Data Management in Smart Grids

Subjects: Others

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Given the importance of data for smart grids, proper management is required throughout its life cycle, ensuring added value, sustainability, and efficiency for stakeholders, and providing information and knowledge about the energy system's operation and consumption practices. Therefore, data architecture facilitates the capture, storage, and processing of information to support data analysis models in smart microgrids.

Keywords: big data ; data architecture ; microgrids ; smart grid ; Non-Interconnected Zones (NIZ)

1. Smart Grids

The maturity of renewable energy technologies is bringing power generation closer through smart microgrids—small-scale electricity grids that operate independently or in conjunction with the electricity grid [1]—mainly to provide power to isolated communities that are difficult to access or have little interconnection with conventional national energy systems.

These have brought about the rapid transformation of the energy sector, as they allow for preventative interventions or immediate responses to outages, peak load changes, and fault management [2]. In the context of alternative energy generation technology sources, they provide options that add value since they enable the efficient management of available sources such as sun, air, biomass, or water, which is a critical factor in these types of projects.

The microgrids' necessary components are elements related to energy generation: low voltage distribution network and energy storage systems integrated with elements related to information technologies including communication infrastructure, control, and management systems and intelligent sensors.

The literature contains several works on smart grids, such as [3], wherein the authors analyse and compare traditional smart grids (SG 1.0) and smart grids based on IoT (SG 2.0), focusing on how smart grids eliminate the disadvantages of traditional grids, as well as the opportunities and challenges associated with bringing the two together. This comparison is made to gain further insights into power transmission lines in Iran. Additionally, the authors of [4] reviewed the design and implementation of a smart metering network for energy metrics that are stored on a cloud server, also explaining that, with this technology, beyond monitoring energy generation, it is possible to predict power generation and consumption. A similar work can be found in the form of [5]; however, the difference in this study is in its incorporation of Arduino boards as an integral part of the system described in this study, as this is a cost-effective technological measure. Reference [6] extends this approach to present an Arduino IoT-based platform for non-invasive electricity measurements.

Reference [7] describes the implementation of a monitoring system for the generation of renewable energy, where the system is based on IoT using Arduino boards, Raspberry PI, and LoRa networks for an operation and maintenance analysis system. In [8], the authors focus on how to reduce energy losses in transmission lines by using the concepts of IoT and smart grid operation. Similarly [9] propose the use of a smart grid based on IoT to analyse and control energy consumption while improving efficiency in the use of electrical energy in addition to helping detect energy theft. In [10], IoT allowed for the monitoring of transmission lines in a smart grid using Arduino boards, sensors, and actuators for real-time management interventions.

Similarly, the authors of [11] highlight the collaboration between different renewable energy generators. Then, they develop an IoT-based architecture that enables the intelligent control of the demand and generation of electrical energy. In [12], the authors propose an automatic management strategy for electricity generated from renewable energy, given their dynamic behaviour. The results shown demonstrate a reduction in the cost of energy production using these strategies.

2. Data Management in Smart Grids

The key issues and findings of contributions relevant to the field of data analysis within the context of smart grids are summarised below:

The key benefits of big data analysis in the context of smart grids in relation to reference [13] include increased system stability and reliability, increased asset utilisation and efficiency, and improved customer experiences and satisfaction.

The authors of reference [14] focused their research on applying data management and analysis to a large-scale metric as fundamental parts of smart grids' technological infrastructure through a framework that includes the life cycle of smart grid data, from data generation to data analysis.

Reference [15] focuses on infrastructure issues and addresses robust data analysis through high-performance computing, efficient data network management, and cloud computing techniques—critical elements for smart grid (SG) operation and optimization.

The authors of reference [16] review publications in the literature on the characteristics of big data and smart grids, discuss the potential problems for smart grids and the analysis of big data, and conclude that "the results have shown that 'data' is now a new feature being added as a significant component of energy systems".

Given the importance of data for smart grids, proper management is required throughout its life cycle, ensuring added value, sustainability, and efficiency for stakeholders, and providing information and knowledge about the energy system's operation and consumption practices. Therefore, data architecture facilitates the capture, storage, and processing of information to support data analysis models in smart microgrids.

Likewise, storage capacities are expanding due to the development of information technologies, and as a result of the above, data-oriented decision making can promote the creation of innovation in processes, products, and services and is projected to be a potential development area in the convergence of innovative technologies, but more research, discussions, and analyses regarding their applications are needed [17], particularly for those related to strategic decisions in sectors such as the energy sector, in which the trends in big data are one of the most important research challenges in relation to the 2020 horizon.

On the other hand, according to the authors of [18], there are several reference models oriented to the management of big data. Some of the most relevant models described in the literature are noted below, as are their applications in enterprise environments:

- **Microsoft:** This reference architecture is a high-level diagram focused on data, representing the flow of big data and the possible transformation of data, from their collection to their use. This data transformation model includes data collection, aggregation, comparison, and mining.

- **Big Data Architecture Framework (BDAF)**: This framework focuses on the definition of the infrastructure and services based on Cloud/Intercloud technologies focused on the reference architecture of Big Data Security from IBM. It supports all types of data processing and management and maps out, among others, data discovery and exploration, data analysis, the management of unstructured data, real-time data analysis, analytical functions and toolsets, governance, event detection and action, security, and business continuity.

- An important issue in the management and control of smart grids is ensuring the security and quality of the data being handled, as this, along with other technical aspects, is what the functionality of the grid is all about. Regarding data security, various methods can be implemented, such as encryption, access controls, and cybersecurity protocols to safeguard information and guarantee confidentiality, integrity, and availability at any time. Nowadays, due to the rate of digital advances, it is essential to study this aspect to create comprehensive and secure solutions. The authors of [19] carried out an exercise on image encryption, since the correct transmission of images was fundamental for their study. Additionally, the authors of [20] used neural networks to create methods for protection against cyberattacks. Moreover, the authors of [21] implemented techniques to improve image authentication. These are all examples of the great advances in data security and the importance of proper data transmission and management.

- **ORACLE**: Oracle offers an integrated solution to address big data requirements in an application context driven by big data requirements for data acquisition, organisation, and analysis in support of decision making.

- **PIVOTAL**: This model provides a variety of open-source platforms, EMC technology, and VMware, with the goal of making it possible to build big data analysis apps designed for the cloud.
- **SAP Big Data Architecture**: This architecture includes data lifecycle management, infrastructure management, and data governance and security.

The above models are mostly presented in layers, and common to all models are three main layers that can clearly be identified: (1) Capture Data, (2) Storage and data transformation, (3) Data Analytics and Reporting.

Here are the most critical challenges found in the literature related to big data and its application to the design of smart grid architectures. **Table 1** shows the challenges that must be considered for each of the data management stages in a reference model for data-driven architectures.

Table 1. Challenges in the stages of data management for smart grids.

Reference	Capture and Storage	Processing	Analysis and Visualisation
[22]	**Sensor networks produce big amounts of raw data. Often, the information collected will not be in ready for testing.**	**There are many ways to store the same information, but not everyone is the best.**	**The ability to analyse big data is of limited value if users cannot understand the analysis.**
[23]	**Various electronic devices accumulate increasing data. Opportunities for building infrastructure with servers, storage, middleware.**	**High-performance computing application usability. Large information management.**	**Development of data visualisation. Traceability assessments.**
[24]	**The data sets are very complex, voluminous, heterogeneous, and incomplete.**	**Storing data sets using traditional technologies and subjecting the data to real-time processing for sophisticated analysis is a very challenging proposition.**	**Using big data's advanced technologies to manage and analyse data of unprecedented size.**
[13]	**It is essential to find a fusion method for the multi-source data set, which has different modalities, formats, and representations.**	**For some applications, such as fault detection and transient oscillation detection, the reaction time scale is in milliseconds.**	**Visualisations can show explicit and granular changes in voltage and frequency. However, finding and representing correlations or trends between data from multiple sources is a major challenge.**
[25]	**Include different types of unstructured data: messages, videos, voice recordings, images, social media data. Measurement errors in the intelligent network due to device imperfections or errors in data transmission. The volume of data generated is too large to be stored and analysed using traditional database technology.**	**Quality and accuracy are less reliable on big data. The requirements for real-time data exchange are increasing.**	**The higher the amount of data, the lower the density of valuable information.**

Figure 1 presents the data acquisition and management architecture for the proposed microgrid; the "Capture" part is the beginning of the architecture, and for this, there is a physical stage consisting of sensors to measure the environmental and electrical variables of the microgrid or, more specifically, the solar panels in this case study. In the "Storage/Integration" part, the process of receiving data, storing data in the cloud, and integrating all the data of the different variables studied is carried out to have two direct final propositions: (1) the "Reporting", which is where the actual monitoring and analysis is carried out by means of business intelligence, and (2) the "Analytic", which is where artificial intelligence and data mining techniques are applied to find patterns and hidden information pertaining to the microgrid to allow for proper management and control.

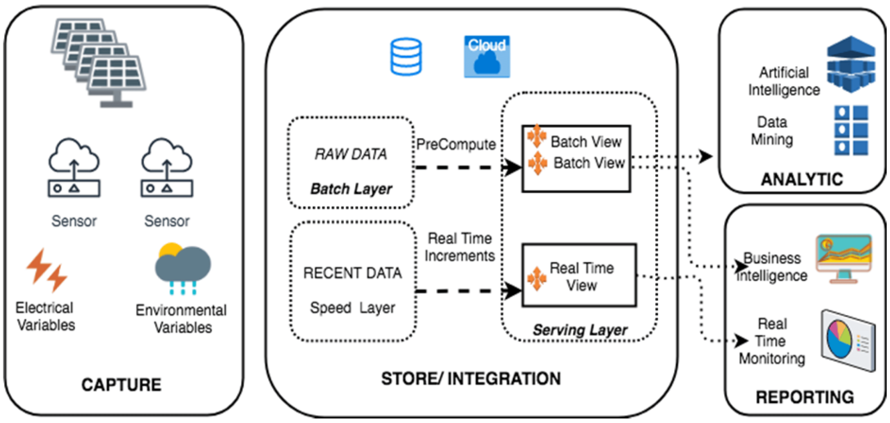

Figure 1. Reference model proposed for the case study.

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