ARDEXA

The Digital Control Platform

Reinventing SCADA

A Cloud-Native Approach
to Unified Control

REIMAGINING SCADA FOR TODAY'S RENEWABLE ENERGY OPERATIONS

The rapid expansion of utility-scale renewable energy has exposed the limitations of traditional SCADA systems, which were designed for an era of simpler, more homogeneous power generation. Today's renewable energy operators face unprecedented challenges: managing diverse and dispersed portfolios of wind, solar, and storage assets; integrating equipment from dozens of vendors; and analyzing massive volumes of operational data to optimize performance; all while maintaining compliance with increasingly burdensome regulations.

A hub and node architecture leveraging cloud-native technology makes possible a Digital Control Platform that unifies diverse plants and control systems without replacing existing technology or limiting SCADA vendor options. This approach transfers control of data, plants, and assets to portfolio owners, accelerating operational improvements. This unified control architecture is inherently secure, ensuring cybersecurity compliance and comprehensive auditability.

Reinventing SCADA through cloud-native technology requires more than just modernization—it demands complete flexibility in deployment. A true Digital Control Platform can be delivered as a service while also supporting a "bring your own cloud" option, empowering operators to choose their preferred hosting environment—AWS, Azure, or others. Moreover, regulatory compliance in some cases necessitates on-premises deployment. The ideal control and data acquisition architecture delivers the advantages of modern cloud technology regardless of deployment model, ensuring complete control while meeting all compliance requirements.

PORTFOLIO LIFECYCLE AND GEOGRAPHY DRIVE COMPLEXITY

Ownership changes lead to control system variety

Most utility scale renewable assets change hands multiple times, from developer to EPC to various owner-operators over their lifetimes. For each new owner, the transition brings inherited SCADA platforms. Even when developers remain as long-term owner-operators, SCADA decisions are often left to EPCs who rarely consider portfolio-wide integration.

Challenges of geography

Geographic dispersity of assets is another prime driver of heterogeneous SCADA solutions. No single solar SCADA provider or wind turbine manufacturer reliably supports large-scale deployments in all countries and regions. Regional EPCs partner with leading SCADA vendors in their local market who in turn offer native support for power plant equipment common in those markets. The result is geographic diversity of SCADA across international portfolios.

TYPICAL PORTFOLIO–VARIED AND WIDESPREAD

Evolution of wind turbines increases complexity

Wind portfolios typically include turbines from multiple manufacturers due to phased development and changing market conditions. Since PPCs and SCADA systems are typically bundled with wind turbines, this typically creates a patchwork of control interfaces and HMIs across portfolios and in some cases even individual wind farms.

BUSINESS IMPACTS DEMAND ACTION

Operational complexity creates risk

Managing diverse SCADA systems, PPCs, and PLCs across large renewable portfolios creates significant operational challenges. Remote operators must master multiple control interfaces and HMI systems to perform critical functions like production scheduling, live trading, grid curtailment, and asset control commands. The additional requirement for separate VPN connections to access local systems further complicates remote operations.

Manual processes lead to costly errors

These complex, largely manual processes are both inefficient and error prone. With thousands of manual curtailments performed across a variety of SCADA systems, even small error rates result in significant financial consequences through negative pricing impacts and commercial penalties.

BALANCING GRID REQUIREMENTS AND PLANT CONTROL

As variable power generation like wind and solar comprise an increasingly significant portion of energy production, grid operators face the complex task of managing inconsistent power flows against relatively fixed demand patterns. Grid operators regularly face periods when production must be curtailed during specific times of day or weather-dependent scenarios when renewable output would otherwise exceed demand. This has amplified the need for third-party control of renewable power plants, allowing grid operators to curtail production when necessary to maintain system stability.

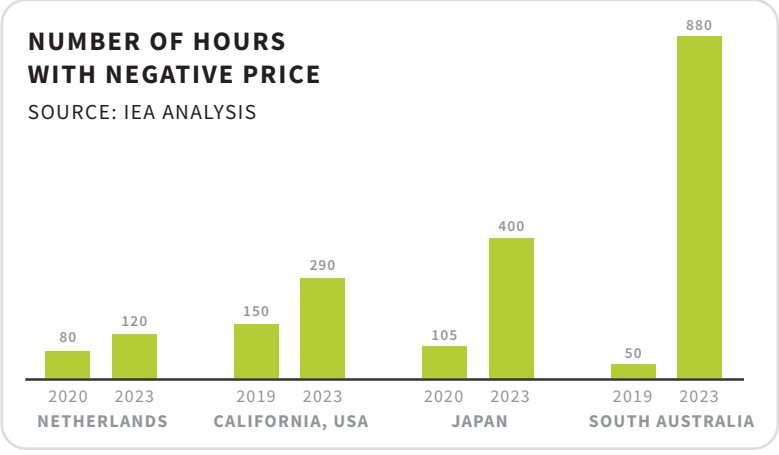
Energy markets and grid control

Grid operators who manage day-ahead and real-time energy markets typically require direct curtailment capabilities that enable them to independently align production with day-ahead settlements and manage congestion in coordination with the real-time market. Balancing operations also necessitate that the power plant transmit telemetry about generation capacity to the grid. In other regions, energy marketers fulfill these functions, acting as intermediaries of telemetry and production control between plant owners and grid operators.

Regardless of who performs these external control functions, owner-operators of renewable assets are increasingly seeking solutions that balance multiple priorities: satisfying grid operational requirements, maintaining robust cybersecurity protections, and preserving transparency into curtailment events that directly impact revenue and performance metrics. The ideal approach provides the necessary operational flexibility while ensuring plant owners maintain visibility and understanding of when, why, and how their assets are being curtailed.

Negative Pricing

Grid operators in areas with lower penetration of variable renewable energy may manage day-ahead balancing strictly through negative pricing policy, sometimes relying on rudimentary communications like emails and phone calls to issue curtailment instructions. For renewable asset owners with multiple plants in such geographies, this creates significant inefficiencies. Portfolio operators increasingly seek centralized solutions to streamline the implementation of production schedules across remote assets.

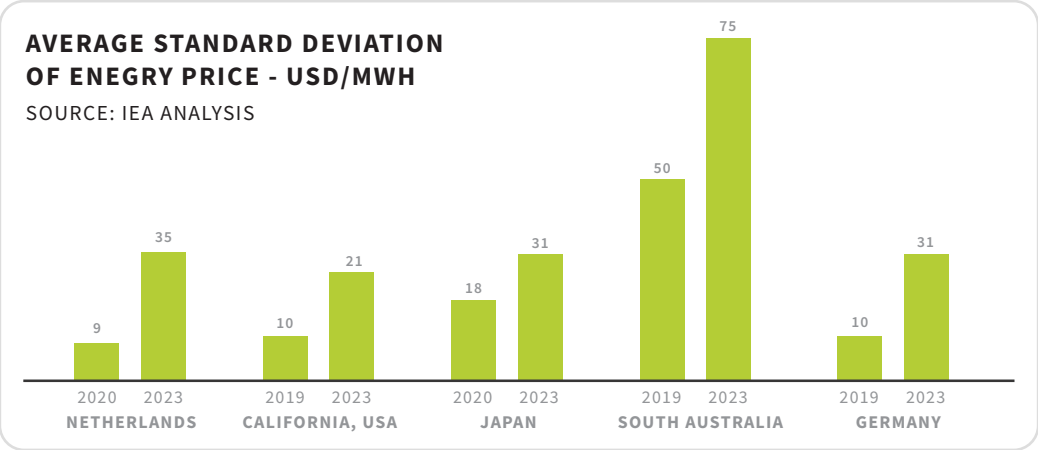


ENERGY STORAGE COMPOUNDS CONTROL REQUIREMENTS

Rising curtailment and negative pricing are accelerating investment in diverse energy storage technologies—especially battery energy storage (BESS). This development is creating three additional operational challenges:

Price Arbitrage Opportunities

Producers increasingly need to capitalize on growing real-time price differentials across all markets. These widening arbitrage opportunities are driving rapid development of sophisticated energy marketing systems that require more responsive control infrastructure.



Increased Control Actions

Portfolio operators must execute more frequent control commands daily to manage more complex hybrid power generation and storage plants.

Integrating Battery Analytics

Operators look to feed real-time BESS data to analytics platforms to optimize battery performance, safety, asset lifespan, and short-term revenue. This requires maintaining secure connections between diverse BESS and internal or external analytics tools.

Analytics insights must then inform BESS control decisions, creating a continuous feedback loop between monitoring and hybrid plant operation. However, the diverse control interfaces across storage assets complicate the implementation of analytics-driven control strategies.

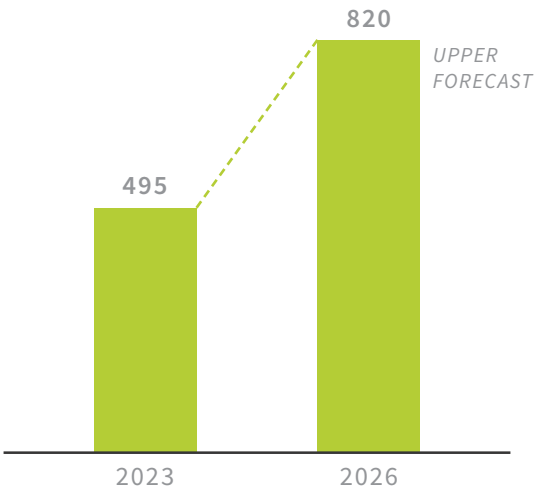
LABOUR MARKET SHORTAGES AND REMOTE OPERATIONS

To keep up with the increasing complexity of remote plant control, renewable energy companies have relied on continually expanding their SCADA and ROCC (Remote Operations and Control Centre) teams. Expanding staff to manage multiple SCADA systems, each requiring extensive training, frequent system updates, and compliance with diverse cybersecurity protocols. As portfolios grow, staffing needs and complexity scale proportionally.

To keep up with the increasing complexity of remote plant control, renewable energy companies have relied on continually expanding their SCADA and ROCC (Remote Operations and Control Centre) teams. Expanding staff to manage multiple SCADA systems, each requiring extensive training, frequent system updates, and compliance with diverse cybersecurity protocols. As portfolios grow, staffing needs and complexity scale proportionally.

FORECAST DEMAND FOR SOLAR DEVELOPMENT JOBS–1000FTE

SOURCE: SOLAR POWER EUROPE, DEC 2022



However, the demand for skilled labour far exceeds supply, driving up costs and increasing turnover of critical personnel. This shortage is expected to worsen—Europe alone anticipates a 100% increase in solar industry jobs over the next four years, further straining the already limited talent pool.

The shortage of skilled labour is a major barrier to scaling renewable energy generation, jeopardizing the ability to meet critical net-zero targets. Even with increased investment in recruitment and retention, the fundamental gap between supply and demand will continue to limit growth potential.

Solutions to labour shortages must recognize the shift toward remote plant operations. An increasing number of functions can now be performed by technicians in distant locations, including offshore centers with lower labor costs. This transition requires adapting SCADA systems and plant equipment specifically to enable and maximize remote operations, maintenance, and control capabilities.

LIMITATIONS OF LEGACY SCADA FOR UNIFYING CONTROL

Extending existing SCADA

Plant SCADA vendors attempting to extend their solutions across multiple levels face inherent integration challenges with proprietary systems. These approaches create inflexible architectures that underperform, lack best practices, and are expensive to maintain. A unified control solution that is independent from equipment manufacturers and SCADA providers is optimal, as directly competing vendors rarely collaborate effectively on unified solutions. Traditional approaches to unified control typically require costly and disruptive replacement of existing local SCADA systems.

Non-standard data interfaces

Contrary to assumptions, unifying control benefits from collecting OT data directly from equipment rather than indirectly through plant SCADA. Equipment like inverters, trackers, and turbines have standardized data structures, making collection more repeatable and scalable than working through bespoke plant SCADA interfaces.

Inflexibility

Modern ethernet-based plant networks combined with cloud technology make direct OT data collection more reliable than legacy technology. This source-to-the-cloud approach eliminates dependencies on SCADA system maintenance and upgrades that can interrupt data flow. It also overcomes the limitations of pre-configured SCADA tags and collection frequencies, significantly improving reliability and flexibility.

THE SOLUTION: HARNESSING A CLOUD-NATIVE APPROACH

Unified Control

To address the labour shortage, forward-thinking renewable energy companies are adopting innovative solutions that reduce dependence on specialized personnel. Implementing an independent, unified control architecture that connects plant OT systems minimizes the need for scarce, vendor-specific expertise. A centralized, independent control plane streamlines operations across multiple plants and enables process automation.

Unified Data Acquisition

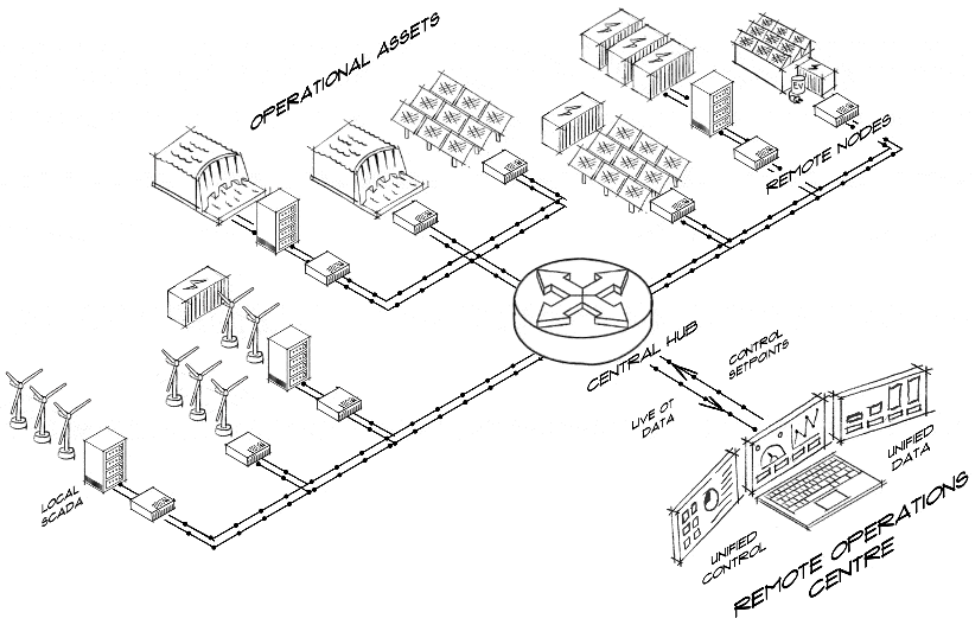
Further efficiency is achieved through standardized data collection methods that bypass custom SCADA interfaces at each site while normalizing performance and alarm data collected directly from plant equipment. This approach enhances agility, flexibility, and operational independence. Ideally, the control plane remains independent of performance and asset management systems, integrating seamlessly with external business applications via RESTful APIs or streaming data connections.

The leading enabling solution for unified plant and asset control is Ardexa's Digital Control Platform.

THE ARDEXA DIGITAL CONTROL PLATFORM (DCP)

The Ardexa DCP is a seamlessly integrated system composed of edge-deployed Remote Nodes and a Central Hub, with data and control signals transmitted over an encrypted, resilient Connector.

DIGITAL CONTROL PLATFORM–UNIFIED REMOTE OPERATIONS



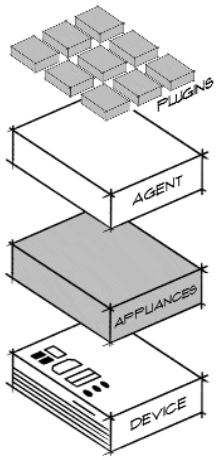
REMOTE NODES

Orchestrate operations within each plant The Remote Node leverages an open, flexible, and robust software stack, running on widely available, commodity hardware to unify data from diverse sources in real-time. Simultaneously, it streamlines remote plant and asset control, making it all possible through a range of industrial protocols.

Remote Nodes access a large library of pre-built Machine Plugins that can be selected, deployed, and updated from the Central Hub—much like smartphone app stores, allowing operators to download, install, and run plugins in minutes. These plugins come in two main types: Data Collection and Control.

Data collection Plugins support an extensive array of equipment: inverters, turbines, weather stations, meters, and more. For similar data sources (e.g. all inverters), plugins normalize data

REMOTE NODE SOFTWARE STACK



MACHINE PLUGINS: Vast library, download-install in minutes. Data collection or control. Normalize collected data at the edge.

AGENT: Compiled binary. Executes commands (collection/control) via Modbus, OPC-UA, DNP3, etc.

SOFT APPLIANCES: Firewall/VPN, Network/Port Scanner, Soft PLC, Power Plant Controller or Grid Control RTU

DEVICE: hardware host for the Remote Node. Runs hardened Linux OS. Wide array of certified options from 24v IPCs to enterprise class rackmount servers. Caches OT data for long periods

across brands and models to consistent standards for naming, format, and units of measure. Users can easily customize which data points are collected and how frequently.

This flexibility comes from the underlying Agent—a compact binary that efficiently executes core functions powering both data collection and control capabilities. The Agent runs on a hardened Debian Linux OS which can be deployed on physical hardware, virtual machines, or containers. When deployed at the Central Hub, the Agent connects to remote plants with local historians via existing VPNs.

Each Remote Node arrives pre-configured with digital certificates from Ardexa's built-in security infrastructure, ready for immediate use.

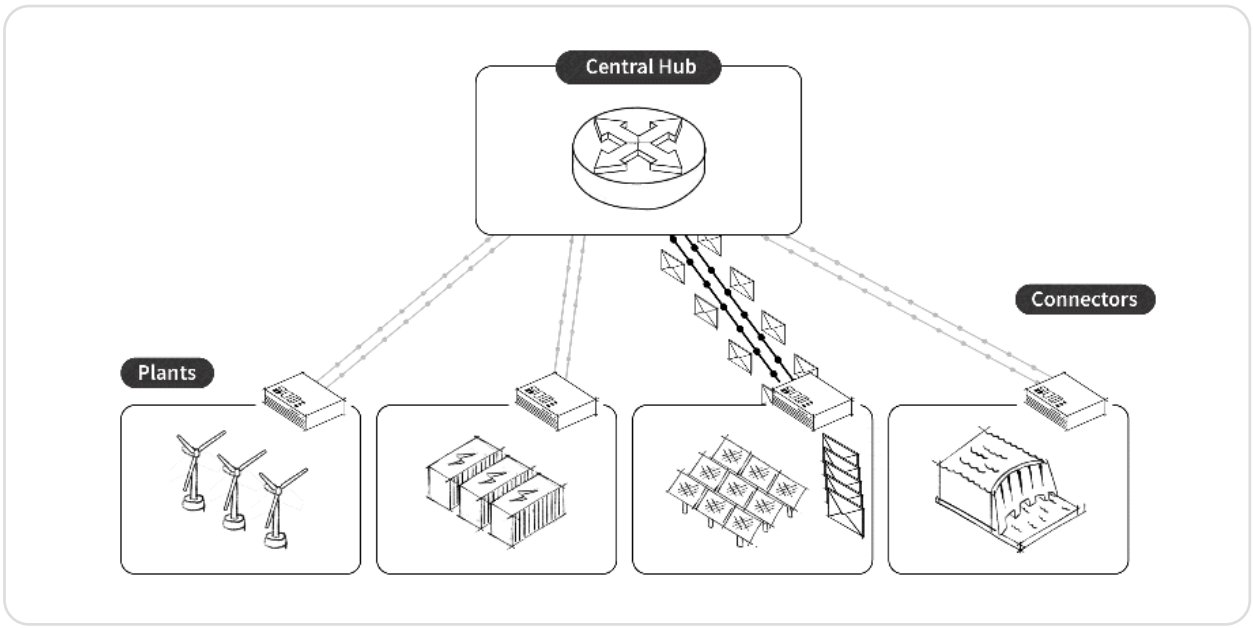
CONNECTORS

Resilient data transport for remote operations

The Connector leverages an enterprise-grade asynchronous message broker to establish secure, reliable communications between Remote Nodes and the Central Hub. It operates over outbound-only connections secured via PKI cryptography, eliminating inbound firewall vulnerabilities.

Data collected by Remote Nodes is cached locally for extended periods—from weeks to months—creating resilience against connectivity issues. As information is gathered, it's packaged into messages and published to a queue for transmission. The system employs rigorous acknowledgment protocols where the Central Hub confirms receipt of each data message, triggering automatic retransmission of any unacknowledged messages.

CONNECTORS–CLOUD-NATIVE MESSAGING ELIMINATES DATA GAPS



This combination of persistent local caching and guaranteed message delivery creates an exceptionally robust framework that virtually eliminates data gaps commonly caused by intermittent internet connectivity, ensuring operational continuity even through extended outages

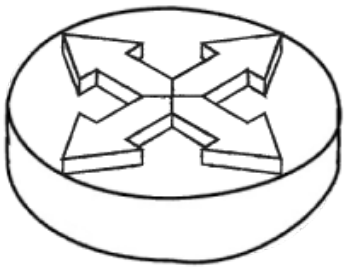
CENTRAL HUB

Command centre for renewable operations

The Ardexa Central Hub provides a comprehensive management platform built around four essential components. At its foundation lies a hyper-scalable cloud data store that efficiently handles vast quantities of operational data from distributed assets. This repository powers a robust RESTful API, secured through digital tokens for authentication and granular access control, enabling seamless integration with third-party applications.

DATA STORE
- Hyper-Scalable Data Store
- External data ingestion
- RESTful API
- Subscriber queue
- Streaming Data *(WebSocket)*

PLATFORM ADMINISTRATION
- Remote Access
- Identity Management
- Fine-grained Access Control
- Immutable Audit Trail
- Data Management



WEB APP
- Data Analysis
- Interactive Dashboards
- Query-based Alerts
- Google-like Search
- Control Execution

REMOTE NODE MANAGEMENT
- Patch/Update
- Remote Configuration
- Health Monitoring
- SecureFile Transfer
- Remote Shell

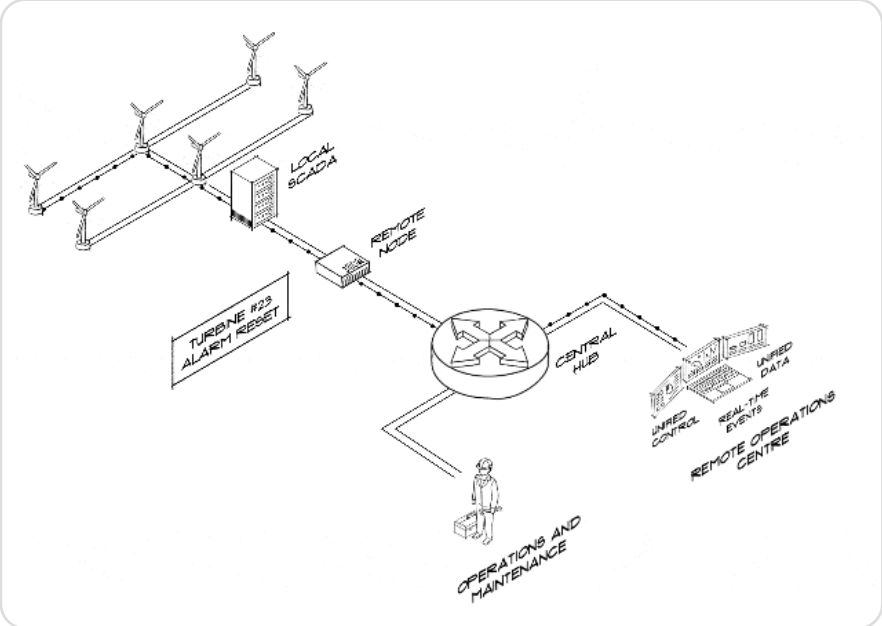
The Hub also hosts an interactive web app for visualizing portfolio performance, analyzing operational metrics, and centralizing both production scheduling and asset control functions. Lastly, the Central Hub provides comprehensive Remote Node management capabilities. Administrators can centrally configure settings, deploy software updates, monitor security logs, and control access through granular, strict permission rules. This centralization delivers significant operational efficiencies by streamlining management functions.

UNIFIED CONTROL IN OPERATION

SCADA Overlay

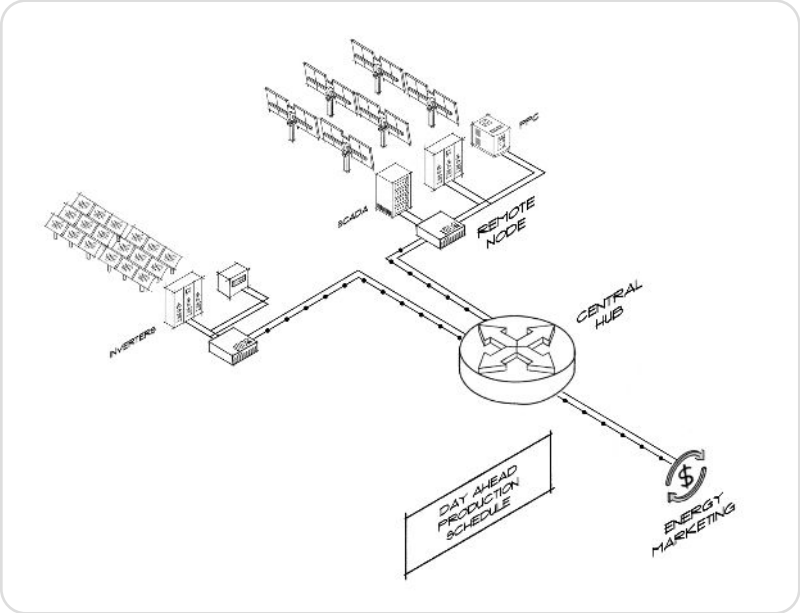
Customizable Control Plugins are available in the Ardexa Plugin library which are designed to interface with 3rd party PPCs and PLCs and local SCADA systems at remote plants. These are available in a broad range of industrial protocols, including Modbus, IEC 104, OPC UA, DNP3, PLC protocols, etc. Ardexa Control Plugins receive commands and schedules over an encrypted connection from the Central Hub and translate them to the relevant command or setpoint which is delivered to the local plant control interface. Typical commands include start, stop, reset and setpoint change.

STREAMLINING REPETITIVE REMOTE PLANT CONTROL ACTIONS



Managing active power and power factor setpoints via automated day-ahead schedules across many plants with heterogeneous PPCs is an illustrative example of Ardexa's Unified Control solution. From the Central Hub web app, operators manage schedules for their entire portfolio simply and easily. Users can create schedules and apply them to the Remote Node at selected plants (or groupings of regional plants). If the Remote Node is offline, the schedule will automatically be transferred as soon as the Node reconnects to the Hub. The Control Plugin then processes the file and sends the setpoint change directly to the local PPC and an "applied" confirmation is sent back and is represented visually in the Central Hub.

DAY AHEAD PRODUCTION SCHEDULING



Operators can leverage analyses, alerting, visualisation, and other tools in the Central Hub to monitor the impact of control signals or detect exceptions automatically. The Central Hub provides ROCC Operators with a single interface for executing curtailment and other plant and asset control functions as well as monitoring plant performance without making changes to local plant SCADA or PPCs.

REINVENTING SCADA FOR MODERN RENEWABLE OPERATIONS

The renewable energy sector's evolution has revealed significant limitations in traditional SCADA architecture. As this paper has demonstrated, today's operators face complex challenges managing diverse asset portfolios, integrating multi-vendor equipment, analyzing vast operational datasets, and maintaining regulatory compliance—challenges that conventional systems were never designed to address.

The cloud-native Digital Control Platform we've outlined offers a transformative approach to these challenges without requiring costly replacement of existing infrastructure. By implementing a hub and node architecture, operators can effectively centralize remote operations while preserving local SCADA investments, streamline day-ahead production scheduling through automated processes, simplify the complexities of hybrid plant control, and implement necessary grid control functions without sacrificing operational visibility.

This unified approach shifts control back to portfolio owners, accelerating performance improvements through better data integration and analysis. The inherent security of this architecture ensures both robust cybersecurity compliance and comprehensive auditability across operations. As renewable energy continues its rapid growth, this reimagined approach to SCADA provides the flexibility, scalability, and visibility needed to navigate an increasingly complex operational landscape.

ARDEXA

business.development@ardexa.com

ARDEXA PTY LTD

Unit 244, 102 Northbourne Avenue,
Braddon, ACT, 2612, Australia

ARDEXA, INC.

201 N Union St, Suite 110,
Alexandria, VA, 22314, USA

ARDEXA GMBH

Mariahilfer Straße 32/6,
Vienna 1070, Austria

ARDEXA PTE LTD

90 Eu Tong Sen Street, #03-02B
059811 Singapore

ARDEXA SOLUTIONS S.L.U

Calle Nanclares de Oca, 1 - B,
Madrid, 28022, Spain