A Business Intelligence Application for the Failure Detection in Automatic Recloser Assets: A Preliminary Investigation

Abstract—**With the growth of the technologies involved with a Smart Grid (SG), besides the new techniques used, such as predictive maintenance, for example, the data generation becomes very large. In this sense, to improve the management of this data and translate it to the operation level, this paper used Business Intelligence and Data Analytics techniques to create a dashboard with an intuitive and interactive layout, presenting the main designation points as KPIs, graphs, and tables. This study is part of the R&D project called Urban Futurability, carried out by ENEL São Paulo Distribution, which aims to form a SG in the neighborhood of Vila Olímpia, in the city of São Paulo, Brazil. This neighborhood was chosen for this project because of its wide diversity of connections, ranging from industrial, commercial, and residential consumers.**

Index Terms—**Predictive Maintenance; Data Analytics; Business Intelligence; Smart Grid; Dashboard.**

I. Introduction

Nowadays, the amount of Power Grid (PG) assets that need to be managed has increased. With the modernization of Smart Grid (SG), these assets have been sensed and the data have been stored in the database. The use of these database has become a useful source of knowledge for the Electric Power Utilities industry to develop predictive maintenance process [1]. These knowledge can provide more accurate maintenance plans and decrease the downtime of the assets.

Several works appeared aiming to improve the asset management. Usually, data visualization approaches such as Business Intelligence (BI) and Data Analytic (DA) systems [2]. These approaches have a large amount of variance and technologies applied to show constructive information to analyze and evaluate in a business-related domain [1]. BI systems can support the decision-making, identify major gaps in the current process, and it can assist in the monitoring of a large number of assets [3].

Automatic Recloser (AR) has a safety role to remotely automate the grid in the overhead system. ARs can be applied to isolate sections under failure and also to transfer cargo from areas affected by faults. These functionalities increase the reliability and quality of service. Given such workability, the number of this asset installed in the PG circuit has been increased [4]. Consequently, the monitoring of the health of ARs must be carried out efficiently, avoiding unforeseen failures.

The objective of this work is to present the application of BI and Data Analitics (DA) for present and guide the detection of failures in ARs.

The highlights of this paper are:

- A simple yet effective method for performing failure detection in Automatic Recloser (AR) using a Business Intelligence (BI) and Data Analitics (DA) system;
- A visual level analysis of the results obtained by the BI and DA system, which points to possible problems;
- To improve the early identification of AR failures and easy to use system based on the rules validated by specialists;

This work is organized as follows: Session II presents the related works. Session III details the background; Session refsec:met is dedicated to presenting the methods used, such as Business Understanding, Data Preparation and Layout Design. Session V shows the results and. Finally, in Session VI the conclusion.

II. Related Works

New technologies of Data Analytic (DA) and BI approaches have been highlighted in SG area. A short survey about BI applied to SG area was presented by [2]. This work highlighted the growing number of legacy systems and complex Big Data. According to the authors, the main challenge is to deal with such different environments and integrated them successfully. [5] presented a systematic literature review about the BI applied in the Electrical Power Systems (EPS). In this study, the BI is divided into Supplier side factors, Customer side factor and Market and supply chain factors. The decrease cost to identify and quantify economic risks, support process and decision-makers by combining the organization and technical views are attributes that makes BI relevant in the industry.

The BI and DA also have been applied in different scenarios of the energy sector. [1] proposes BI and DA methods in the security process of the distribution area. The proposed framework was based on two parts: business architecture and technological architecture. The BI and DA approach make the relationship analysis between the accidents and attitudes variables feasible. Also, the approach shows information about the effectiveness of the security training. [6] proposed a BI approach to the electricity market analysis in SG. In this study, it was used different indicators to forecast the Serbian electricity market index, such as Risk value, Imbalance settlement price, Balancing group deviation, among others. The results of the proposed approach lead to more effective market management in data-rich smart grid environments. A BI and DA approach was also applied to the monitoring of sustainable aspect of energy indicators [7]. The indicators used in this work were SDG7 and SDG13 that ensure the access of affordable, reliable, sustainable, and modern energy for all. The Design Science Research method was used to develop the system and it was applied in Romania. The results demonstrate that Romania developed a proper strategy for clean and affordable energy with satisfactory products and promising groundwork for future advancement.

Given the facilitate feature to identified problems and to monitor KPIs, the BI and DA was applied to Predict Maintenance (PM) problems. Recently, [8] presented a survey of the PM 4.0 applied in EPS. In this study, it was presented the main points to perform data analysis and the types of models (descriptive, inference, and prescriptive). It highlights an evolution in the SG area increasing the reliability and the quality of its grid. A BI system to predict the energy supply demand in real-time was showed by [9]. To manage data processing efficiently, it is proposed a large number of flex-offer by an grouping similar ones with minor flexibility loss. The results indicate an accurate forecast and the system can response in real-time demand. A PM system framework to identify earlier detection of possible machine failures was proposed by [10]. The framework suggested presents Prognosis and Health Management (PHM) and the Condition-based Maintenance (CBM) techniques. The framework design focus on the improvement of the interaction among humans and machines. The design of an intelligent and PM framework consistent with industry 4.0 standards is described in [10]. This paper describes the Open System Architecture for CBM (OSA-CBM) practical block structure. The proposed technology enhances the relationship between humans and machines by integrating decision support systems. In [11], it was shown a PM system and the procedure to develop this end-to-end software. The modules of the system include data collection, data interoperability, data analytics, and dashboard. Different types of Machine Learning (ML) were used (R4RE, SVM, LR, RBF, ANN, Auditive Regression, Decision Table). The results indicated that the R4RE proposed in the paper was the approach with the lowest error rate.

The literature review showed that BI and DA approaches can be well applied in different EPS scenarios, including in the PM problem. We observed that the business and management areas achieve a new level of decision-maker. Business understanding, data preparation, and system development were usually task performed in this researches. Regarding this scope, we also use BI and DA systems and strategies for development. Differently from the literature works, We focus on detecting failures in AR. To the best of our knowledge, it was not found similar work.

III. BACKGROUND

A. Automatic Recloser

The adoption of Automatic Reclosers (ARs) is supported by studies that show that more than 90% of short-circuits are temporary and eliminated on the first reclosing [12]. Humidity, tree branches, birds, high winds, salinity, insulator contamination, and network overvoltages are all potential causes of these issues [13]. The ARs are set to treat the defect as temporary and attempt to reclose the system up to three times, obviating the requirement for a filed team and reducing emergency response time. If the problem continues, the system will be turned off. When ARs are used, the frequency of exposure scenarios for employees on electrical lines increases [14].

The ARs equipment is responsible for the automation of medium voltage overhead grids through remote control operation. The main advantages to be derived from its use can be summarized as being the reduction in the number of supply interruptions to the consumer. Also, the ability to introduce instantaneous fault elimination, reducing the time of faults and reducing the damage caused by faults and also permanent faults [15]. The ARs are located in strategic sections of the primary overhead distribution circuit, monitoring electrical quantities of the circuit, identifying faults, acting on them, and restoring the energy supply from transient faults.

Despite the previous features of AR to the overhead power distribution system, this asset is equipment that presents a high degree of exposure to environmental intrusion. Thus, predictive maintenance can contribute to preserving the integrity of this equipment. This preservation is performed by anticipating maintenance in fault detection in ARs and prescribing activities to mitigate future failures [8].

B. Business Intelligence and Data Analytic

BI&DA refers to a set of decision-making tools for obtaining, accessing, and analyzing data to assist enterprise users (executives, managers, and analysts) in making better and faster business decisions [16]. The concept suggests a thorough understanding of all the aspects that influence a company's operations. To make effective and high-quality business decisions, firms must have a thorough understanding of issues such as consumers, competitors, business partners, the economic climate, and internal processes. These types of decisions can be made with the use of business intelligence [17]. Executives, managers, and knowledge analysts will be able to make better and faster decisions by using these tools in companies [18].

The typical components of Business Intelligence architecture for an Enterprise are:

- Data Sources: Operational databases, historical data, external data (for example, from market research firms or the Internet), and information from an existing data warehouse system are all possible data sources. Relational databases or any other data structure that supports a line of business applications can be used as data sources;
- Data Integration: Extract-Transform-Load (ETL) and refers to a set of tools that aid in the discovery and correction of data quality issues as well as the efficient loading of massive amounts of data into the warehouse;
- Data Warehouse and Data Marts: Business intelligence is incomplete without the data warehouse. By handling the multiple corporate records for integration, cleansing,

aggregation, and query operations, the data warehouse aids in the physical propagation of data. A data mart is an orderly collection of subject areas for decision assistance depending on the demands of a specific department. The data mart is that built around a specific, predefined need for a particular grouping and configuration of select data;
- Data Presentation: Spreadsheets, enterprise portals for searching, performance management applications that enable decision-makers to track Key Performance Indicators of the business using visual dashboards. Also, these tools allow users to pose sudden queries, viewers for data mining models. These systems are all popular frontend applications through which users perform BI tasks. Rapid data visualization can aid in the discovery of relevant facts for BI by allowing for dynamic examination of patterns and outliers.

IV. Material and Method

In this work is presented a BI and DA system for monitoring failures in AR. Figure 1 shows the overview of the development process. This system was developed using the following steps: business understanding, data processing, layout design, build the dashboard, and deployment of the model. The four first steps were evolved iteratively with the specialist validation. In the next sections, we will describe each of these steps.

A. Business Understanding

In the business understanding, we gathered the requirements definition phase included the mandatory interviews with end-users. For this phase, three technicians specialized in monitoring and maintenance of the AR support this research. The focus was on the failure detection efficiency improvement for AR. The specialist team provides an in-depth perspective on the system analysis. In this step, they presented the business rules that are used to detect malfunction behaviors in ARs. Also, they presented features that could be useful to the evaluation and gaps in their current analysis approach.

Nowadays, the analysis process of each asset is accomplished manually based on the evaluation of open and closed alarms registers in a log list. This procedure is performed daily and requires man-hours work fully allocated. Given the number of demands in the management area, compile all failures manually could be unfeasible. In addition, extract insights manually about the problems is not an easy task to perform in the current scenario. According to the specialist, an system to auxiliary this analysis with report per day and week or using the localization of the assets could be useful for an quick analysis and identification of the problems.

We used three use cases to identify failures in AR (battery failure, coil to trip open fail, and coil to trip close fail). These problems were chosen given the amount of data available and for the critical of the issue. The malfunction for each problem was defined based on the time that an alarm or an ensemble of alarms stay open. The time for each issue was defined for the electricians based on their empirical analysis. Table IV-A shows the relationship between the failures and the alarms. Some problems are related to one sensor (coil), while others need to be analyzed with two alarms (battery issues).

TABLE I
Business rules for Automatic Reclosers failures prediction based on specialist criteria.

Failures Description	Alarms	Time Thresholds
Failure in an open coil of switch	74TC	On for one minute
Failure in an close coil of switch	74CC	On for one hour
Failure in the battery	BXTB	On for one hour
	FLCA	Off for one hour (when BXTB is on)

It was defined Key Performance Indicators (KPI) related to the failures detected as a part of the business requirement phase. The users defined the KPIs that need to be tracked through the BI system. For this paper, the KPI gathered were those associated with the total amount of failures, affected circuits, customers, and maintenance. Others addressed to a period analysis (week and hour). Also, problems related to places, such as neighborhoods and circuits.

B. Data Preparation

An analysis of the data architecture was performed, as presented in Figure 2. Currently, the data of ARs are stored and clustered in a Data Lake (DL). This DL includes the information from different assets, which includes alarms and field time date, position geospatial, assset identification (ID), electrical circuit, among others. The information are receive from Extract Transform Load (ETL) scripts from Supervisory Control and Data Acquisition (SCADA), Geographic Information System (GIS), Systems Applications and Products (SAP), among others ENEL legacy system.

In this work AR information was extracted from the DL from different databases that concentrate information from SCADA, GIS, among other ENEL-SP systems. Table II shows the information after the data extraction.

TABLE II
Information extracted from the Data Lake

Information	Description
AR identification	Open and close alarms information, alarm description, time information (fieldtime, date and hour).
AR register	AR identification, installation date, electrical circuit, circuit location, city, region, maintenance register.
Clients information	Number of clients related to electricity grid assets, and respective asset identifications.

For the purpose of this paper, only the objects from the highest layer was discussed, given the confidential information about the data architecture inside of the DL.

In the pre-processing step, the data cleaning was performed to remove duplicate samples. Also, information with missing values and abnormal fieldtime registers was excluded from

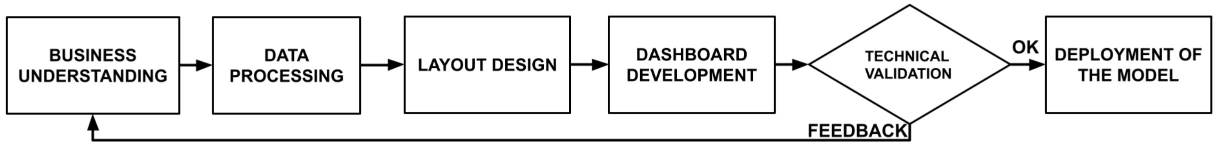

Fig. 1. Development approach to build the BI system.

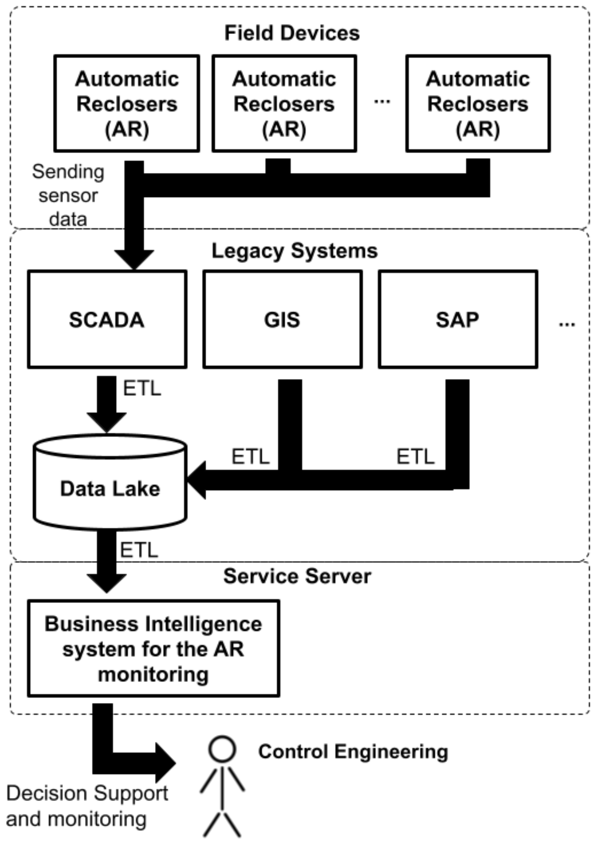

Fig. 2. Overview of the data architecture.

the database. To integrate the database used the ID of the AR are quite similar in both databases. In this regard, it needed a processing step to pattern this attribute such as removal of additional strings or other information appended in the identification register. A data engineering task was also performed to generate new information with the integrated database (duration of the failures, number of maintenance, among others). These insights were clustered daily, weekly, and annually. This information was stored for integration with the BI interface.

C. Layout Design

The layout design of the system was based on the business requirement and also using the dataset pre-processed. Along the requirements gathering step was identified principal components in the layout, such as filters, Key Performance Indicators (KPI), charts and tables. Also, we validate the proportion of each of them in the layout, see Figure 3.

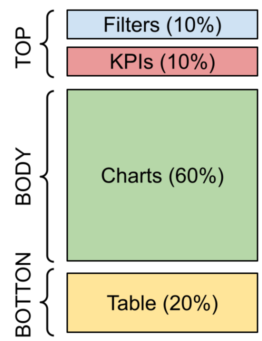

Fig. 3. The components in the interface and the respectively proportion.

In the top of the layout were inserted KPIs and Filters components. The KPIs requested by the specialist (see Section IV-A) were developed to allow a quick analysis of the global state of the assets. The KPIs defined in this system were: total number of failures related to battery, open coil, and close coil; number of effected circuits, costumers, and maintenance performed; critical week and period of the day; most problematic circuit and neighbourhood. The filters are connected with other components of the interface, and, it changes the values according to what is selected. The filters developers include: per year, month, and day of the week; by a specific AR id, circuit, location, city, region, and failure type. In the body of the layout were designed an area to include charts that shows the visual information about the failures. The features in the charts include quantitative information, temporal data, and geospatial description. In the bottom of the layout proposed a table with the register information of the charts. This table allows a quick analysis of each sample.

V. Results and Analysis

To generate the system, it was used the RedData® Big Data Analytics platform to integrate the data pre-processed (see Section IV-B) with the graphic interface. Also, RedData was used to generate the layout design. In this work, we used Python 3.6 programming language. We used the scrum approach to develop the system, which was developed in 3 sprints with validations of technicians. To ensure data

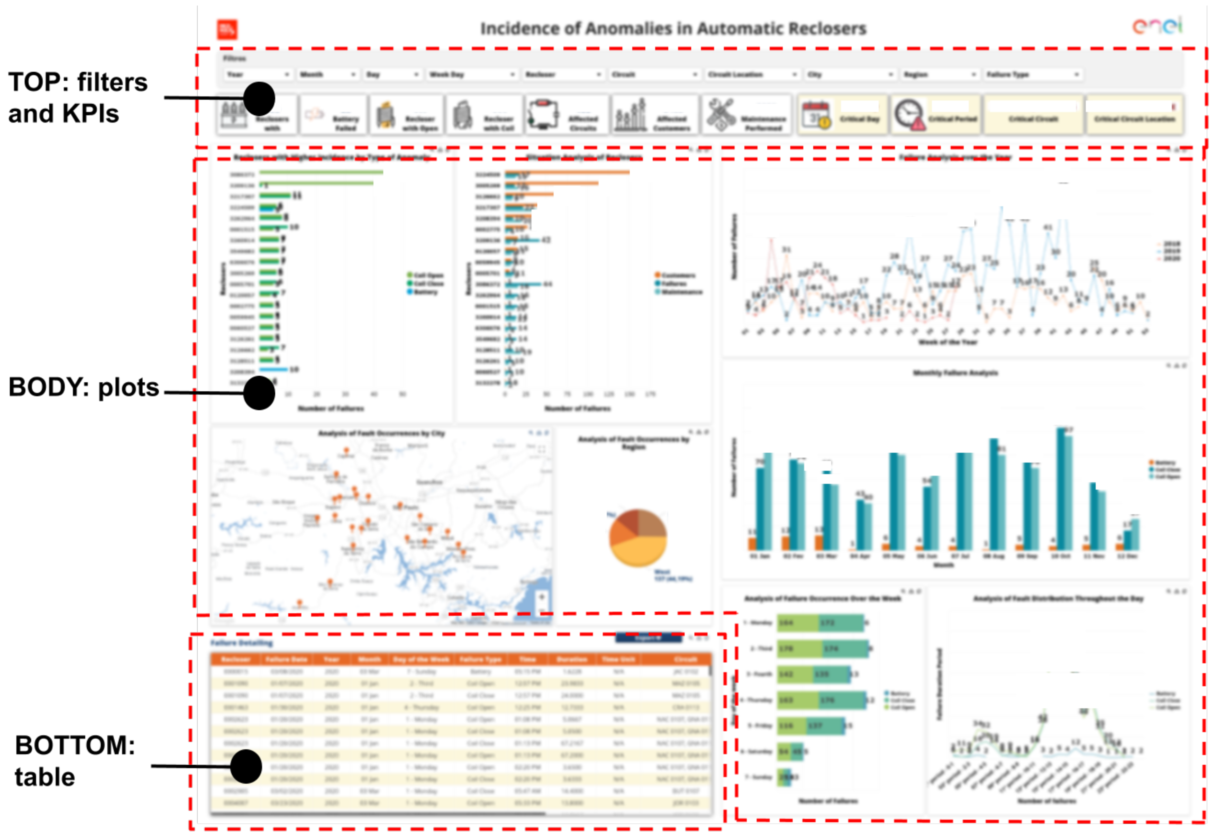

Fig. 4. Overiview of the Business Intelligence and Data Analytic graphic interface to monitoring failures in Automatic Rec losers.

confidentiality requested by the enterprise, we are restricted to show only the overall reports. In addition, all information presented in this section is normalized or blur to suppress the raw values.

Figure 4 shows the final graphical interface of the failures identified in ARs developed in this work. As well as design in the business understating step, we developed the interface in three sub-areas (TOP, BODY, and BOTTOM). All components requested by the specialists were developed (see Section IV-A), and they were integrated with filters. In this sense, KPI values and quantitative plots can be changed according to the combination of the parameter selected in the filters. Also, it changes the number of problems presented by each region of São Paulo, failures that appear on the map, and the list of issues shown in the table. The analysis of the specialist indicated that the system could supply the requirements to optimized to maintenance process in ARs. Given the variety of customization with the filters, a unique interface can evaluate the current scenario and a historical scenario of a maintenance project.

Figure 5 showed the number of failures (normalized) per week using the data from 2019 to 2020. It was observed that the highest amount of problems related to ARs is between weeks number 22 to 46. On the other hand, between weeks 1 to 21 and weeks 47 to 53, there are fewer problems. This

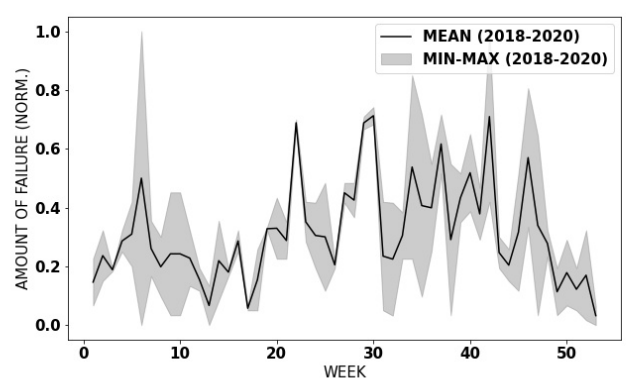

Fig. 5. Amount of failure per week of year.

characteristic could be due to seasonality.According to the analysis of the electricians, the period of higher occurrences is during the rainy and windy seasons (winter and spring seasons). This behavior could increase the probability of accidents in the assets. For example, the number of networks blocked by felled trees grows in this season, and the amount of vegetation interference in the RAs raises in this period.

In Figure 6, we analyzed the number of problems per

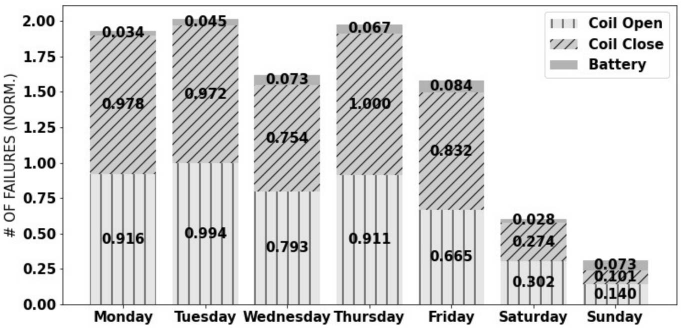

Fig. 6. Representation of the final layout of the Business Intelligence system.

day of the week using the data from 2019 to 2020. The results suggested that a higher number of problems occurs from Monday to Friday. On weekends, it is observed that the number of problems is lower than the usual workday. During these days, the KPIs showed that a higher amount of problems happen between 12:00 pm to 14:00. These results indicate new insights about the current scenario of the problems to the maintenance professionals. This information will be incorporated in the scheduling strategy and the maintenance strategy in the planning area.

Figure 7 shown the percentage of failures in each area of São Paulo city (North, South, West, and East). The area with the highest incidence of failures is the west (44,19%). This area has more than twice times issues compared to the second-worst region in the South (25,16%). The east and north regions were the lower problematic regions with 16.77% and 13.87%, respectively. According to the specialist, the west region needs particular attention to maintenance given the proportion of the coverage area. This result could be more realistic by dividing it into sub-areas of the west region.

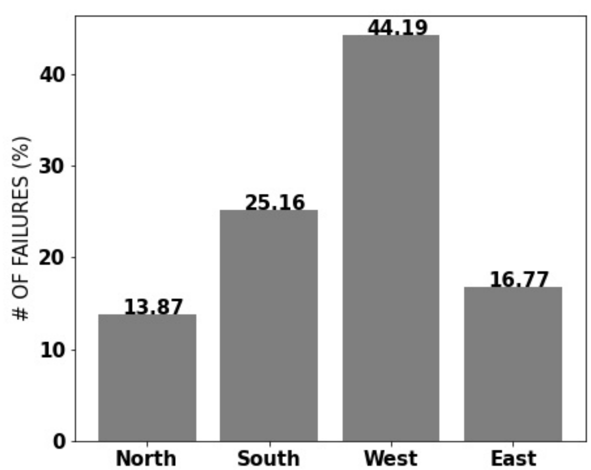

Fig. 7. Number of incidents per area.

VI. Conclusion

The development of a solution to detect failures in Automatic Reclosers (ARs) was carried out through the rule-based algorithms generated by specialists. This process was accomplished by collecting data from the sensors and making them available in an online and interactive visualization system using Business Intelligence and Data Analytics (BI&DA) technologies. The information about the RAs is present in different layers, from the fine-grain data of each ARs to the coarse-grained insights to analyzes the overall KPIs of the asset set.

This solution was validated with a set of professionals that work in the AR maintenance activities. Given the facilities to analyze issues in the ARs at different levels, the resulted system has a high level of acceptance by the business area. The tool is placed on the minimum impact in the current process, once the methodology used was elaborate with the business area specification. According to the specialists, the system has a high level of aggregation to the planning and monitoring processes, due to the acceleration of the systematization. The historical analysis showed patterns that can be added into the strategy of the company maintenance, decreasing the reactive actions to a more preventive approach. Consequently, a decrease in downtime of these assets are expected. Furthermore, the deployment of the system will demand fewer human resources focused on this activity.

Future works will include in deployment this service on cloud and the production environment. Other sensors analysis will be considered to the failures detection in RAs. The addition of Machine Learning algorithms using the historical data could be used to make inference of future events of failures.

This paper presents the preliminary results of a study developed between Enel Distribution São Paulo company and the RedMaxx company for the Brazilian Research and Development (R&D) project called Urban Futurability (UF), whose intention is the development of a SG at São Paulo, Brazil. The project foresees the implementation of Predictive Maintenance 4.0 in several areas of the company, such as automation, subtransmission, overhead and underground distribution, aiming to improve the availability of its assets, increase the reliability of its grid and increase the quality of energy supply to its customers.

Acknowledgment

The authors thank the Research Program and Technological Development of the electricity sector regulated by ANEEL and Enel Distribuiçao São Paulo for the financial support to the project. RedMaxx for allows to use their plataform.

References

[1] G. Escobedo, N. Jacome, and G. Arroyo, "Business intelligence and data analytics (bi&da) to support the operation of smart grid," in *Proceedings of the International Conference on Internet of Things and Big Data (IoTBD 2016)*, 2016, pp. 489–496.

[2] I. Martín-Rubio, A. E. Florence-Sandoval, J. Jiménez-Trillo, and D. Andina, "From smart grids to business intelligence, a challenge for bioinspired systems," in *International Work-Conference on the Interplay Between Natural and Artificial Computation*. Springer, 2015, pp. 439–450.

[3] B. Jena, "An approach for forecast prediction in data analytics field by tableau software," *International Journal of Information Engineering and Electronic Business*, vol. 11, pp. 19–26, 2019.

[4] L. F. Grisales, O. D. Montoya, A. Grajales, R. A. Hincapie, and M. Granada, "Optimal planning and operation of distribution systems considering distributed energy resources and automatic reclosers," *IEEE Latin America Transactions*, vol. 16, no. 1, pp. 126–134, 2018.

[5] T. N. G. Huynh, "Business intelligence in the electrical power industry," Ph.D. dissertation, University of VAASA, 2020.

[6] M. Radenković, J. Lukić, M. Despotović-Zrakić, A. Labus, and Z. Bogdanović, "Harnessing business intelligence in smart grids: A case of the electricity market," *Computers in industry*, vol. 96, pp. 40–53, 2018.

[7] M. Muntean, D. Dănăiaţă, L. Hurbean, and C. Jude, "A business intelligence & analytics framework for clean and affordable energy data analysis," *Sustainability*, vol. 13, no. 2, p. 638, 2021.

[8] S. B. Righetto, M. A. I. Martins, E. G. Carvalho, L. T. Hattori, and S. De Francisci, "Predictive maintenance 4.0 applied in electrical power systems," in *2021 IEEE Power & Energy Society Innovative Smart Grid Technologies Conference (ISGT)*. IEEE, 2021, pp. 1–5.

[9] U. Fischer, D. Kaulakienė, M. E. Khalefa, W. Lehner, T. B. Pedersen, L. Šikšnys, and C. Thomsen, "Real-time business intelligence in the mirabel smart grid system," in *International Workshop on Business Intelligence for the Real-Time Enterprise*. Springer, 2012, pp. 1–22.

[10] A. Cachada, J. Barbosa, P. Leitño, C. A. Gcraldcs, L. Deusdado, J. Costa, C. Teixeira, J. Teixeira, A. H. Moreira, P. M. Moreira *et al.*, "Maintenance 4.0: Intelligent and predictive maintenance system architecture," in *2018 IEEE 23rd international conference on emerging technologies and factory automation (ETFA)*, vol. 1. IEEE, 2018, pp. 139–146.

[11] I. T. Christou, N. Kefalakis, A. Zalonis, J. Soldatos, and R. Bröchler, "End-to-end industrial iot platform for actionable predictive maintenance," *IFAC-PapersOnLine*, vol. 53, no. 3, pp. 173–178, 2020.

[12] A. J. N. d. Silva, I. M. d. Almeida, R. A. d. G. Vilela, R. W. B. Mendes, and S. L. B. Hurtado, "Acidentes de trabalho e os religadores automáticos no setor elétrico: para além das causas imediatas," *Cadernos de Saúde Pública*, vol. 34, 2018.

[13] A. D. Baka and N. K. Uzunoglu, "Analysis of two electrocution accidents in greece that occurred due to unexpected re-energization of power lines," *Safety and health at work*, vol. 5, no. 3, pp. 158–160, 2014.

[14] M. L. G. L. de Castro, "Quando as luzes não se apagam... a gestão coletiva dos riscos na manutenção em rede energizada," 2016.

[15] V. Artemev, N. Prikhodko, and V. Tatarin, "An automatic recloser," Jan 1982.

[16] M. Obeidat, M. North, R. Richardson, and V. Rattanak, "Business intelligence technology, applications, and trends," 02 2015.

[17] G. Escobedo Briones, N. Jacome, and G. Arroyo-Figueroa, "Business intelligence and data analytics (bi&da) to support the operation of smart grid - business intelligence and data analytics (bida) for smart grid," 01 2016, pp. 489–496.

[18] G. Yeoh and A. Koronios, "Critical success factors for business intelligence systems," *Journal of Computer Information Systems*, vol. 50, 03 2010.