PowerNet Explorer™

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I. Challenges of DSOs

Modern electric distribution networks face increasing strain from the growing presence of intermittent and distributed energy resources (DERs) such as small-scale solar power plants (PV), electric vehicle (EV) chargers, and changing consumption patterns (heat pumps, air conditioning, etc.). These factors disrupt traditional energy flows and create new consumption and generation patterns.

The urge for electrification from all sectors to replace fossil energies creates a higher dependency on electric infrastructure and requires strengthening the grid's physical robustness and cybersecurity layers. DSOs face challenges in meeting rising customer demands, influenced by emerging energy policies, decarbonization goals, and market forces promoting grid flexibility. Simultaneously, the physical and technical capacity of grids remains limited, often struggling to accommodate these transformations without extensive upgrades.

To address these issues, grid operators require an advanced analytical framework that provides a real-time, **comprehensive model of the network**. Such a model is essential for improving decision-making and ensuring grid reliability, flexibility, and adaptability.

Transformation of DSOs

- Grid operators must transition from a centralized balancing model with one-way energy flow to a decentralized model with two-way energy flow, and ultimately, to a distributed model where production and storage assets move on and off grid.

- This complex transformation journey requires a phased approach with intermediate milestones and a focus on securing a return on investment to track business benefits. An agile methodology is essential to guide grid transformation, as the path will be impacted by market evolution, new policies, and regulations.

Electric grids need to accelerate their **transformation from traditional to digital grids at scale**:

- The energy transition significantly increases the complexity of grid operations. DSOs must aggregate billions of data points to avoid local congestions, manage multi-directional power flow, and provide reactive power support to TSOs.

- DSOs must integrate various data layers and effectively manage data across the entire grid lifecycle: from planning and design to monitoring and operations (including real-time data management for grid balancing), grid maintenance, and customer services (to optimize electricity consumption patterns).

- DSOs need to rethink how they gather, validate and analyze data in real-time to reduce peak demand, optimize use of DERs, improve outage response, and enhance asset management to minimize capital expenditures.

II. Our Solution

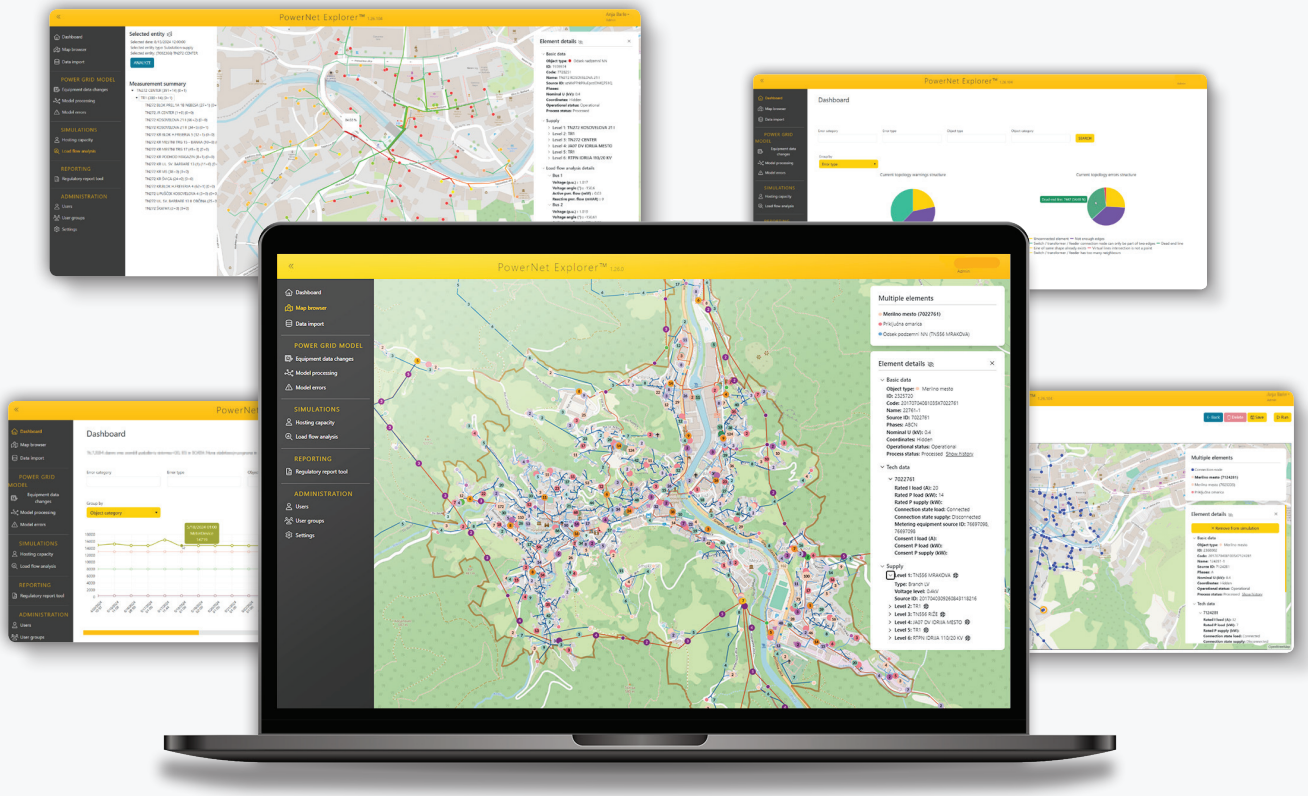
PowerNet Explorer™

PowerNet Explorer™ is a state-of-the-art software solution designed to comprehensively process network topology and enable advanced energy analytics for electrical distribution grids. By integrating key IT/OT systems and leveraging big data processing capabilities, it serves as a pivotal tool for addressing modern grid challenges and ensuring operational excellence. It **provides all the building blocks to establish observability**, i.e., to monitor and understand the grid's state in real-time based on known topology and sufficient measurements, and **simulation capabilities** to analyze the effects of connecting additional prosumers and scenarios of future grid developments. The **development agenda** of PowerNet Explorer™ includes further development of analytic capabilities focused on assuring operational stability of the grid and other analytic services.

The core objectives of PowerNet Explorer™ are to support:

- **Reliability:** Ensuring consistent and dependable grid performance.
- **Accessibility:** Enhancing connectivity and accommodating new users.
- **Security:** Protecting the grid from operational disruptions and anomalies.

To achieve these goals, PowerNet Explorer™ provides real-time observability, simulation and predictive capabilities for grid development and maintenance, and tools to ensure high-quality service for users.



Grid Observability

Improving **grid observability** is essential for modernizing the grid and ensuring it can handle the complexities of today's energy landscape. Key aspects of grid observability include:

- Data collection and integration: Observability relies on extensive data collection from measuring and OT infrastructure
- State estimation: utilizing the collected data to estimate the current state of the grid, including voltage and phase angle at different nodes
- Situational awareness: High observability provides operators with a clear picture of the grid's status, helping them to detect and respond to issues promptly
- Grid stability and reliability: Enhanced observability is crucial for maintaining grid stability and reliability, especially with the integration of renewable energy sources and distributed energy resources
- Advanced control systems: Observability supports advanced control systems that can manage the grid more efficiently

Grid observability forms the foundation for efficient grid management, delivering direct benefits in the form of accelerated DER connection at a lower cost by leveraging all available grid capacity, minimizing losses in the grid, improving reliability indicators (SAIFI, SAIDI, etc.), optimal investment in grid reinforcement etc.

Optimized Grid Development

The solution advocates an optimized approach to **grid development** based on modeling and simulation while leveraging historical, real-time and forecast data from multiple data sources. The approach emphasizes:

- Targeted upgrades: Precise expansions and reinforcements guided by data-driven analysis.
- Avoiding overextensions: Considering financial and spatial constraints by focusing on efficient development strategies instead of extensive grid overhauls.

The **analytics capabilities** maximize the benefit of equipment investments or defer capital investment through better optimization of generation, storage and energy efficiency.

Operational Stability and Compliance

The development agenda includes advanced tools for **anomaly detection**, fault analysis, and predictive maintenance ensure operational stability while reducing downtime and maintaining compliance with **regulatory targets**.

III. PowerNet Explorer™ Features

Digital Integration Hub

PowerNet Explorer™ acts as a central hub, integrating GIS data, SCADA inputs, customer contracts, connection requests, and measurement points into a single platform. This enables operators to maintain a **complete and accurate network topology for any given moment in time**. Robust **error detection** mechanisms identify inconsistencies, while **corrective workflows** provide mechanisms to ensure data accuracy.

Data Validation Process

To ensure data accuracy, PowerNet Explorer™ incorporates robust validation and transformation mechanisms. It addresses common data quality issues, including:

- **Measurement data issues:** Errors and missing measurements are flagged and resolved through user notifications or automated corrections.
- **Contract misalignments:** Discrepancies in customer contracts, consents, and device records are rectified using geospatial validation or through user notifications.
- **SCADA equipment state errors:** Inconsistent switch states are standardized for accurate processing.
- **Incomplete geospatial data:** Missing catalogue data is replaced with standard element types. Grid element changes are detected, and a time series of changes is constructed. Elements with incomplete identifiers are flagged and user notifications are generated.

Target Data Structure

The data structure of PowerNet Explorer™ is designed to ensure accuracy, reliability, and traceability. **Incremental data loading** eliminates the need for data overwrites or deletions, focusing instead on detecting changes and importing only the modified elements. This approach ensures that all network states, past and present, remain fully accessible, providing operators with complete visibility at any given point in time.

- **Centralized data Hub:** Integrates diverse data sources (GIS, SCADA, customer data, etc.) into a single platform.
- **Accurate network topology:** Enables operators to maintain a complete and accurate real-time network model.
- **Robust data validation:** Includes mechanisms to detect and address data quality issues (e.g., measurement errors, contract misalignments).
- **Incremental data loading:** Ensures data accuracy and traceability by focusing on changes and maintaining a historical record of network states.
- **Complete visibility:** Provides operators with a comprehensive and up-to-date view of the entire distribution network.

Grid Topology

The **Topology Processor** serves as the backbone of PowerNet Explorer™, enabling the creation of a complete digital model of the 3-phase grid. It constructs a detailed **network graph**, building logical connections between elements based on geographic and measurement data. The processor also supports single-pole transformer diagrams and hierarchically organizes the network into low-voltage (LV) and medium-voltage (MV) branches and transformer stations. Operators can seamlessly switch the model between default and actual switch states.

Performance optimization is achieved through a persistent in-memory cache that updates dynamically with every data change.

Key Benefits

The integration and processing of data from diverse sources into a single unified platform allows for:

- Building a **verified logical and electrical connectivity model** of all network elements.
- **Phase identification** for a 3-phase connectivity model.
- **Chronological tracking of network topology changes** due to field events/ works and equipment states (switches, etc.).

Phase Identification

Phase Identification functionality enables building 3-phase connectivity models without documentation including phase information (e.g., LV networks). Phase Identification is performed with AI algorithms utilizing measurement and geographic data.

Error Resolution & Data Quality

One of the processor's key functionalities is its support for **error resolution** process. Common issues, such as poorly documented LV networks, are identified based on geospatial data or inconsistencies in measurement data. The topology processor handles: incomplete links, identifies errors (e.g., overlapping lines), and resolves cycles and parallel connections within the topology. The errors are categorized based on severity (e.g., critical errors or warnings). The system suggests automatic corrections where feasible, while proposes other errors for field inspections. Missing impedance data for certain elements is estimated using derived physical parameters or it is hierarchically inherited.

The list of potential errors is an input for the data **quality assurance process cycle** within the DSO. Topology processor supports features such as: manual adjustments, versioning, and audit trails which ensure a record of all changes made to the topology, ensuring transparency and accountability.

- **Complete digital model** of the 3-phase grid.
- **Phase identification** leveraging AI algorithms.
- **Time series** of network topologies.
- **Identifies & resolves Errors** in data sources.
- **Persistent in-memory cache** for performance optimization.

Simulations and Analyses

PowerNet Explorer™ integrates advanced analytical tools to support operational decision-making. Core analyses to support the operation of the grid and connecting new prosumers include:

- **Network element properties:** Provides a comprehensive view of network element properties, including a chronology of changes and associated administrative data
- **Supply hierarchy:** Determines the supply hierarchy for every grid node at any given point in time.
- **Load flow analysis** Ensures quality - voltage and stability across the network while optimizing energy distribution.
- **Nodal hosting capacity:** Evaluates grid capacity for new prosumer connections, considering historical time profiles of conditions at the node, previously issued consents, and the time profile of the new load/generation. Users can also simulate infrastructure changes (e.g., cable replacements) to asses their impact.

Advanced analytics, such as load flow calculations and reliability evaluations, enable operators to detect anomalies, plan for upgrades, and optimize grid performance. These tools are critical for addressing technical challenges like unbalanced load distribution, voltage fluctuations, and system losses.

Simulations for long-term network planning allow operators to explore optimal upgrades and reconfigurations under various criteria such as voltage characteristics, technical losses, and maximum load values. PowerNet Explorer™ seamlessly integrates with tools for planning and simulating new technologies and concepts such as **DIgSILENT PowerFactory**.

Core Analyses:

- Network element properties
- Supply hierarchy
- Load flow analysis
- Nodal hosting capacity

Network Planning:

- Long-term planning simulations
- Integration with external tools (e.g., DIgSILENT PowerFactory)

PowerNet Explorer™ is highly flexible and modular platform that can be used in many different scenarios of electricity power analyses including analyses of industrial networks. Examples of **possible extended usages** are:

- Detection of important loads at customers (heat pumps, EV chargers…) for enhanced grid observability
- Detection of grid tampering: Sophisticated analytics can help identify anomalies in grid and irregular consumption patterns indicative of unauthorized usage
- Reliability analysis: Calculates reliability indices (e.g., SAIFI and SAIDI) and assesses technical losses for deeper insights into network performance.
- Phase asymmetry analysis: Evaluates technical losses caused by phase imbalances to improve grid efficiency.
- Predictive maintenance: The solution's predictive capabilities extend to the maintenance of grid assets. By detecting anomalies in network elements and analyzing fault patterns, PowerNet Explorer™ can help anticipate maintenance needs. For example, time-variable impedance data and correlations with weather patterns or load profiles enable operators to predict failures before they occur, reducing unplanned outages and maintenance costs.

Extended Usages:

- Detection of important loads (e.g., heat pumps, EV chargers)
- Grid tampering detection
- Reliability analysis
- Phase asymmetry analysis
- Predictive maintenance

Data Exchange and Reporting:

The platform ensures seamless data integration for regulatory reporting, compliance with Common Information Model (**CIM**) data exchange standards, and delivery of user-specific services (e.g., REST APIs).

Data Exchange & Reporting:

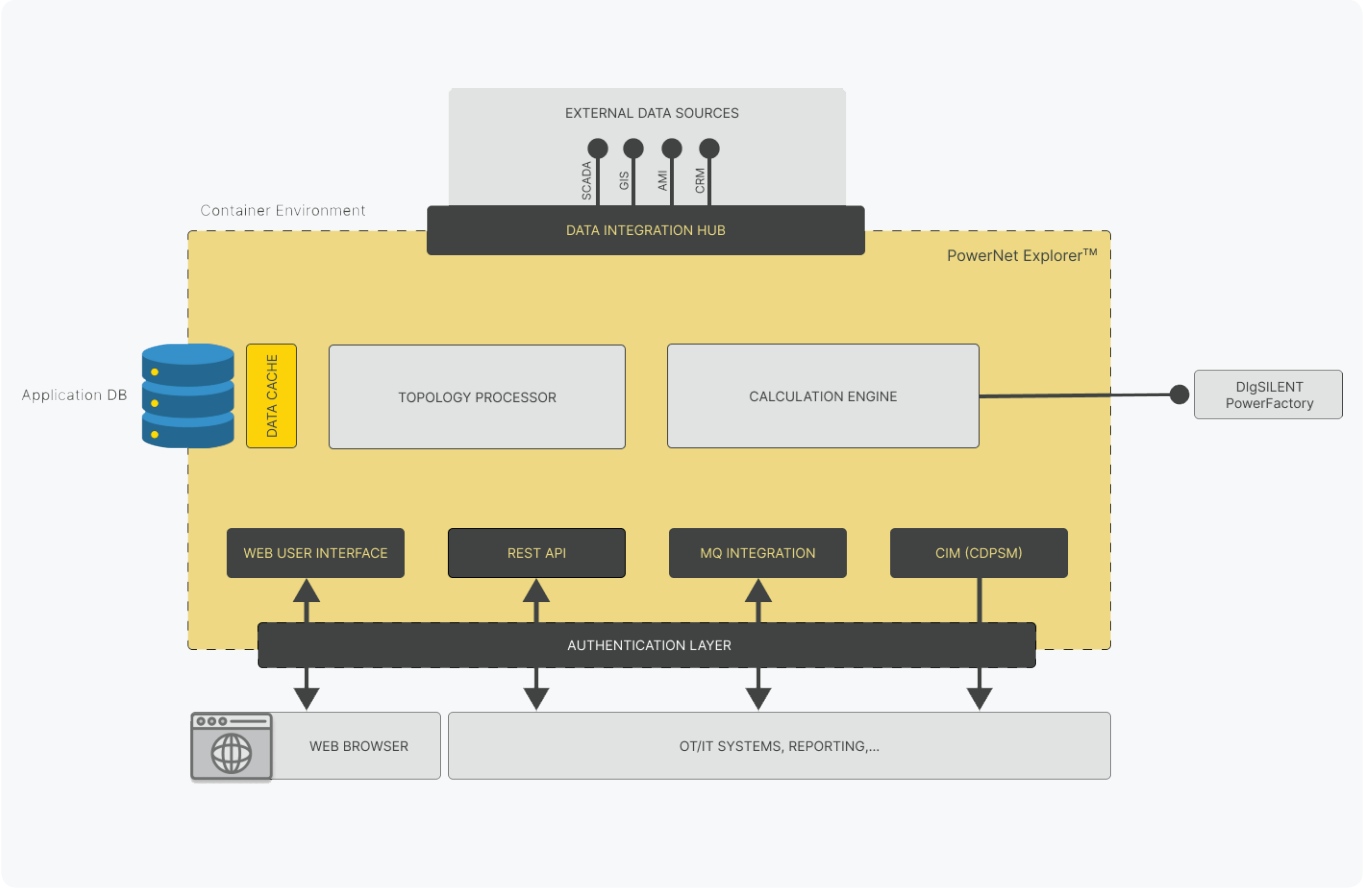
- **Seamless data integration** for regulatory reporting
- Compliance with **CIM standards**
- User-specific **services** (e.g., REST APIs)

IV. Solution Architecture

PowerNet Explorer™ is built on a **containerized**, **scalable architecture** designed to seamlessly adapt to evolving demands. Deployable in both **cloud and on-premise** environments, it offers unparalleled flexibility. In-memory caching and parallel execution optimize performance, ensuring efficiency at every level.

Key architectural components include:

- **Container environment:** Kubernetes, Docker Swarm, etc.
- **RDBMS:** PostgreSQL + Timescale + PostGIS
- **Data cache:** Stores current network topology and frequently accessed data in memory for rapid access.
- **Data integration Hub:** Transfers data from diverse sources to the application database.
  - Each integration operates as an independent module/container, enhancing fault tolerance.
- **Common Information Model (CIM):** Represents network topology using the standardized CIM data model.
  - Accessible via relational database or in JSON/XML format.
- **Topology processor:** Creates a verified logical and electrical connectivity model of all network elements.
- **Calculation engine:** Scalable and instance-independent.
  - Integrates with DIgSILENT PowerFactory (via connector service).
- **Web GUI:** Provides an interactive and user-friendly interface for grid visualization and analysis.
- **REST APIs:** Facilitate secure and efficient data exchange with third-party systems.



V. Key Advantages

PowerNet Explorer™ offers a comprehensive approach to managing the complexities of modern electrical distribution networks. By leveraging advanced analytics and real-time monitoring, it ensures efficient, reliable, and future-proof network operations. With its robust features and capabilities, PowerNet Explorer™ is the ideal solution for utilities looking to enhance their network management and meet the challenges of the evolving energy landscape.

Key Benefits of Implementation

- **Integrated operations and planning**: Streamlines operations and planning processes within a single platform.
- **Accelerated DER connections**: Facilitates faster and more cost-effective integration of DERs while minimizing grid constraints.
- Maximized benefit of equipment investments: Optimizes the utilization of existing grid infrastructure, **maximizing the return on investment** in grid assets.
- Deferred capital investment: Enables more efficient grid usage, **potentially deferring the need for costly grid upgrades**.
- Regulatory compliance: **Supports compliance** with relevant industry regulations and standards.

PowerNet Explorer™ is Addressing Modern Grid Challenges

- Intermittent and Distributed Energy Sources: helps **manage the variability and intermittency** of these sources, ensuring a stable and balanced network.
- Evolving Consumption Patterns: by understanding and **predicting load/generation patterns**, it ensures that the network can meet the dynamic needs of its users
- Digital Twin Technology: provides a real time, **accurate representation of the network**, enabling better decision-making and operational efficiency. Real-time data collection and analysis allow for immediate detection and resolution of issues, minimizing downtime and enhancing reliability.
- Network Development: development decisions based on accurate models. By using detailed and precise models, it **supports strategic planning** (extensions, reinforcements…) of network infrastructure
- Anomaly Detection: proactive approach **reduces the risk of unexpected failures** and extends the lifespan of network components.

PowerNet Explorer™ empowers utilities to:

- Improve grid reliability and efficiency.
- Optimize grid operations and maintenance.
- Accelerate the integration of renewable energy sources.
- Enhance customer service.
- Ensure grid resilience and future-proof operations.

By embracing the capabilities of PowerNet Explorer™, utilities can effectively navigate the challenges of the evolving energy landscape and build a more sustainable and resilient grid for the future.

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