Big Data Solutions for Efficient Operation of Microgrids

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Abstract

In this paper, we propose a big data solution architecture for the efficient operation of the microgrids that have emerged as a consequence of distributed generation, storage systems and advances of ICT technologies. The main goal is to develop a smart adaptive platform for Big Data analytics for microgrids efficient operation that involves monitoring and control of electrical appliances, generation and storage activities, demand response and market mechanisms.

The platform essentially necessitates Big Data solutions that will process, manage and analyze large volumes of data generated by microgrids and modern appliances (IoT & sensors), small- and mid-scale generators based on renewable energy sources such as photovoltaic panels (PV) or micro-wind turbines which are integrated with storage devices (banks of batteries), smart loads, Electric Vehicles (EV) stations, settlement mechanisms and market trading activities.

Key words: big data, demand response, distributed generation, sensors
J.E.L. classification: C8, C55, P28, Q41, Q42, Q47

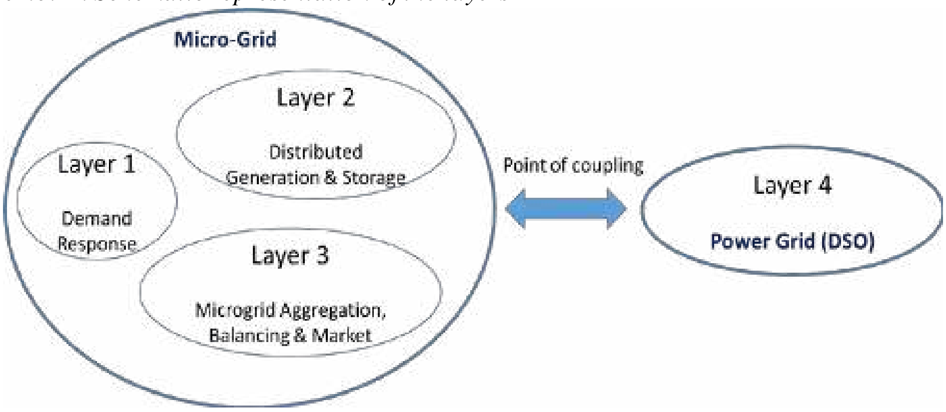
1. Introduction

The traditional energy flows from large power plants to the end-users has changed and new devices and sensors emerged that generate large volume of data.

The smart adaptive Big Data platform proposed in this paper is modular and scalable, build on the following layers since there is a high diversity of development stages related to microgrids (as in

Figure *1*): *L1 - Demand Response* mechanism, *L2* - operation and maintenance of the *Distributed Generation & Storage, L3 - Community Microgrid aggregator & Market* trading and *L4 - Power Grid* integration and exchange.

Figure no. 1. Schematic representation of the layers



L1 Demand Response (prosumers, smart appliances, micro-generation, batteries, EV)
L2 Distributed Generation & Storage (large-scale PV, micro-wind turbines or other gen, battery banks)
L3 Microgrid Aggregation, Balancing & Market (prosumers communities, distributed generation & storage, balancing, settlements)
L4 Power Grid (Distribution System Operator - DSO & interconnected microgrids)

2. Theoretical background

In (Liu et al., 2018), a control center handling big data is included into a microgrid (with distributed generation, storage and loads) to ensure its management. Real-time data generated by sensors is collected, processed and analyzed predicting and optimizing the activities of the microgrid improving its operation.

A framework that integrates IoT consisting in a multi-layer model with layers for data collection, management and analytics for improving the energy efficiency in a manufacturing factory in Italy is proposed in (Bevilacqua et al., 2017). The data is taken from smart meters and manufacturing machines and integrated to improve decisions and decrease the energy costs of the factory.

Energy consumption patterns for buildings of smart cities can be extracted from large volumes of data generated by sensors with big data technologies. Based on these patterns, the authors of (Pérez-chacón, Luna-romera and Troncoso, 2018) used machine learning and proposed some polices to optimize the electricity consumption at a university campus.

A review of big data methods, analytics and challenges for buildings from electricity consumption perspective is proposed in (Koseleva and Ropaite, 2017) considering the large volume of raw data that comes from smart appliances and buildings.

Also, in (Jiang et al., 2016), the authors described and reviewed the concept of big data in smart grid, several big data architectures, recent studies and big data applications in energy, challenges, obstacles, addressing the security issues.

Reduction of energy consumption and emissions for energy-intensive manufacturing industries have been approached in (Zhang et al., 2018) applying energy big data acquisition and data mining, showing that the energy consumption and energy costs could be decreased by 3% and 4%. These findings promote cheaper products and sustainable development of manufacturing factories.

MapReduce framework especially Hadoop coexists with Spark or Flink, a comparative assessment of these technologies being necessary according to (Veiga et al., 2016) considering case studies and indicators such as performance and scalability or these solutions. The results showed that replacing Hadoop with newer technologies such as Spark or Flink reduces the execution times by 77% and 70% respectively.

The MapReduce and Hadoop are analyzed in (Wu et al., 2018) considered as feasible solution for buildings big data management; disadvantages of using Hadoop are also addressed. The authors reviewed several studies regarding energy efficiency with Hadoop clusters, providing useful information to better implement Hadoop on improving the energy efficiency with big data analytics.

3. Research methodology

The layers were depicted in Figure 2 and in the following paragraphs:

Layer L1 – Demand Response (DR) approaches the electricity consumers and prosumers supplied at the microgrid level. Nowadays, most of the consumers own modern appliances, mostly based on batteries, that can be remotely controlled and continuously generate large volumes of data that will be the input data for load profiles, short-term forecast and dynamic consumption optimization including the operation of the distributed generation systems and the potential of peer-to-peer exchanges. Also, *L1* involves setting DR strategies and analyzing prosumers behavior based on incentives, tariffs, surveys, questionnaires and web/social media interactions.

Layer 2 - Distributed Generation & Storage (DGS) addresses large-scale generation, operational optimization and forecast focusing on short term, but also on maintenance aspects focusing more on mid- and long-term optimization (reduce downtime of PV/wind turbines, extend generation lifetime, decrease cost of Operation and Maintenance (O&M), enhance safety and reduce risks). To support O&M activities for PV/wind turbines and storage devices, some challenges must be overcome. One of them is the amount of data that should provide a continuous transparent picture of the DGS performance over its expected lifetime. Also, the data produced by DGS has at least four characteristics describing Big Data: volume, velocity, variety and veracity of data. In addition, O&M require real-time monitoring, diagnose and predictive analytics, optimization, forecast and advanced Key Performance Indicators (KPI) reporting. Therefore, data generated by DGS and process modelling require Big Data solutions to support decisions regarding O&M activities.

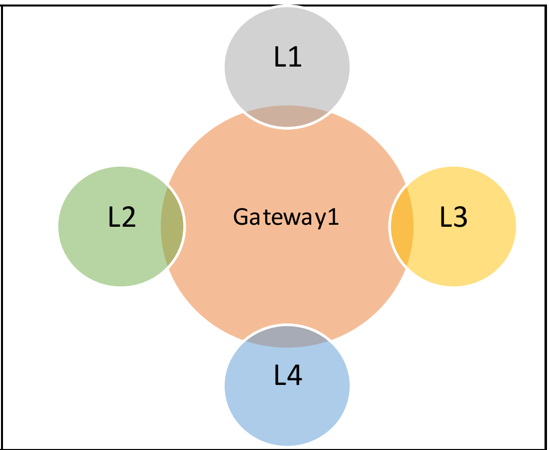
Figure no. 2. Layers connectivity

L1 Demand Response (prosumers, smart appliances, micro-generation, batteries, EV)

L2 Distributed Generation & Storage (large-scale PV, wind turbines or other gen, battery banks)

L3 Microgrid Aggregation, Balancing & Market (prosumers communities, distributed generation & storage, balancing, settlements)

L4 Power Grid (DSO & interconnected microgrids)

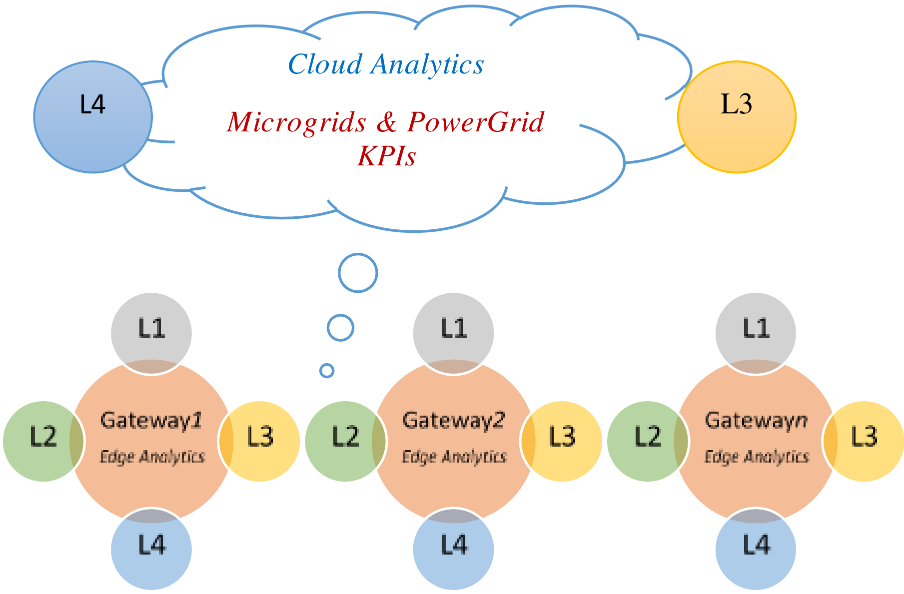


Source: Authors' contribution

Layer 3 - Microgrid Aggregation, Balancing & Market (MABM) integrates and is above *L1* and *L2*, manages the interactions and exchanges between prosumers, community and distributed generation by the settlement mechanisms, provides support for balancing, market trading activities and other microgrids or power grid exchanges. L3 requires Big Data analytics for decision support on L1 and L2 management, balancing and market trading activities.

Layer 4 – Power Grid (PG) represents the supervisor layer from the DSO perspective and other microgrids interconnections. L4 integrates the previous layers and requires Big Data analytics to enhance the efficiency of operation of interconnected microgrids (as in Figure 3).

Figure no. 3. Big Data analytics in cloud

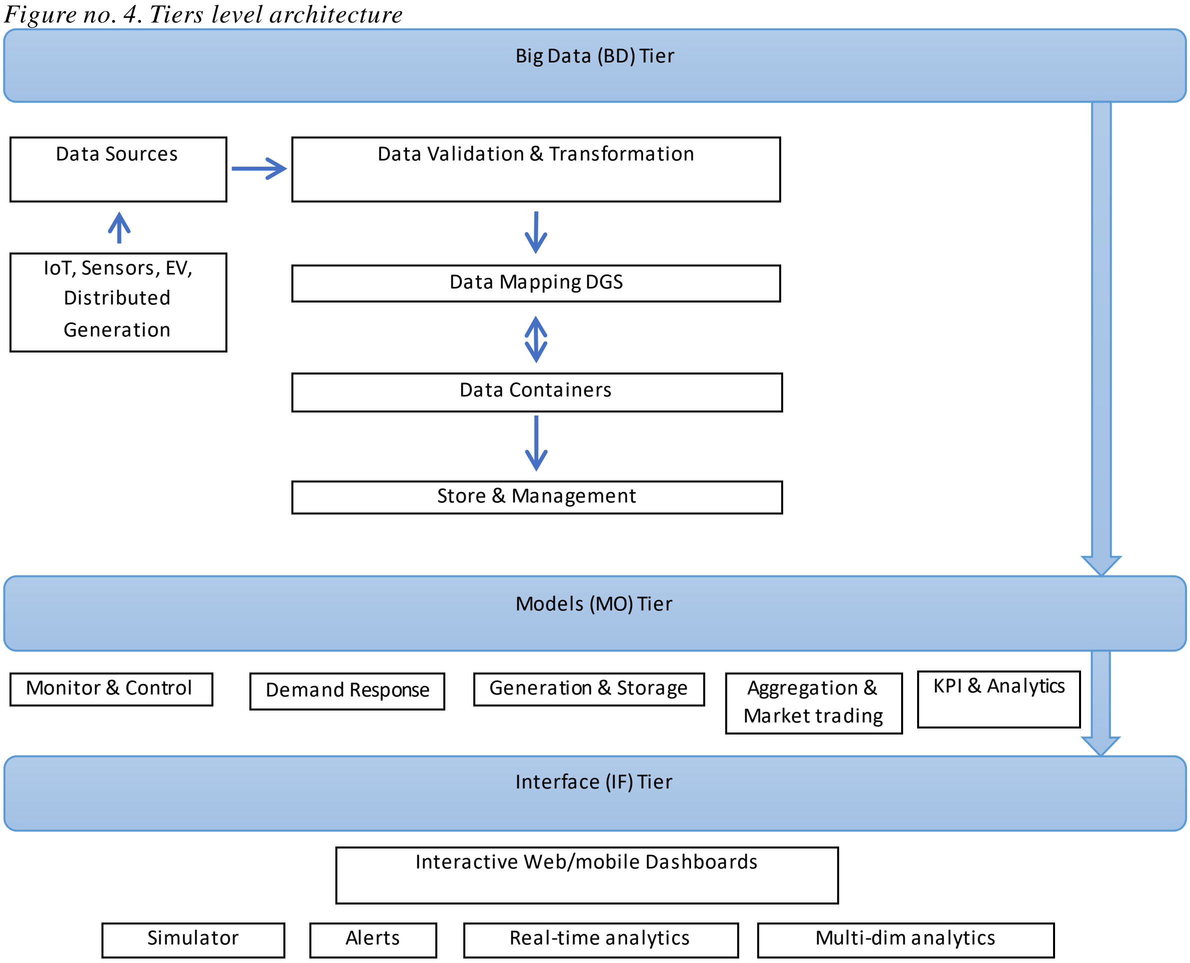


Source: Authors' contribution

4. Findings

The platform will be developed on three physical tiers (as in Figure 4) to support the data and analytics for each layer: *Big Data tier* for data integration and processing, *Models Tier* for implementing the algorithms, Key Performance Indicators (KPI) and Big Data analytics, *Interface Tier* for users' access to platform based on web-services dashboards.

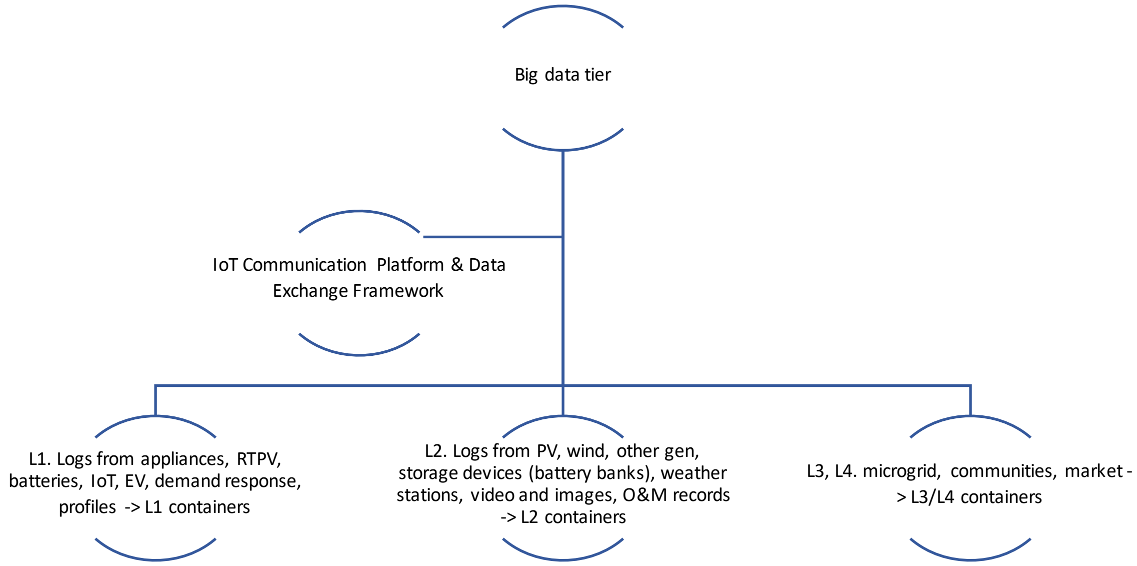
Figure no. 4. Tiers level architecture



Source: Authors' contribution

Big Data (BD) tier (Figure 5) aims to support the acquisition, processing and management of large amounts of data collected from modern appliances (IoT devices), smart meters, sensors, PV/wind systems (including sensors, video and images), EVs, storage devices, consumers activities (web/social media, surveys and questionnaires) and market trading. This layer will be mainly implemented on gateways for L1 and L2 to enable edge computing to reduce the communication bandwidth. To collect the data sources, BD tier will contain a data exchange component build on top of an IoT & sensors communication platform. For the management of the Big Data streams, an in-memory sliding time window processing mechanism will be developed to transform the data sources into flexible data containers that represent customizable data sets that integrate the sources and provide support for the layers' models. For L3 and L4, the BD tier will be developed in cloud to integrate all the data from L1 and L2 and will provide a complete data framework for the microgrid operation.

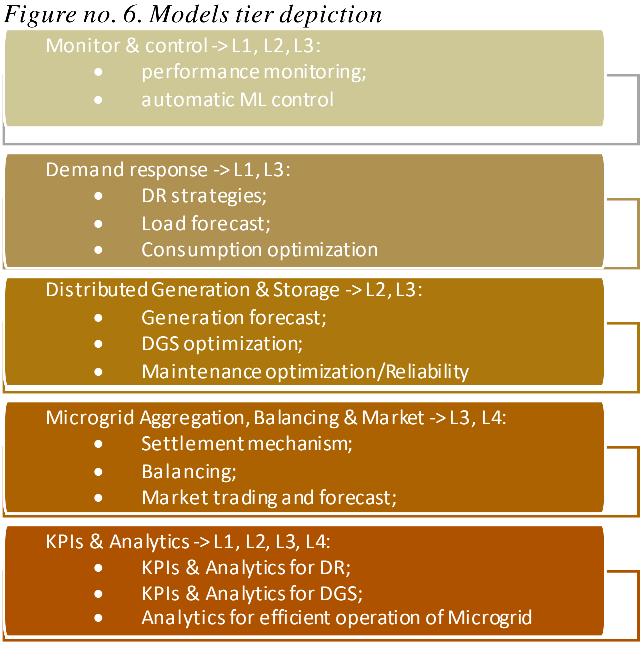
Figure no. 5. Big Data tier depiction



Source: Authors' contribution

Models (MO) tier (Figure 6) contains models for each layer to support decisions that should lead to a better integration of the distributed generation, DR mechanism and the improvement of the overall microgrids exchanges. MO tier will contain models for real-time monitoring and automatic control, operation and maintenance, load and generation optimization, forecast, consumers' behavior analysis, balancing, market trading, blockchain and DR strategies. Machine Learning (ML) algorithms will be developed on top of the BD tier to implement these models. To reduce the communication bandwidth, some of these ML algorithms will be implemented at the level of the gateways to enable edge analytics. In cloud, a set of KPIs for each layer will be developed to provide Big Data analytics for efficient operation of the microgrids.

Figure no. 6. Models tier depiction



Source: Authors' contribution

Interfaces (IF) tier offers access to the platform via web-services for prosumers, users of the power plants, aggregators and DSO. The IF tier will contain dashboards to access the models, KPIs and Big Data analytics for each layer.

The platform will be modular, scalable, open source-based technologies for Big Data management, models and analytics to provide advanced monitoring and decision-making support for increasing the microgrids efficient operation.

5. Conclusion

A big data solution architecture for the efficient operation of the microgrids that have emerged as a consequence of distributed generation, storage systems and advances of ICT technologies is proposed in this paper. Our main goal is to develop a smart adaptive platform for Big Data analytics for microgrids efficient operation that involves monitoring and control of electrical appliances, generation and storage activities, demand response and market mechanisms.

The smart adaptive Big Data platform proposed in this paper is modular and scalable, build on layers since there is a high diversity of development stages related to microgrids. The platform will be developed on three physical tiers to support the data and analytics for each layer: *Big Data tier* for data integration and processing, *Models Tier* for implementing the algorithms, Key Performance Indicators (KPI) and Big Data analytics, *Interface Tier* for users’ access to platform based on web-services dashboards.

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7. References

- Bevilacqua, M., Ciarapica, F.E., Diamantini, C. and Potena, D., 2017. Big data analytics methodologies applied at energy management in industrial sector: A case study. *International Journal of RF Technologies: Research and Applications*.
- Jiang, H., Wang, K., Wang, Y., Gao, M. and Zhang, Y., 2016. *Energy big data: A survey*. *IEEE Access*.
- Koseleva, N. and Ropaite, G., 2017. Big Data in Building Energy Efficiency: Understanding of Big Data and Main Challenges. In: *Procedia Engineering*.
- Liu, L., Wang, Y., Liu, L. and Wang, Z., 2018. Intelligent Control of Micro Grid: A Big Data-Based Control Center. In: *IOP Conference Series: Earth and Environmental Science*. p.52037.
- Pérez-chacón, R., Luna-romera, J.M. and Troncoso, A., 2018. Big Data Analytics for Discovering Electricity Consumption Patterns in Smart Cities. *Energies*.
- Veiga, J., Expósito, R.R., Pardo, X.C., Taboada, G.L. and Tourifio, J., 2016. Performance evaluation of big data frameworks for large-scale data analytics. In: *2016 IEEE International Conference on Big Data (Big Data)*. pp.424–431.
- Wu, W.T., Lin, W.W., Hsu, C.H. and He, L.G., 2018. Energy-efficient hadoop for big data analytics and computing: A systematic review and research insights. *Future Generation Computer Systems*.
- Zhang, Y., Ma, S., Yang, H., Lv, J. and Liu, Y., 2018. A big data driven analytical framework for energy-intensive manufacturing industries. *Journal of Cleaner Production*.