https://doi.org/10.37815/rte.v37nE1.1360
Original articles

Development of a Protocol Converter from SMA Data to Modbus TCP for SCADA Integration

Desarrollo de un Convertidor de Protocolo de SMA Data a Modbus TCP para la Integración SCADA

Santiago Ismael Araujo Ochoa[1] https://orcid.org/0009-0006-8903-4849, Joe Fernando Tigre Quituizaca[1] https://orcid.org/0009-0001-2301-9922, Juan Diego Belesaca[1] https://orcid.org/0000-0001-8609-0358, Fabian Astudillo-Salinas[1] https://orcid.org/0000-0001-7644-0270

[1]*Universidad de Cuenca, Departamento de Ingeniería Eléctrica, Electrónica y Telecomunicaciones,* Cuenca, Ecuador
santiago.araujo@ucuenca.edu.ec, fernando.tigre@ucuenca.edu.ec, juan.belesaca@ucuenca.edu.ec, fabian.astudillos@ucuenca.edu.ec

Sent: 2025/06/29
Accepted: 2025/08/24
Published: 2025/10/15

Abstract

The integration of distributed energy resources into smart microgrids frequently necessitates seamless communication between heterogeneous devices and centralized supervisory systems. However, specific power electronics equipment, such as the SMA Sunny Island inverter, relies on proprietary communication protocols that are incompatible with standard SCADA interfaces. The present work delineates the design and implementation of a protocol converter that facilitates transparent translation between SMA Data and Modbus TCP, thereby enabling native integration of the Sunny Island inverter into Modbus-based SCADA environments. The proposed converter was developed using a Raspberry Pi platform and employs a modular architecture that combines the YASDI communication library with a custom Python-based Modbus TCP server. The system retrieves operational data from the inverter, maps it to Modbus input registers, and allows configuration commands to be issued from the SCADA system and applied to the inverter in a controlled manner. The experimental validation was carried out in the Microgrid Laboratory at the University of Cuenca. In this setting, the converter demonstrated reliable performance in two specific tasks: data acquisition and parameter configuration. The response times exhibited a range of 10 to 30 seconds, contingent upon the system's state. Following power cycles and communication interruptions, the converter demonstrated complete recovery capability. The

Summary: Introduction, Materials and Methods, Results and Discussion, Conclusions and Future Work.

How to cite: Araujo, S., Tigre, J., Belesaca, J. D. & Astudillo-Salinas, F. (2025). Development of a Protocol Converter from SMA Data to Modbus TCP for SCADA Integration. *Revista Tecnológica - Espol, 37(E1), 12-24.* https://doi.org/10.37815/rte.v37nE1.1360

findings substantiate the viability of the proposed method as a cost-effective and resilient solution for integrating proprietary energy devices with industrial monitoring platforms. Its flexibility and resilience render it suitable for broader deployment in smart grid infrastructures and distributed energy management systems.

Keywords: microgrid, inverter, Modbus, SMA data, gateway, converter.

Resumen

La integración de recursos energéticos distribuidos en microrredes inteligentes suele requerir una comunicación fluida entre dispositivos heterogéneos y sistemas de supervisión centralizados. Sin embargo, ciertos equipos de electrónica de potencia, como el inversor SMA Sunny Island, dependen de protocolos de comunicación propietarios que son incompatibles con las interfaces SCADA estándar. El presente trabajo describe el diseño y la implementación de un convertidor de protocolos que facilita la traducción transparente entre SMA Data y Modbus TCP, lo que permite la integración nativa del inversor Sunny Island en entornos SCADA basados en Modbus. El convertidor propuesto se desarrolló utilizando una plataforma Raspberry Pi y emplea una arquitectura modular que combina la biblioteca de comunicación YASDI con un servidor Modbus TCP personalizado basado en Python. El sistema recupera los datos operativos del inversor, los asigna a los registros de entrada Modbus y permite que los comandos de configuración se emitan desde el sistema SCADA y se apliquen al inversor de forma controlada. La validación experimental se llevó a cabo en el Laboratorio de Microrredes de la Universidad de Cuenca. En este entorno, el convertidor demostró un rendimiento fiable en dos tareas específicas: la adquisición de datos y la configuración de parámetros. Los tiempos de respuesta oscilaron entre 10 y 30 segundos, dependiendo del estado del sistema. Tras ciclos de alimentación e interrupciones de la comunicación, el convertidor demostró una capacidad de recuperación completa. Los resultados corroboran la viabilidad del método propuesto como solución rentable y resistente para integrar dispositivos energéticos patentados con plataformas de monitorización industrial. Su flexibilidad y resistencia lo hacen adecuado para un despliegue más amplio en infraestructuras de redes inteligentes y sistemas de gestión de energía distribuida.

Palabras clave: microrred, inversor, Modbus, SMA data, puerta de enlace, convertidor.

Introduction

Supervisory Control and Data Acquisition (SCADA) systems play a crucial role in managing distributed energy resources within modern microgrids. These systems facilitate centralized control, real-time monitoring, and historical data visualization across a diverse array of distributed energy resources (DERs), including smart inverters, energy meters, and storage systems (Li et al., 2017). Typically, communication between these devices and the SCADA system relies on standardized industrial protocols, such as Modbus TCP/IP, which provide a uniform and robust framework for interoperability (Kermani et al., 2021). However, a significant number of commercially available inverters continue to operate using proprietary communication protocols, thereby limiting their direct integration into open SCADA platforms.

The University of Cuenca's microgrid laboratory has installed several pieces of energy generation and management equipment (Espinoza et al., 2017), including the Sunny Island inverter (SMA, 2015). One of the most significant challenges is integrating of the SMA Sunny Island inverter family, which utilizes the proprietary SMA Data protocol for communication with SCADA systems that use the Modbus protocol. Unlike Modbus, the SMA Data protocol is not openly documented and lacks native compatibility with SCADA environments. It requires the use of intermediate solutions to bridge the protocol gap. Several studies have examined protocol conversion in the context of industrial automation and smart grids. For instance, Suryani et al. (2024) reviewed Interoperability in Microgrids, emphasizing the complexity of translating proprietary formats into open standards. Most efforts to convert protocols in the literature focus on bridging open but heterogeneous interfaces, such as Modbus RTU, MQTT, and IEC 61850, rather than undocumented, proprietary formats. For example, Si et al. 2021 describe middleware that translates Modbus RTU into MQTT to enable cloud compatibility in smart microgrids. Similarly, Hemmati et al. (2021) evaluated the interoperability of the IEC 61850 protocol in hardware-in-the-loop microgrid testbeds, highlighting the need for translating between heterogeneous communication standards.

Despite these advances, a lack of documented, low-cost, and field-tested methods remains for converting SMA Data to Modbus TCP/IP in microgrids. Most existing solutions are commercial black boxes or require deep customization at the firmware level, which complicates reproducibility and academic validation. The absence of standardized translation strategies hinders the effective integration of inverters and data acquisition in research environments focused on energy transition and intelligent grid control.

The following article presents the design, implementation, and laboratory validation of a protocol conversion system that bridges the proprietary SMA Data protocol and the Modbus TCP/IP protocol. The conversion architecture is developed using low-cost embedded hardware and custom software, deployed in the Microgrid Laboratory at the University of Cuenca. The system intercepts SMA Data communications from Sunny Island inverters and translates these into standardized Modbus register formats compatible with existing SCADA infrastructure. The converter facilitates seamless integration with SCADA systems without the need to modify inverter firmware or use proprietary SMA modules. It is achieved through the implementation of real-time parsing, data mapping, and Modbus frame construction. The experimental results demonstrate the successful recovery of real-time measurements (e.g., voltage, current, power) through Modbus polling, thereby substantiating the interoperability and usability in both grid-connected and islanded operational modes.

This contribution addresses a significant gap in the extant literature by providing a documented, replicable, and cost-effective solution for integrating legacy SMA Sunny Island inverters, especially those without native Modbus support, into open SCADA platforms. The approach is scalable and adaptable to other proprietary protocols aligning with modern microgrid research demands for reproducible and standardized data acquisition. Finally, the remainder of this manuscript is organized as follows: The second section delineates the materials and the experimental methodology that were utilized in the construction and evaluation of the protocol converter. In Section 3, the results of the converter's validation are presented, including performance metrics and interoperability tests. Section 4 discusses the implications of this work and outlines potential paths for future enhancements.

Materials and Methods

This section outlines the experimental configuration and methodological framework used to design, implement, and validate the converter tool that translates the SMA Data protocol into Modbus TCP/IP. First, the physical and network environment of the Microgrid Laboratory is described, with a focus on the Sunny Island inverter and the existing SCADA infrastructure. In the following section, an exposition of the hardware and software architecture of the conversion system is provided.

Experimental Setup

The protocol converter under consideration was developed and validated within the Microgrid Laboratory of the University of Cuenca, an academic facility with a focus on research and development in distributed energy systems. The laboratory is equipped with a hybrid energy configuration, comprising photovoltaic generation, an Ampere Square S inverter, an SMA Sunny Island inverter, and a diesel-based backup system (Gutiérrez Otavalo & Padilla Guamán, 2024). These components are interconnected through a fiber-optic ring that links multiple operational devices with a centralized SCADA platform.

The SCADA system is responsible for acquiring and displaying real-time measurements of electrical parameters, as well as storing historical data and triggering event-based alarms. The primary means of establishing communication between the SCADA server and field devices is through the use of Modbus TCP/IP. Devices such as smart meters and Programmable Logic Controllers (PLCs) are natively compatible with this protocol. However, some aspects within the microgrid, notably the SMA Sunny Island inverter, operate using proprietary communication standards. In this case, the SMA Data protocol is transmitted via the Speedwire interface. This absence of protocol compatibility poses a substantial integration challenge, as it hinders the direct acquisition of inverter data by the SCADA system.

This environment provides a realistic and operationally demanding testbed for evaluating the performance of the developed protocol converter. The integration of the converter into the existing communication infrastructure facilitates the assessment of its capacity to extract pertinent data from the SMA inverter, as well as its interoperability within a live SCADA-monitored microgrid environment.

Communication Context and Integration Challenge

The integration of DERs into modern microgrids is contingent upon the standardization and interoperability of communication protocols. SCADA systems are designed to aggregate and manage data from heterogeneous sources using open communication protocols. Among these protocols, Modbus TCP/IP has been adopted most widely in industrial and academic applications. This protocol enables the SCADA system to query specific data registers on remote devices, facilitating real-time monitoring, historical logging, and event management.

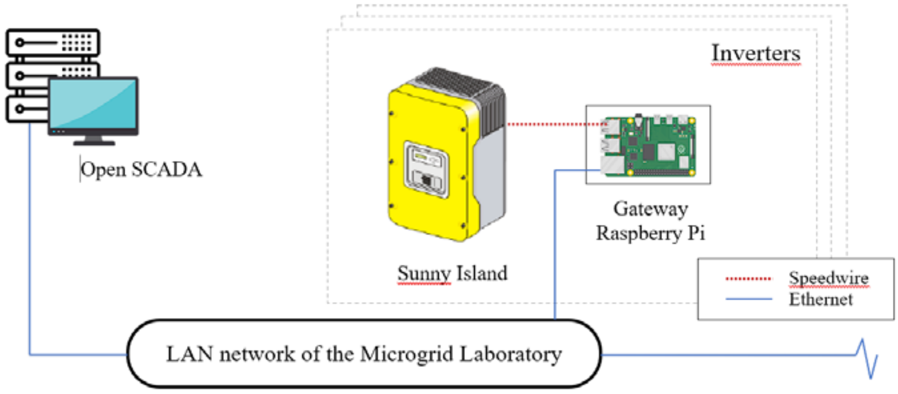
In the case of the Microgrid Laboratory at the University of Cuenca, most field devices, including power meters and PLCs, are inherently compatible with Modbus TCP. However, specific equipment, such as the SMA Sunny Island inverter, is not compatible. This inverter employs the SMA Data protocol, a proprietary communication standard developed by SMA. The protocol is transmitted via Ethernet through the Speedwire interface. In contrast to Modbus, the SMA Data protocol does not disclose public register maps or function codes that a standard SCADA system can directly interpret. Consequently, this absence of interoperability hinders the SCADA from accessing inverter parameters, such as voltage, frequency, state of charge, and power output. These parameters are indispensable for effective monitoring and control functions within a microgrid environment.

To address this limitation, a gateway device was introduced as an intermediary between the inverter and the microgrid's local area network. This gateway is deployed on a Raspberry Pi 3 and captures the proprietary SMA Data frames, processes them, and responds to Modbus TCP requests issued by the SCADA server. In this manner, the gateway effectively emulates a Modbus-compatible device, thereby enabling the SCADA system to retrieve inverter data as if it were communicating with any other standard field unit. This approach obviates the necessity for invasive hardware modifications or firmware alterations on the inverter itself.

The communication topology resulting from this integration is illustrated in Figure 1, which delineates the physical connections between the SMA Sunny Island inverter, the gateway, and the SCADA network. As illustrated, the gateway plays a pivotal role in facilitating bidirectional information exchange between a closed, proprietary device and an open monitoring architecture.

Figure 1

Simplified communication topology



Converter Deployment and Functional Overview

Two primary roles characterize the converter's functionality. Initially, it establishes and maintains communication with the inverter through the SMA Data protocol over a Speedwire. Subsequently, it exposes operational data from the inverter as Modbus TCP registers, thereby making it accessible to the SCADA system as if the inverter were a native Modbus agent device.

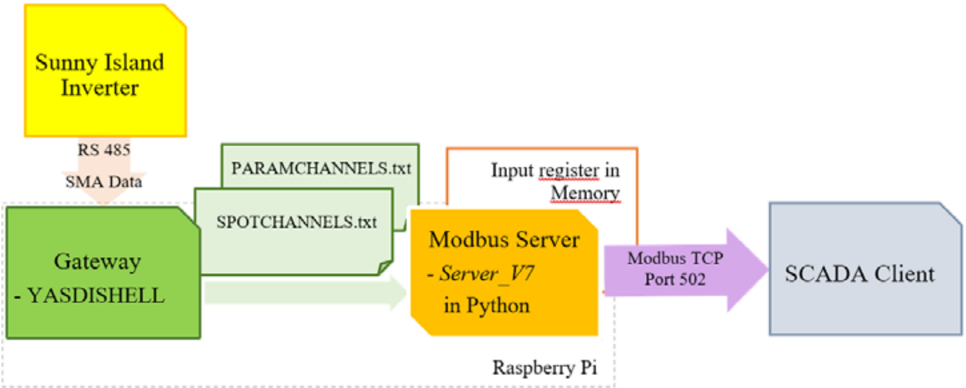
The sequence of events starts when the converter makes a request for and subsequently obtains real-time operational data from the inverter. It is facilitated by the utilization of the YASDISHELL program and the YASDI libraries (Eckhard M; Pknowledge). These data include critical parameters such as input/output voltage, current, power, battery state of charge, and device status. Each data point is stored temporarily in intermediary files (SPOTCHANNELS.txt and PARAMCHANNELS.txt) on the Raspberry Pi.

Subsequently, a Modbus TCP server implemented in Python (named Server_V7) reads these intermediary files and maps the extracted values into input registers. This mapping adheres to Modbus conventions, thereby ensuring compatibility with standard SCADA clients. The server maintains these registers in memory and updates them continuously as new data arrives. Furthermore, the server facilitates TCP socket communication to receive write requests from the SCADA system and, when authorized, directs these requests to the inverter via an additional shared file (SetInformation.txt), thereby serving as a control interface. The complete development of the SMA Data to Modbus TCP/IP protocol converter is available in the repository https://github.com/fabianastudillo/microred-sunnyisland-ampere.git.

Figure 2 provides a detailed schematic of the data transformation pipeline managed by the converter. The figure illustrates the process of retrieving the inverter's data through the SMA Data protocol. The YASDISHELL application parses the protocol, and the data is stored temporarily in structured text files. The data is subsequently mapped to Modbus TCP input registers. These registers undergo continuous updates and are transmitted to the SCADA client via a standard TCP/IP Modbus interface. This modular pipeline facilitates decoupled data handling and ensures compatibility between heterogeneous communication standards.

Figure 2

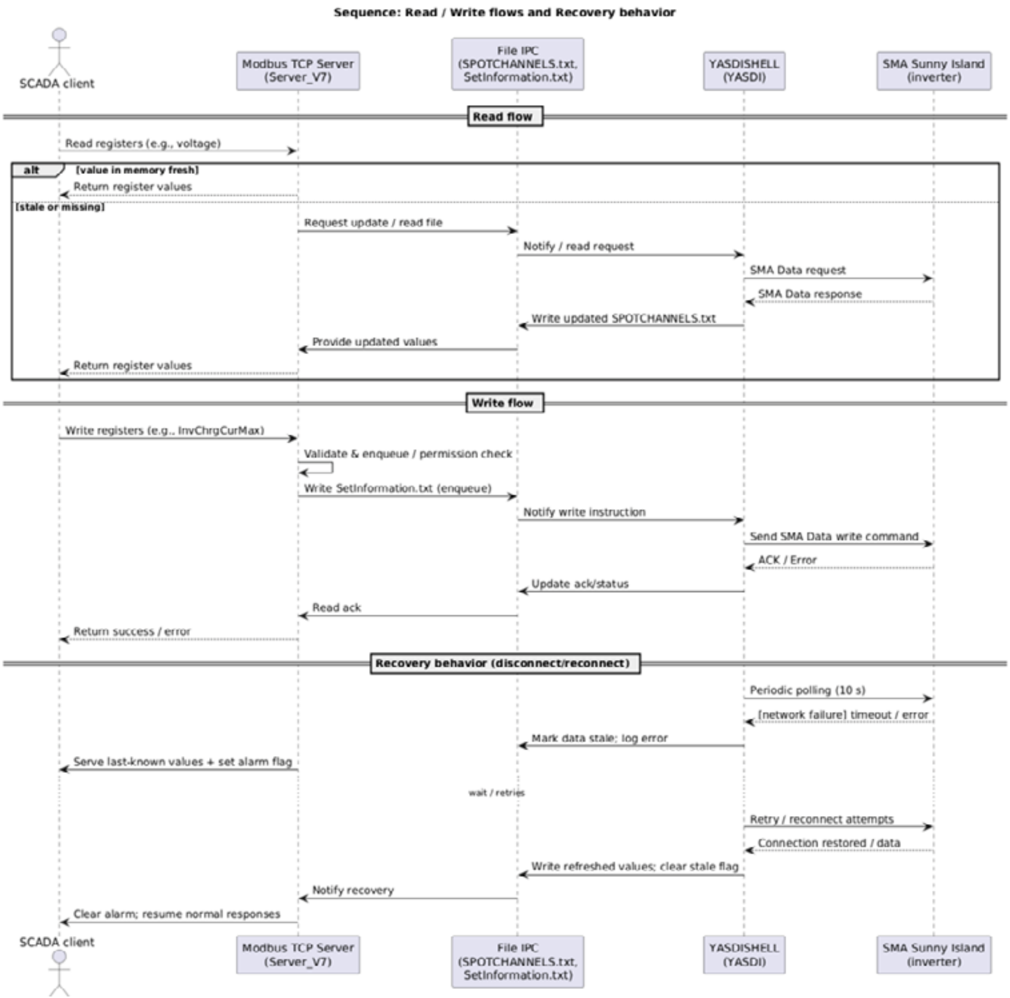
Data flow pipeline from SMA inverter to SCADA via converter



As illustrated in Figure 3, the sequence diagram delineates the standard read and write operations between the SCADA client and the SMA Sunny Island inverter via the Raspberry Pi gateway. The diagram also illustrates the recovery behavior during a temporary communication outage. The diagram under consideration highlights the role of the file-based IPC (SPOTCHANNELS.txt / SetInformation.txt) and the YASDI bridge in facilitating of SMA data conversions.

Figure 3

Sequence diagram for read/write and recovery interactions



Experimental Procedure

The validation of the converter was conducted under controlled conditions within the Microgrid Laboratory at the University of Cuenca. The objective of this procedure was to demonstrate that the implemented converter facilitated reliable and transparent communication between the SCADA system and the Sunny Island inverter, which natively employs the proprietary SMA Data protocol.

The validation process was initiated by powering on the system and observing the automatic initialization of the services embedded in the Raspberry Pi. These services included the YASDISHELL application for communication with the inverter and the Modbus TCP server. After initialization, the SCADA client endeavored to establish a Modbus TCP connection. Upon successful connection, the system initiated a polling cycle of the Modbus registers exposed by the converter to retrieve inverter data.

The primary variables that were monitored during the experimental phase included inverter output voltage and current, battery voltage and state of charge, instantaneous power, and internal device temperature. The selection of these parameters was informed by their demonstrated relevance in operational monitoring and safety assessment in isolated or hybrid microgrid environments.

To assess the writing capabilities of the system, specific parameters were modified from the SCADA interface. These parameters included the maximum charge current and the minimum battery temperature required for restart. Subsequently, the updated values were verified against the inverter's internal status indicators to ascertain the correct implementation of the alterations. This process necessitated meticulous timing, as the system's architecture incorporates a minor delay due to its polling-based data acquisition loop and asynchronous file-based inter-process communication.

To assess system robustness, the physical connection between the inverter and the Raspberry Pi was intentionally interrupted and then reestablished. During the disruption, the behavior of the converter was meticulously monitored. It was determined that the system had the capacity to recover communication without the need for manual intervention on its own. This resilience is imperative for real-world deployments, where intermittent connectivity or power fluctuations are to be expected.

Results and Discussion

This section presents the experimental results obtained during the deployment and validation of the communication converter developed to interface the SMA Sunny Island inverter with a Modbus TCP-based SCADA system. The evaluation concentrated on system initialization behavior, real-time data acquisition, parameter writing functionality, temporal performance, and robustness under connection interruptions. The findings substantiate the operational viability and reliability of the converter within a laboratory-scale microgrid environment.

System Initialization and Service Execution

The initialization of the converter system is a critical factor in ensuring continuous and autonomous operation within the SCADA-integrated microgrid. To evaluate this aspect, the Raspberry Pi device hosting the converter services was powered on under standard laboratory conditions. The startup process was then observed in terms of duration and service activation.

The total startup time required for the Raspberry Pi to fully boot and launch the two key services: the YASDISHELL application and the Modbus TCP server. This process was approximately three minutes. The duration encompasses the loading of the operating system and all requisite network and USB subsystems, which are indispensable for serial communication with the inverter and TCP communication with the SCADA client.

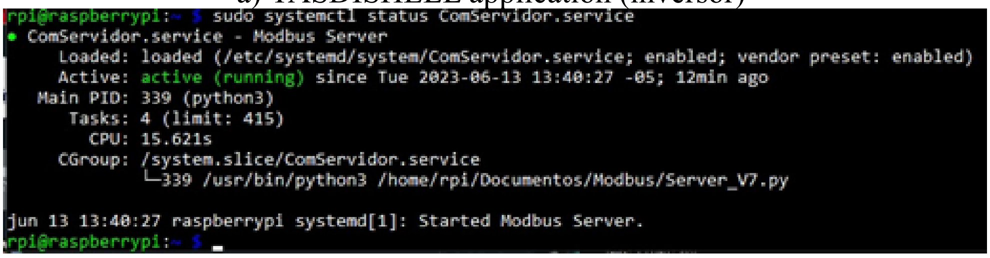
After the initialization of both services, it was ascertained that they were operating in an active state. This verified the successful deployment of the services as background processes utilizing system-level service management. This automatic startup behavior is essential to guarantee system availability without requiring manual intervention after power interruptions or planned maintenance. As illustrated in Figures 4a and 4b, the confirmation messages verify the successful activation of both services, thereby facilitating seamless communication with the Sunny Island inverter and ensuring immediate availability for Modbus TCP connections.

This automated service configuration has been demonstrated to have a substantial impact on enhancing system resilience. In the event of an unexpected power cycle or network disruption, the converter automatically restores its full functionality, ensuring minimal downtime and continuous data acquisition for the SCADA platform.

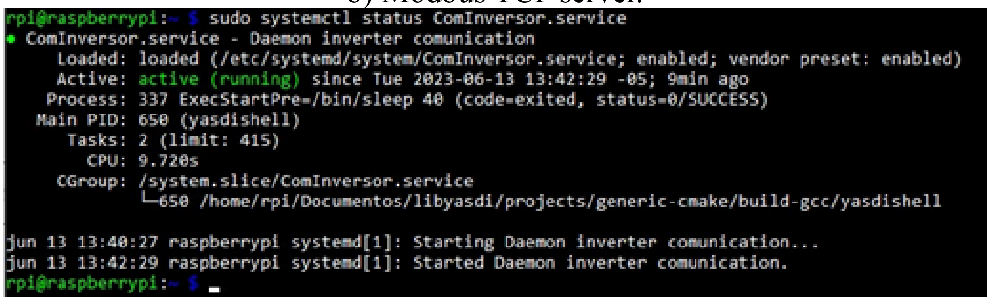
Figure 4

Active status of services

a) YASDISHELL application (inversor)



b) Modbus TCP server.



Data Acquisition and SCADA Visualization

After the converter's full operational capacity and the Modbus TCP server's activation, the SCADA system successfully established a connection and initiated data polling from the Sunny Island inverter. The graphical interface, developed in LabVIEW, displayed real-time measurements retrieved via the converter, confirming that the protocol translation from SMA Data to Modbus was functioning as intended.

The SCADA dashboard exhibited grouped data according to relevant categories, including inverter status, battery information, power flow, and external grid parameters. These values were updated at ten-second intervals, and no communication failures were detected during the observation periods. As illustrated in Figure 5, the monitoring interface displays real-time operational data in a clear and intuitive manner.

The inverter output voltage and current, battery voltage and State of Charge (SOC), system frequency, and instantaneous power were identified as the key variables to be monitored. A direct comparison was made between these values and the physical display on the inverter, revealing complete agreement in terms of numerical consistency. For instance, the battery system's overall health, measured in percentage (SOC) at 76%, and the auto-start counter, which registered at 3, were both displayed on both the inverter panel and the SCADA interface. These values served to substantiate the efficacy of the data mapping process that was executed by the converter.

Figure 5

Monitoring interface for the Sunny Island inverter (the Spanish language is in accordance with the native language of the microgrid operators). Note: the figure reproduces the actual operator HMI used by the microgrid staff (Spanish-language interface)

The ability to seamlessly visualize inverter data within the SCADA environment, without the need for proprietary SMA software, demonstrates the efficacy of the protocol conversion approach and its suitability for integration into more extensive monitoring infrastructures.

Parameter Configuration from SCADA

Beyond data acquisition, the converter was also evaluated for its ability to enable parameter configuration of the Sunny Island inverter directly from the SCADA system. This functionality is essential for supervisory control environments, where remote reconfiguration is often necessary to adapt to changing operational conditions or user-defined profiles.

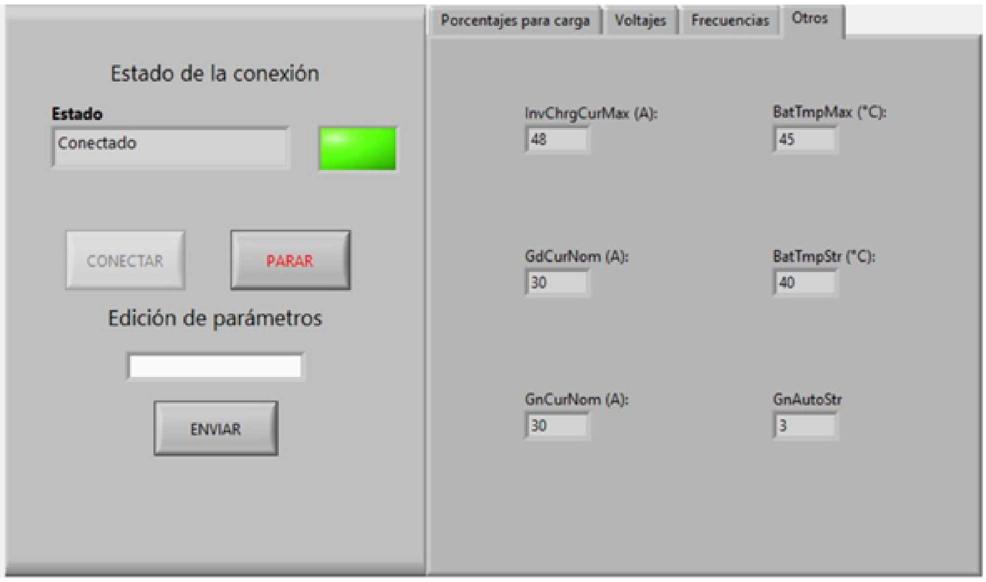
The SCADA interface incorporated a configuration menu that enabled users to view and, when authorized, modify inverter parameters. The interface is presented in Figure 6, which illustrates various editable parameters, including maximum charge current (InvChrgCurMax), battery restart temperature (BatTmpStr), nominal grid current (GdCurNom), and generator auto-start count (GnAutoStr). These values were dynamically read from the Modbus Input Registers maintained in the converter's memory and reflected any changes made at the source device level.

The writing process involved the issuance of a command from the SCADA interface, which was subsequently captured by the converter's Modbus TCP server. Subsequently, the server transferred the write instruction into a shared file, which was monitored by the YASDISHELL application. Upon detecting a pending instruction, YASDISHELL parsed and applied the new value using the appropriate command structure of the SMA Data protocol. Subsequently, the inverter processed the change and updated its internal state.

The efficacy of this configuration pathway was validated by writing test values into the parameters and subsequently verifying their application through both the SCADA interface and the inverter's onboard display. The round-trip time—defined as the interval between the issuance of a SCADA command and the confirmation of its value—exhibited variability depending on the system's execution phase. If the converter was in a state of idleness, anticipating instruction, the alteration was manifested within a time span of approximately 10 to 15 seconds. If the system was executing a read cycle at the time that the write request was issued, the response time increased to between 15 and 30 seconds due to polling synchronization delays.

Figure 6

Configuration interface for the Sunny Island inverter. Note: the figure reproduces the actual operator HMI used by the microgrid staff (Spanish-language interface).



This performance reflects the polling-based nature of the converter's architecture, where read and write operations are decoupled and synchronized through shared files and conditional execution. Despite this non-real-time behavior, the delays observed are acceptable for the intended application, where operational parameters evolve on the order of seconds or minutes, rather than milliseconds.

Despite these timing variations, the configuration mechanism proved to be consistent and reliable, enabling remote parameter updates without interrupting the SCADA monitoring process. The converter's dual read/write capability signifies its robustness and its potential for full bidirectional integration within intelligent microgrid management platforms.

Resilience and Recovery Behavior

The reliability of a communication converter in a SCADA-integrated microgrid is determined by more than just its steady-state performance; its ability to recover from disruptions such as power loss, network disconnection, or interface instability is also a critical factor. To assess this dimension, a series of tests was conducted. In these tests, the connection between the Raspberry Pi gateway and the inverter was deliberately interrupted and later re-established under different operational conditions.

In scenarios involving temporary physical disconnection of the Speedwire interface or loss of Modbus TCP communication, the system demonstrated self-recovery behavior. After the restoration of the connection, the YASDISHELL process resumed data polling, and the Modbus server continued to expose the updated values to the SCADA client. During these transitions, no service crashes or data corruption events were observed. The experimental procedure was executed in the Microgrid Laboratory of the Universidad de Cuenca, employing a Sunny Island inverter and a controlled battery bank. Tests were performed in normal operating mode, with short-duration runs (5 minutes) and modest load variations to verify communication stability and read/write functionality of the gateway. The conditions under which the work was conducted provided sufficient evidence of feasibility. A concise summary of the system's observed performance (based on 10 runs) is provided in Table 1.

Table 1

Summary of observed performance (laboratory testbed)

METRIC	OBSERVED VALUE (LAB)	MEASUREMENT NOTES
Boot time (Raspberry Pi + services)	4 minutes (±1 minute)	Time from power-on to YASDISHELL + Modbus server active
Write / round-trip (SCADA → converter → inverter → confirmation)	10 seconds (±5 seconds)	Depends on converter state (idle vs during active read cycle)
Polling interval (configured)	10 seconds	SCADA dashboard updated every 10 s in experiments

Furthermore, the file-based interprocess communication approach utilized by the converter contributed to its fault tolerance. Intermediate data and command buffers were preserved in temporary storage,allowing the system to resume its data flow from the last valid state without requiring complete reinitialization or reconfiguration.

This resilience serves to substantiate the converter's aptitude for incorporation into critical monitoring environments, where communication disruptions are a recurring phenomenon. The ability of microgrids to recover autonomously and continue operating without human intervention is essential for minimizing downtime and ensuring continuous visibility into microgrid performance.

Limitations

The primary constraints of this study pertain to the scope of evaluation and the nature of the prototype. The experimental design involved conducting tests within a single laboratory setting, eliminating the need of extensive campaigns across multiple sites or under high operational load conditions. This methodological approach, characterized by its restriction to a single laboratory environment, naturally imposes limitations on the extent to which the obtained performance results can be extrapolated to other contexts. The present architecture relies on file-based interprocess communication and polling, which introduces additional latency and may not scale efficiently. While the reported response times are adequate for monitoring and configuration, they are not suitable for real-time control applications. However, significant concerns remain regarding the security aspects of the system, particularly about authentication, encryption, and functional safety mechanisms. Additionally, the system does not currently incorporate transactional guarantees for write operations, which is a fundamental aspect of ensuring data integrity and reliability. Furthermore, scalability tests and long-duration experiments, including those involving fault injection or stress conditions, were not conducted.

Additionally, dependence on the proprietary SMA Data protocol restricts portability and may pose compatibility risks. A notable limitation of the study is the absence of a direct comparison with commercial gateway solutions. Such a comparison would have facilitated a more comprehensive contextualization of the study's findings, particularly about the approach’s strengths and weaknesses. These limitations are consistent with the exploratory nature of this thesis and define the next steps required for a production-ready deployment.

Conclusions and Future Work

This work demonstrates the successful implementation of a communication converter that enables protocol translation between SMA Data and Modbus TCP, allowing for the seamless integration of the SMA Sunny Island inverter into a Modbus-based SCADA environment. The solution, implemented on a Raspberry Pi, effectively addresses the discrepancy between proprietary inverter communication protocols and standard industrial interfaces utilized in supervisory systems.

Through experimental validation, the converter demonstrated its capacity to reliably retrieve real-time operational parameters from the inverter and expose them to the SCADA platform using conventional Modbus input registers. Additionally, the system enabled parameter configuration from the SCADA interface, with alterations accurately propagated to the inverter via a regulated asynchronous mechanism. The observed response times, ranging from 10 to 30 seconds depending on system state, were found to be acceptable for typical microgrid monitoring and control applications.

The converter also exhibited robust performance in the face of operational disturbances. The system's capacity for autonomous recovery from power cycles and communication interruptions, as evidenced by the absence of data loss and the need for no of manual intervention, is attributed to the integration of automatic service initialization with resilient file-based communication mechanisms.

Subsequent endeavors will focus on enhancing the converter's functionality to integrate multiple SMA devices concurrently and to incorporate supplementary inverter models that utilize different communication protocols. The enhancements will also aim to reduce response times through optimized polling strategies and explore the integration of publish/subscribe architectures, such as MQTT, for event-driven data transmission.

Acknowledgements and Declarations

The authors would like to express their gratitude to the Microgrid Laboratory at the Universidad de Cuenca and the Department of Electrical, Electronic, and Telecommunications Engineering, which provided the laboratory and equipment for the development of this work. This work is part of the thesis: “INTEGRACIÓN DE LOS INVERSORES SUNNY ISLAND Y AMPERE SQUARE S AL SISTEMA SCADA DEL LABORATORIO DE MICRO-RED DE LA UNIVERSIDAD DE CUENCA”.

The authors declare equal contribution and sharing of authorship roles for this publication.

The authors declared that, in the preparation of this article, AI tools were used.

References

Eckhard, M. (n.d.). Python wrapper for SMA converter YASDI C library. https://github.com/EckhardM/pyYASDI

Espinoza, J. L., González, L. G., & Sempértegui, R. (2017). Microgrid laboratory as a tool for research on non-conventional energy sources in Ecuador. *2017 IEEE International Autumn Meeting on Power, Electronics and Computing (ROPEC)*, 1–7. https://doi.org/10.1109/ROPEC.2017.8261615

Gutiérrez Otavalo, L. V., & Padilla Guamán, C. E. (2024). *Análisis de la factibilidad de mejorar la disponibilidad del sistema SCADA durante los procesos de mantenimiento de los equipos de la micro-red de la Universidad de Cuenca*. [Tesis de pregrado, Universidad de Cuenca]. Repositorio Institucional de la Universidad de Cuenca. https://dspace.ucuenca.edu.ec/handle/123456789/45307

Hemmati, M., Palahalli, H., Gruosso, G., & Grillo, S. (2021). Interoperability analysis of IEC61850 protocol using an emulated IED in a HIL microgrid testbed. 2021 *IEEE International Conference on Communications, Control, and Computing Technologies for Smart Grids (SmartGridComm)*, 152–157. https://doi.org/10.1109/SmartGridComm51999.2021.9632327

Kermani, M., Adelmanesh, B., Shirdare, E., Sima, C. A., Carnì, D. L., & Martirano, L. (2021). Intelligent energy management based on SCADA system in a real microgrid for smart building applications. *Renewable Energy, 171*, 1115–1127. https://doi.org/10.1016/j.renene.2021.03.008

Li, S., Jiang, B., Wang, X., & Dong, L. (2017). Research and Application of a SCADA System for a Microgrid. *Technologies, 5*(2). https://doi.org/10.3390/technologies5020012

Pknowledge. (n.d.). Fork of the YASDI library for solar SMA inverters. https://github.com/pknowledge/libyasdi

Si, Y., Korada, N., Ayyanar, R., & Lei, Q. (2021). A High Performance Communication Architecture for a Smart Micro-Grid Testbed Using Customized Edge Intelligent Devices (EIDs) With SPI and Modbus TCP/IP Communication Protocols. *IEEE Open Journal of Power Electronics, 2*, 2–17. https://doi.org/10.1109/OJPEL.2021.3051327

SMA. (2015). *Inversor con batería SUNNY ISLAND 4548-US/6048-US Instrucciones de funcionamiento*. SMA.

Suryani, A., Sulaeman, I., Rosyid, O. A., Moonen, N., & Popović, J. (2024). Interoperability in Microgrids to Improve Energy Access: A Systematic Review. *IEEE Access, 12*, 64267–64284. https://doi.org/10.1109/ACCESS.2024.3396275