements.
- Dynamic power control: Enabling grid operators to issue setpoints that adjust the maximum permissible power output of DERs.
- Safe mode operations: In the event of communication loss, predefined power limits are automatically enforced to prevent grid destabilisation. Upon communication restoration, buffered measurement data is transmitted to ensure seamless reintegration.

The RTI architecture involves two endpoints:

- Customer endpoint: Installed at the energy producer's premise to send data and receive operational commands, with strict security measures, including physical connections.
- DSO endpoint: Operated by DSOs to monitor grid conditions and issue control commands.

The interface uses the IEC 61850 protocol for secure and interoperable communication.

*1.3 Objectives and scope of the research*
This research focuses on the design, development, implementation, and validation process of a standardised customer endpoint, specifically the Teleport Gateway, within the RTI framework.

## 2 System design and development

*2.1 Overview of the Teleport Gateway*
The Teleport Gateway was initially designed as a versatile, independent local controller for DERs. Its purpose was to optimise energy production, storage, and consumption behind-the-meter while processing balancing market signals and ensuring operations adhered to contracted grid limits. The gateway supports integration with various energy assets, including photovoltaic (PV) systems, wind turbines, and Battery Energy Storage Systems (BESS). This interoperability allows the gateway to manage and coordinate diverse energy assets across a wide range of operational scenarios. Additionally, the Teleport already incorporated in its design cybersecurity measures aligning with ISO27001 requirements and guidelines from the European Network for Cybersecurity.

*2.2 RTI development objectives*
The Teleport's transformation into an RTI-compliant customer endpoint centered on several objectives related to functionality, compliance, and interoperability, with the following objectives:

*2.2.1 Compatibility with both DSO setpoints, market signals and local control loop:*

- DSO setpoints: Enabling the system to respond to dynamic grid constraints and ensure grid stability.
- Market signals: Including day-ahead (e.g., EPEX), balancing and congestion markets.
- Local control loops: Facilitating dynamic optimisation of power flows behind-the-meter and safeguarding contracted grid connection limits.

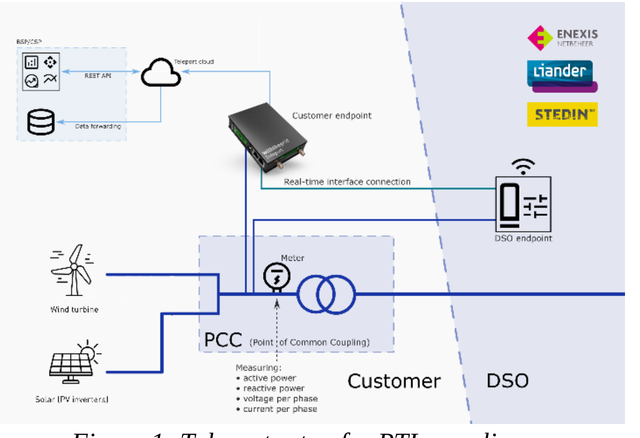

*Figure 1: Teleport setup for RTI compliance*

*2.2.2 Integration of cybersecurity measures:* Incorporating cybersecurity measures to protect data exchanged with DERs, DSOs, and other connected systems, as well as to ensure compliance with critical energy infrastructure cybersecurity standards.

*2.2.3 Leveraging existing infrastructure:* Prioritising the use of existing infrastructure, including:

- Existing Modbus communication capabilities of the Teleport for straightforward asset integration.
- Adoption of standardised protocols (e.g., IEC 61850) to facilitate widespread compatibility.

*2.3 Asset library and compatibility requirements*
The Teleport already featured an extensive asset library [5] to communicate with a wide variety of DERs. Integrating this library with the RTI was crucial, as the RTI's primary function is to manage these assets during emergencies.

The Teleport hardware is powered by a robust processor running a Linux-based operating system. It features dual Ethernet interfaces, which are essential for implementing network segmentation - a key security requirement for the RTI: one Ethernet interface must be exclusively dedicated to RTI operations.

With its processing capabilities and dual Ethernet ports, the Teleport hardware was well-equipped to support the RTI and IEC 61850 protocol.

*2.4 Leveraging the IEC 61850 library*
Developing the IEC 61850 protocol from scratch was impractical due to its complexity. Instead, an existing IEC 61850 library was adopted as the foundation for RTI communication. However, options for such libraries were limited, both in terms of suppliers and their programming language support, primarily restricted to C or C++. This necessitated creating a binding mechanism between the Teleport's asset library and the IEC 61850 library.

*2.5 Testing IEC 61850 compliance*

*2.5.1 Scope of compliance testing:* Compliance testing focused on the specific components of the IEC 61850 standard. For the RTI, not all components of the standard were relevant; only required sections were tested.

*2.5.2 Hardware requirements for testing:* The testing setup required hardware capable of handling digital and analogue inputs and outputs to process external signals. As the Teleport lacked native support, an external Modbus-compatible device with manual I/O switches was used. The Teleport's inherent Modbus support simplified integration, providing a robust foundation for IEC 61850 compliance testing.

*2.6 Challenges in achieving IEC 61850 compliance*

*2.6.1 In-house testing setup:* Achieving IEC 61850 compliance was a complex, iterative process due to the protocol's extensive requirements and multi-step test procedures.

To minimise costs, in-house testing was conducted using the certification authority's software, enabling comprehensive pre-compliance testing and reducing reliance on external services.

*2.6.2 Data model and configuration debugging:* Initial testing focused on debugging the data model and configuration based on the RTI specification. Some errors originated in the RTI model, which were reported to Netbeheer Nederland and manually corrected. Early pre-compliance tests showed a 20% failure rate due to mismatches between documented values and library behaviour or unnecessary services in tests. Iterative updates to data models, configurations, and documentation reduced these inconsistencies and improved compliance.

*2.6.3 Dealing with library bugs:* The server and reporting functionalities were the most challenging aspects of compliance due to the library's layered structure and the IEC 61850 standard's vast scope (spanning over 10,000 pages). Given the efficiency of the Teleport hardware, debugging relied heavily on inserting and analysing logs in the library code.

A systematic approach of expanding logs, reviewing outputs, and thoroughly investigating issues led to the identification and detailed documentation of errors, which were then reported to the library supplier. While the supplier resolved some bugs, others necessitated internal fixes. Each solution underwent repeated compliance testing, though some fixes introduced regressions, causing previously passing tests to fail and requiring further refinement. Solutions were eventually validated.

*2.7 Challenges in achieving RTI compliance*

*2.7.1 Implementation overview:* In contrast to the complexities of the IEC 61850 standard, implementing the RTI was relatively straightforward. Built atop the IEC 61850 protocol, the RTI defines a specific data model and actions, such as processing steering signals. Technical specifications and a compliance verification plan provided by Netbeheer Nederland clearly outlined the logic and tests required for RTI compliance.

*2.7.2 Integrating market signals:* A significant challenge in RTI implementation was integrating it with existing market signals already managed by the Teleport. These include day-ahead (EPEX), balancing market signals, and local control loops, which optimize power flows to maximize feed-in while adhering to grid constraints.

The RTI adds a new layer: a dynamic limit on power feed-in or consumption. And unlike a setpoint, which defines an exact power target, the RTI limit specifies a maximum allowable threshold. To reconcile this limit with existing market signals, the system calculates effective setpoints and limits by taking the minimum value of all constraints. This ensures compliance with RTI limits while allowing flexibility for market-based optimization, such as shutting off production entirely or operating at intermediate levels when required.

*2.8 Testing and finalization of the RTI*

*2.8.1 Beta testing:* As the RTI specification was not finalised during initial development, testing began with the beta.4 version. Withthegrid actively contributed to refining the specification through feedback on the data model, test procedures, and overall documentation.

At this stage, no dedicated compliance testing tool existed, so a small, manual test tool was developed for verification purposes. These tests were simpler than the rigorous IEC 61850 compliance tests and focused on validating specific behaviours defined in the RTI specification. For example, one test ensured that the Teleport correctly transitioned to safe mode when a connection was lost.

Despite the evolving specification, the Teleport quickly achieved beta.4 compliance. Minor issues arose, such as handling negative setpoint signals, but these were straightforward to address due to the in-house development of the Realtime Interface implementation.

*2.8.2 Final certification:* After finalising the specification, clarifications and updates necessitated minor adjustments to the implementation. For instance, certain settings required for establishing a RTI connection were made configurable to enhance security in version 1 of the RTI. After these changes, the Teleport was re-certified, becoming the first certified customer endpoint in April 2024.

# 3 Results and implementation

*3.1 Lab and field testing with Enexis*

*3.1.1 Lab testing:* Withthegrid partnered with the Dutch grid operator Enexis for lab testing and the first pilot project. Enexis created a detailed test setup in their lab, while Withthegrid operated a Teleport from their own lab, representing the customer endpoint. The lab setup did not include real DER assets; instead, the Teleport simulated an asset, generating synthetic measurements (e.g., active power) and responding to control signals.

Initial tests verified basic communication between the devices, ensuring the measurements generated by the Teleport matched those received by Enexis. More advanced tests examined behaviours in specific scenarios, such as enabling safe mode, issuing curtailment signals, and simulating communication loss between the devices. Both systems followed predefined responses, with collected data compared against expected outcomes to confirm compliance.

*3.1.2 Field testing:* Field testing introduced real-world assets and operational conditions. A Teleport and power meter were physically installed at the test site on the customer side of the transformer station, while Enexis deployed equipment on the grid operator side. The two setups were connected via an Ethernet cable for RTI communication. Additionally, the Teleport was linked to solar inverters and the power meter through a separate Ethernet network.

Field tests replicated many lab scenarios but incorporated actual measurement data and real-time control of the solar inverters. This setup allowed for direct observation of power changes and other measurement data on both sides of the transformer station, validated by Enexis's equipment.

Testing began with the beta.4 RTI specification, with subsequent updates evaluated remotely using the Teleport's connectivity. One notable challenge was establishing communication with solar inverters located 50 metres from the transformer station. This was resolved by installing additional Ethernet infrastructure to bridge the distance. Despite logistical hurdles, the field tests successfully demonstrated the Teleport's ability to operate under real-world conditions, meeting both operational and compliance requirements for the RTI.

# 4 Discussion

*4.1 Lessons learned*

*4.1.1 Technical complexity:* IEC 61850 compliance was a major challenge due to the protocol's complexity compared to the more often used Modbus protocol. Iterative testing and debugging of the IEC 61850 library code required significant time and expertise, highlighting the need for a methodical implementation approach.

*4.1.2 Operational constraints:* Field testing revealed logistical issues, such as ensuring reliable communication with DERs over long distances. The installation of enhanced Ethernet infrastructure highlighted the importance of proactive planning for real-world deployment challenges.

*4.1.3 Stakeholder collaboration:* The RTI's success relied on close coordination between Netbeheer Nederland, DSOs, and market participants. Iterative refinement of the RTI specification during pilot deployments demonstrated how stakeholder feedback can address both technical and operational issues effectively.

*4.1.4 Specification strictness:* Interoperability tests with Enexis, followed by the ones with Stedin and Liander, highlighted the importance of precise specifications. Minor differences in RTI implementations caused small issues, underscoring the need for strict adherence to standardised protocols.

*4.2 Scalability and broader applications*
The standardised design and deployment process of the Teleport demonstrate its scalability and adaptability for broader applications. Its compliance with EU regulations, particularly those under Commission Regulation (EU) 2016/631, makes it a strong candidate for adoption in other European countries with similar initiatives.

*4.2.1 Similar European initiatives:* Comparable initiatives can be found across Europe, for example in Greece and Belgium. Greece's Hellenic Electricity Distribution Network Operator (HEDNO) mandates remote monitoring and control for DERs above 400 kW [6], leveraging the IEC 60870-5-104 protocol within its existing SCADA infrastructure, driven by a need for rapid, wide-scale deployment. Meanwhile, Belgium's Fluvius is offering to use either the IEC 60870-5-104 protocol, or analogue signals [7]. While these systems differ from the Dutch one in terms of protocol sophistication and data modelling capabilities, they reflect a growing European consensus on the need for active DER control by DSOs.

*4.2.2 Adapting the Teleport:* The Teleport has already been successfully adapted and certified for use under Greece's national regulatory and technical standards, demonstrating its versatility beyond the Dutch context. Combined with its RTI certification in the Netherlands, this positions the Teleport as a scalable and transferable solution, supporting Europe's goal of digitalised energy systems and accelerated renewable energy integration across diverse markets.

## 5 Conclusion

*5.1 Summary of findings*
The development and deployment of the RTI marks a significant step forward in addressing the challenges posed by the energy transition in the Netherlands. This initiative represents a collaborative effort by grid operators, regulatory bodies, and market stakeholders to integrate renewable energy sources into the grid while maintaining its stability and efficiency.

Through the design, implementation, and certification of the Teleport, a standardised customer endpoint, this project has demonstrated the feasibility of real-time communication between DSOs and DERs. The rigorous compliance testing, field trials, and iterative refinement processes underscore the system's operational reliability, cybersecurity robustness, and scalability. These attributes ensure that the Teleport effectively supports congestion management, facilitates market integration, and adheres to both European and Dutch regulatory requirements.

*5.2 Future work*

*5.2.1 RTI version 1.1:* Scheduled for 2025, RTI 1.1 will focus on improving cybersecurity by incorporating Transport Layer Security (TLS) encryption. This will provide stronger data integrity, confidentiality, and authentication, addressing the increasing threat of cyberattacks on critical energy infrastructure.

*5.2.2 RTI version 2.0:* The planned RTI 2.0 will transition to an internet-based architecture, enabling both real-time and ahead-of-time control of energy assets. This evolution will expand the RTI's capabilities, further integrating renewable energy systems into dynamic and efficient grid operations.

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