A STOCHASTIC MODELING OF OUTAGE BEHAVIOR ON POWER DISTRIBUTION SYSTEM PERFORMANCE

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***Abstract*— This paper aims to analyze the failures of power distribution on the system by the behavioral analysis of emergency orders occurrences, week by week, defining a predictive model to each weekday that is willing to look forward and to prevent the major impact caused by these emergency events that cause distribution failures, considering the damage coverage in respect to affected users amount and the electric power shortage, as well as the affected area and the specific location of these events. The developed method aims to contribute with the decision making of operational centers about the maintenance schedule and planning, highlighting the grid spots that most present failures in the stochastic review, achieved through the statistical database analysis.**

Keywords*— decision making, electric power utilities, failure, forecast method, reliability improvement, shortage.

I. Introduction

The electrical distribution companies' main goal is to ensure the power system performance and reliability using efficient strategies and their resource productivity to promote a power supply with quality and continuity to their final consumer.

When Considering the set of reliability indicators used to define the efficiency of power utilities provided service [1][2], we can see the significance off analyze the behavior of electrical system and the indispensability of know the impact caused by the energy faults in certain grid spots, as well as the importance of define a strategy and the electric utilities positioning to solve these failures [3].

Several methods are proposed to improvement of continuous electricity supply, as well as distribution system reliability, suggesting a lower frequency and coverage of outages. These methods draw strategies based on power company database analysis to achieve costs reduction cluster to routine maintenance and corrective measures, changing the feeder's topology of each affected area or even adding protection devices to the known grid [3-5].

The random occurrence of events that cause power outages, commonly called 'emergency orders' affect the standard conditions of distribution grid operation [6], causing the commitment of continuity of energy supply and the reliability of provided service by power utilities. Even considering the automatization level and equipment independency by remote control of grid in a smart grid scenario, human intervention is a requirement and a must reality [7].

With an evident need of maintenance crews to repair these grid problems and service of these events that causes power outages, it is necessary that the response time be minimized, justifying the optimization problem which is being investigated [8].

This paper is intended to advance the emergency occurrence events throughout a predictive methodology that analyses a real south Brazilian power utility database, using a general occurrence record, filtering the ones that present power outages and that affect the reliability indexes. Stem from this analysis, we pretend to define a risk map, pointing the highest attention spots related by the biggest impact of power outages to operation center, considering the spread area of the grid that these events occurs and the most likely day to it happens.

This methodology tends to contribute as a decisionmaker of operations and maintenance center, providing a proactive and dynamic approach on orders dispatch to each maintenance crew, considering the priority and emergency events as prospective and the impact caused by theses probable events, imminent and calculated by the forecasting.

II. The outage impact and location

The interruptions occurrence on distribution grid of energy supply it is unavoidable, however the solution speed of the problems that cause the outages is crucial on the reduction of impact caused by them. Considering the necessity of human intervention on a complete power restoration in certain cases, is indispensable to consider the location to dispatch the service orders, in other hand it is not used the impact factors of each outage occurrence to do these dispatches nowadays.

As we are applying the methodology in a Brazilian scenery, the regulatory agency that defines all the quality and reliability parameters to the power electric agents, the Power Electric National Agency (ANEEL), decided to adopt aspects about frequency and duration of outages to quantize the reliability indexes [11]. Nowadays the impact of outages is calculated and settled by the power company's database information transmitted to ANEEL agency and analyzed by them. The

Power Distribution Company RGE Sul; Brazilian Federal Agency for Support and Evaluation of Graduate Education within the Brazil's Education Ministry -CAPES.

effect of this practice in distribution power companies is the penalties [11].

About the studies of outage and fault location that tackle the distribution system, the methodologies developed consist in two main types. The first deal with the automated equipment entitled information which belong to the distribution system. It is used the measures and information sent by remote controlled switches, reclosers and other equipment that deal with voltage, electric current, phasors and impedance, depending on the distribution system and equipment feedback [3] [10]. In the second group, the studies address the treatment of occurrences historic stochastically, considering all the important previous information to analyze and define the system behavior and forecast [9]. These paper deals with the second group and suggest a stochastic approach in a power distribution company database to know the grid and outages behavior and predict the possible future events, endorsing a decision-making that deals with the service orders dispatch.

The management of service dispatch is a dynamic problem, especially treating the random occurrences which result in a contingency case. The stochastic approach counts for a historical analysis and a forecasting to the network operation center, that have in the emergency service attendance a higher impact task. The necessity of efficiency and effectiveness on random outages and occurrence response set the achievement of the reliability targets and decrease the penalties [8][9].

With the optimization of dispatching problem, the response time minimization, the period between the outage detection and the restoration service begin, contribute directly to the outage ending, therefore boosting the reliability of power distribution system [9] [13].

III. Proposed Methodology of Analysis

The paper proposed methodology is based on the predictive importance on power utilities working, especially in the case of service demand, that is a complex and dynamic problem. The behavior definition is a decision-making facilitator, because it helps to define the possible location of a random outage case and calculate the impact of these occurrences using the outage duration, frequency and the number of affected consumers.

Considering the outage impact in a dynamic way, the predictive modeling used give us a forecast, defining the probable future events and, by the number of users attached to the damaged area and the time, the impact is calculated. With this, the caused impact is projected to each outage in a quantitative way, to allow the maintenance crew in a geographic distribution. The waited rewards lead to the service quality improvement, reflecting directly on system reliability indexes, a better service and product provided by the power electric distribution companies, as well as the consumer satisfaction.

As shown by the flowchart (fig.1), the decision making is based in a multicriteria methodology, after the impact of outages were calculated. The outage duration, frequency and the number of affected users was calculated.

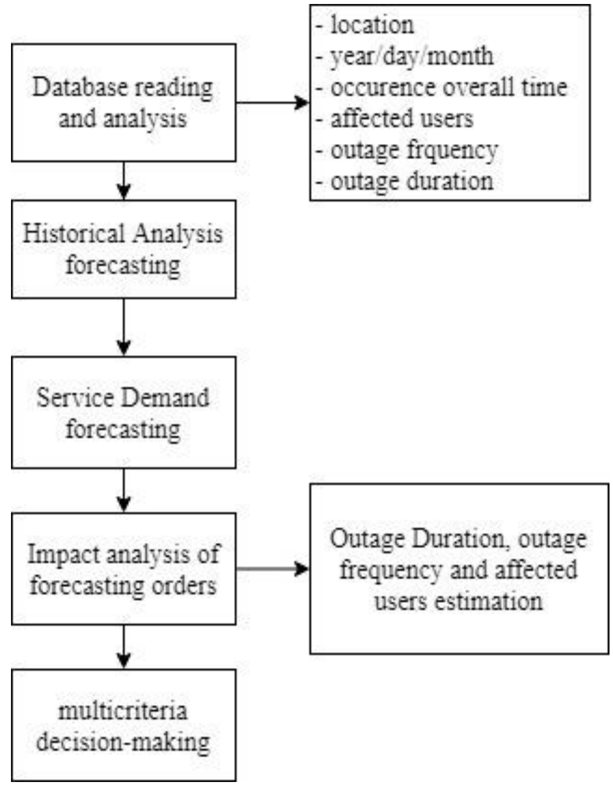

Fig 1. Methodology Flowchart

A. *Database analysis – Linear regression to forecasting*

For methodology application it is necessary to use a set of data that include location parameters, as latitude and longitude of studied area, and a set of information to represent the occurrence period, in this case are used the year, month, day and weekday. Also, are used the information data about duration and frequency of each order, to calculate the Brazilian reliability indexes Equivalent Outage Duration to Consumer unit (DEC) and Equivalent Frequency of outage to Consumer unit (FEC).

To analyze the database provided, matching with the objective of this paper and the developed methodology, are used the linear regression technique to define the forecast, and before the analyze each estimated result, define the behavior and the predictive modeling of the week. The method was chosen because it is a causal method that deals with mid-term forecasting, which aligns with the objective of this paper and method that aims to recognize the forecasting scenario of emergency occurrences.

It is important to highlight that the causal models make suppositions quite similar of time series models and the used data follow a pattern over time that have a relationship distinguishable between the factors and information acquaintance and the forecasting achieved.

The regression model is used to relate two different variables and find the statistic relationship between the factor being forecasted, called dependent variable, and the independent one. Considering the variables X and Y, n-even data Y could be a linear function of X, establish a linear regression whose statistical model is shown by (1) [14].

$$Y = a_0 + a_1X_1 + a_2X_2 + \dots + a_nX_n \quad (1)$$

Which a_n are models' parameters that define the regression line and the sample size estimated.

B. *Impact*

Each outage in Brazil is treated as an emergency occurrence and the impact of these events is calculated in order to evaluate the duration and the frequency of each one, to the specific users' group that was affected, occurred in critic or regular days. The indexes are called DEC and FEC, and it is used to calculate the penalties that power companies need to pay to affected consumers and to regulatory agency if the indexes moves outside limits [1].

DEC is the index that represent the equivalent time that a consumer unit stays without power in the considered period. It is calculated by (2).

$$DEC = \sum Outage\ total\ time\ /\ Consumer\ unit \quad (2)$$

The index called FEC represent the quantity of occurrences that tackled the consumer unit was without power and it could be calculated by (3).

$$FEC = \sum Outage\ frequency\ /\ Consumer\ unit \quad (3)$$

It is important to highlight that these parameters do not perform alone in reliability analysis, for this reason the focus in this paper is the reliability improvement by the operational center response time decrease, that affect directly the DEC index and the affected consumers. The DEC and FEC indexes were previous calculated to make a benchmark of the previous index, achieved by power utility in the previous year used as forecasting reference.

The realized study evaluates the area of power companies that operates the distribution system, using the contingency and outages historic, for a certain period, herewith the data grid, the proposed method works with the occurrence forecast in a stochastic way.

To validate the methodology effectiveness for a decision-making process to distribution system failures, we compare the occurred events random response and the known outage impact caused by the real events with the prospected impact to the projected and forecasted events.

IV. Case Study

To illustrate the methodology appliance, we tested a database provided by RGE Sul utilities, that include several information assigned to each service order, even the ones that does not result in a power failure.

A. *Parameters*

The database used in this case have a historical data set consisting of approximately 20000 orders, originating in one year of miscellaneous occurrences attendance by a power distribution company at Santa Maria city region. The sample embrace all the service orders that the company provide in 2017.

The valid orders are presented in fig. 2, showing all the orders that represent outage cases, filtered by calculated DEC and FEC that present values bigger than 0 and defined as unknow or not booked occurrences, therefore categorized as emergency type.

These untypical orders result in a base of 7341 orders to analyze as emergencies, pursuant to know the behavior, analyze the prediction and compose the study of forecast.

B. *Forecasting*

Based on the situation of impacts that outages can happen to the grid, the forecasting of emergency orders that resulting in a blackout or outages could help to decrease the indexes and the perform parameters of reliability. To make the forecast are considered the valid emergency orders of all historic database,

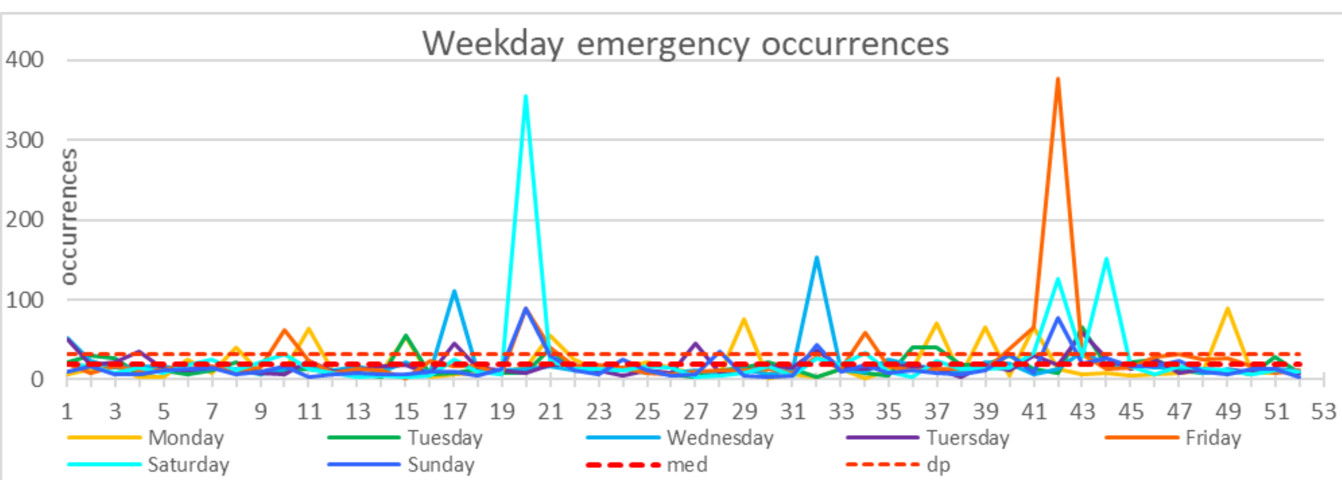

Fig 2. Emergency orders sample ratified by weekday to each week of the year

and all the linked information, as the consumers affected, the outage frequency and the duration of each outage, as well as using the simple regression method, the database report several series. The common behavior of a typical week forecasting is presented in fig 3.

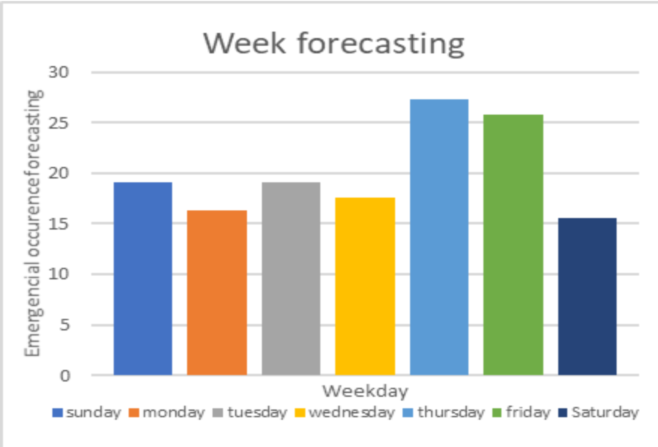

Fig 3. Emergency orders sample ratified by weekday

The behavior of each weekday, the forecast database and, consequently, the predictive orders shows some atypical weeks and some days that present higher variance, which can present a higher error to the forecast of the day. It is possible to analyze in the chart (fig.4) that Thursday have the bigger variation, as well as the higher number of occurrences in comparison to forecasting of the other days of the week. It happened due to critical day of faults at different scenarios in Thursdays of the year analyzed, as well as the low interconnection of the regression forecasting (fig. 9).

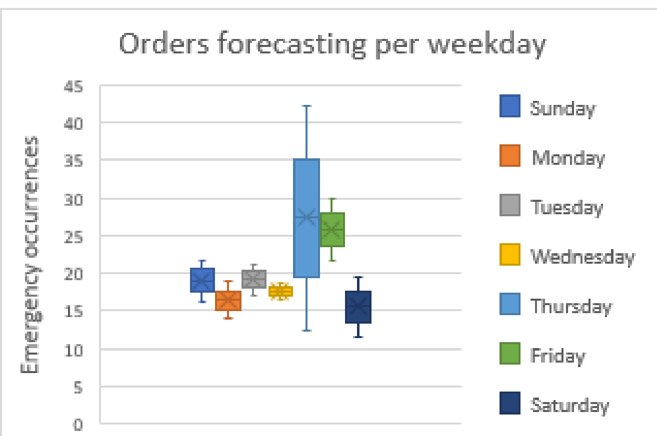

Fig 4. Emergency orders sample ratified by weekday

The followed charts (fig. 6 to fig. 11) shows the predictive model by simple linear regression, with the dispersion of occurrences that result in outages to the role sample, showed the emergency occurrences forecasting to each month to the year analyzed.

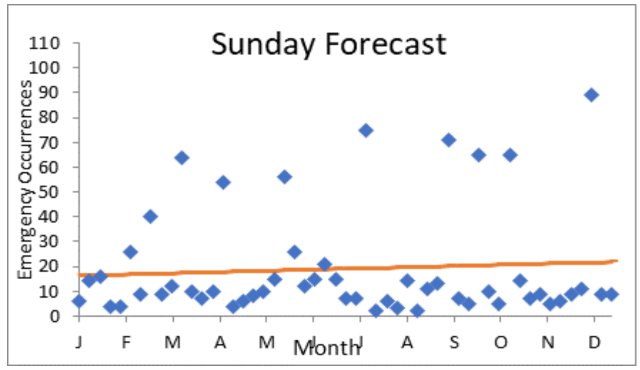

Fig 5. Emergency orders ratified by Sunday and their forecast

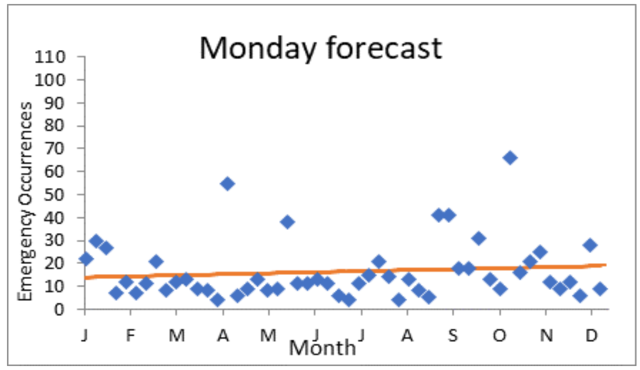

Fig 6. Emergency orders ratified by Monday and their forecast

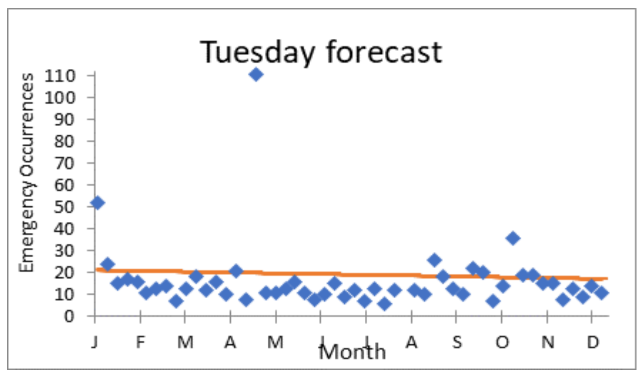

Fig 7. Emergency orders ratified by Tuesday and their forecast

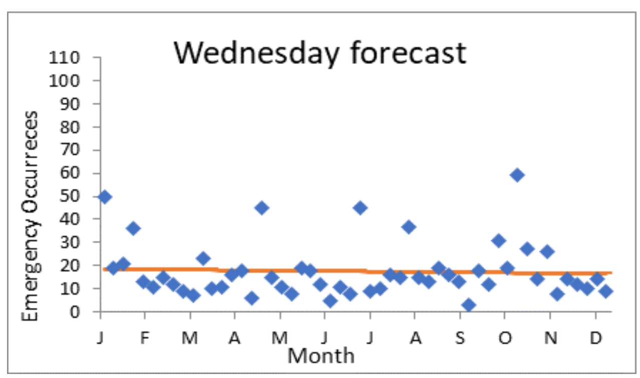

Fig 8. Emergency orders ratified by Wednesday and their forecast

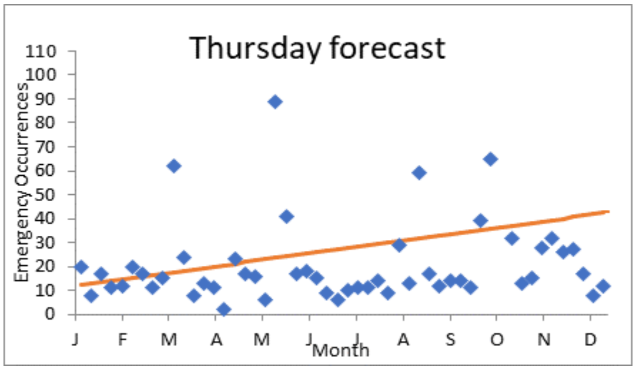

Fig 9. Emergency orders ratified by Thursdays and their forecast

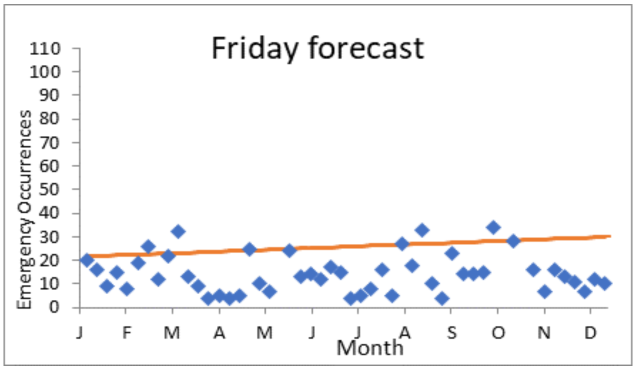

Fig 10. Emergency orders ratified by Friday and their forecast

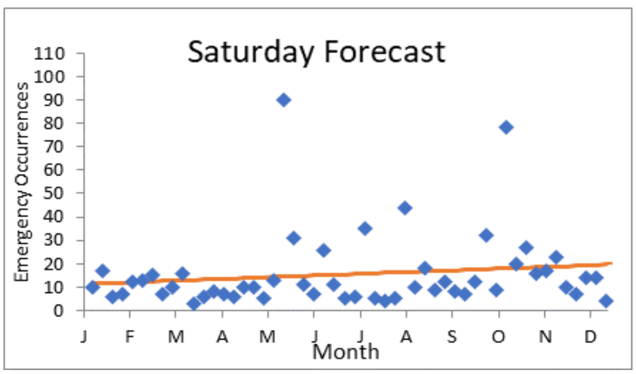

Fig 11. Emergency orders ratified by Saturday and their forecast

C. Impact

Calculated stem from the predictive analysis, that was made for each regarded parameter, the impact was analyzed and calculated to each day of the week behavior. These predictive analyses report the frequency of occurrence in each day, the quantity of affected consumers, the possible location and the duration of outages.

It is possible to analyze the impact of the forecasted outages in Fig. 12 and fig 13, that shows the equivalent duration to affected consumer per unit (DEC) and the number of consumers that will be affected to the emergency occurrences forecasted.

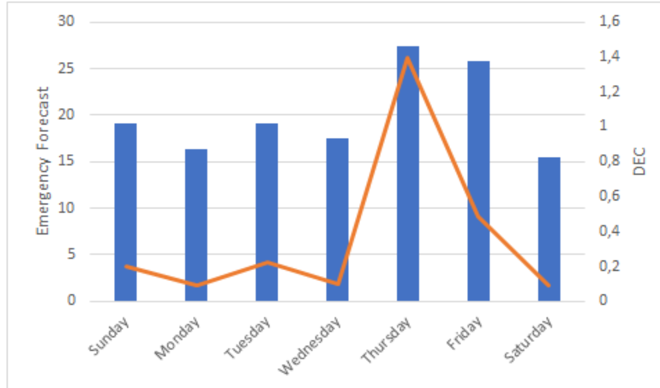

Fig 12. DEC forecasted per weekday

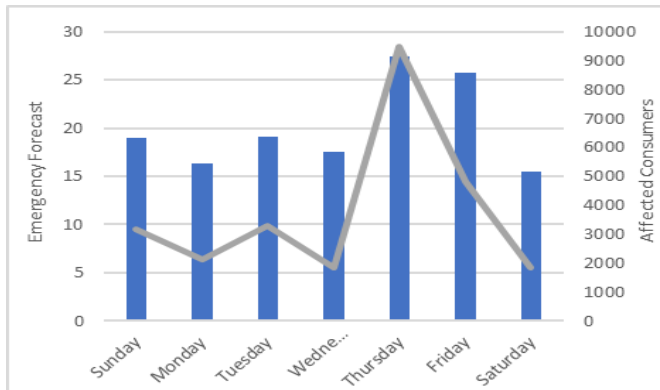

Fig 13. Number of consumers affected by outages per weekday

D. Location

Besides the mentioned indexes of reliability, the location of outages is important to review the impact and to realize the possible outage causes. The spread location of emergency events forecasted (fig 14) state the behavior which describes that the bigger impact and occurrence of outages passes by the downtown and city centers. The chart presents the latitude and longitude points in the utilities area that emergency occurrences forecasted happen.

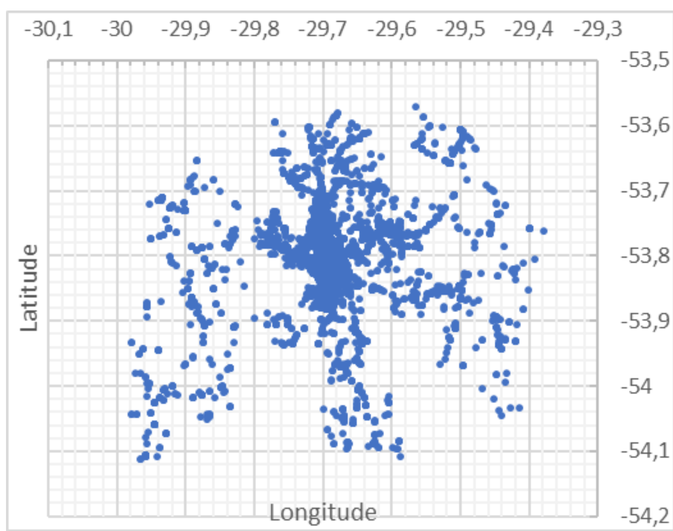

Fig 14. Outages occurrences dispersion at studied area

It is important to highlight that the higher impact occur in city center because the number of consumers is bigger than the outskirts, as well as the majority of trading's business are localized.

The histograms (fig. 15 and fig. 16) confirm that in some points of latitude in the covered region of power utilities studied present more occurrences than the others, as the points -29.699825, -29.727758 and -29.671892. These points present a peak of occurrences, centralizing the outages in a range, meanwhile in longitude points the histogram is flatter, which seems that the spread of longitude points is bigger and the latitude is more centralized.

This behavior corresponds with the location and urban geography of studied city, having a high concentration of buildings and infrastructures, as well as population, in a small range of latitude point and a sparse range of longitude points.

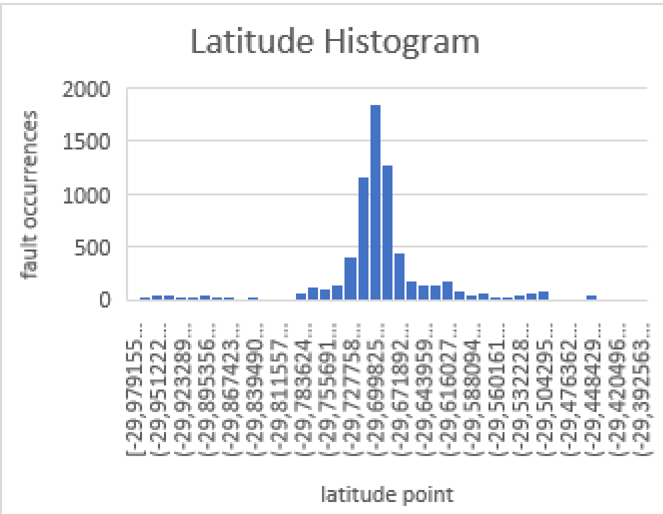

Fig 15. Latitude spread of emergency occurrences forecasted

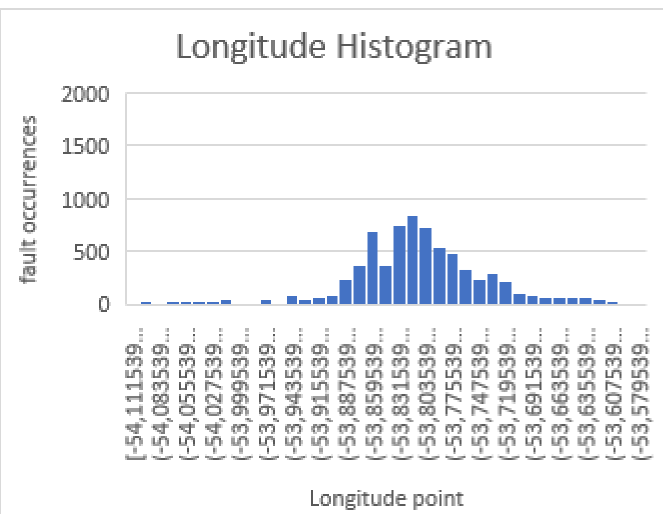

Fig 16. Longitude spread of emergency occurrences forecasted

V. Final Remarks

The methodology presented by this paper contributes with the decision taking embedded the possible location and the number of probable occurrences in each weekday. By the forecasting analysis we can obtain the service time to attend all the orders stratified by each region, also restricted by a time weekday and plan the other type of services. With the result achieved, we can conduct the decision-making process, that define the demanded hours and the staff necessary to attend all the predictive services in the time interval in a grid geographic location, allowing a proactive-routing approach, when it is possible to analyze the causes of each outage.

The main contribution of this methodology is making to increase the accuracy of the forecast, by the treatment of involved data as well as the stratification, resulting in a better making-decision process, updating the variation coefficient in each defined geographic area analyzed. This approach considers the importance of each order in a global aspect, treating the critical ones before the others, to any database or location.

By monitoring the data, it is possible to predict the impact calculating the DEC and the affected consumers amount by the forecasting. The linear regression it is used because the range of data and forecast possible with the methodology. With the forecast weekday behavior, the planning accuracy is higher and the impact is knew previously, which contribute to balance the capital invested to each predictive maintenance as well emergency maintenance.

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