FORECAST OF STEADY-STATE VOLTAGE PROBLEMS CONSIDERING SIMULATION AND SOCIO-ENVIRONMENTAL INFORMATION

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ABSTRACT

This article presents the general panorama of the use of multiple sources of information to identify consumers who could receive voltage quality different from the appropriate. It is observed that only simulations of power flow, and consequently levels of voltage, are not sufficient for a good prediction of regions and consumers out of the appropriate levels of steady-state voltage. To work around this problem, adjustments and reforms are made to the distribution networks databases, improving the assertiveness of the simulations. However, the simulations still distance themselves from the ideal model of prediction. Using spatial statistics and machine learning techniques, together with data on voltage measurements of the ANEEL product quality campaign and socio-environmental information, there is a significantly better prediction than the one obtained only by power flow simulations. The predictive results from each model is presented and compared.

INTRODUCTION

To reach the appropriate levels of steady-state voltage for all consumers is an arduous task for power Distributors. The Brazilian National Electric Energy Agency (ANEEL) determines appropriate limits to the levels of voltage in its module 8 of PRODIST, which deals with the quality of the electrical energy, so that infringing them results in compensation for the consumer and, consequently penalty for the power distributor. Therefore, it is in the best interest of the distributors to identify potential customers with inadequate levels of voltage. However, there are countless uncertainties in the process, related to the characterization of distribution networks, consumer information, and also the socio-environmental aspects involved.

This article presents the general panorama of the use of multiple sources of information to identify consumers who could receive voltage quality different from the appropriate. It is observed that the use only of power flow calculation, and consequently levels of voltage, does not prove efficient for the identification of regions and consumers out of the appropriate levels of steady-state voltage, nor of its intensity. To work around this problem, adjustments and reforms are made to the distribution networks databases, improving the assertiveness of the simulations. However, the simulations still distance themselves from the ideal model of prediction. Working around this problem, with the use of spatial statistics and machine learning techniques, together with data on voltage measurements of the ANEEL product quality campaign, there is a significantly higher prediction, observed in the initial results, than the one obtained only by power flow simulations. The great differential of this model, named LUZ model, is in the database used of socio-environmental information, as geographical identification and data of the Brazilian Institute of Geography and Statistics (IBGE) for the forecast of areas that are more likely to suffer voltage problems. Such predictive capabilities are evaluated, sufficient to observe the different between the ideal model, LUZ model and power flow simulations.

EXISTING REGULAIONS

In Brazil, the quality of the product and the service are regulated through Module 8 of the manual of distribution procedures – PRODIST, defined by ANEEL. Among the various aspects considered in this manual, this article is interested in the steady-state voltage.

In general, metrics are defined for standards of steady-state voltage levels. Currently the understanding of ANEEL is that the consumer is entitled to receive compensation from the moment it's observed the violation of proper voltage. The monitoring of electrical energy quality is carried out through indicators, calculated through measurements, and provide a parameter for the evaluation of these phenomena in the electrical network from the comparison of the calculated value with a pre-established reference value.

Reading data and purges

The voltage measurements should be collected considering a period of integralization equal to 10 consecutive minutes, except the readings that are eventually purged. The intervals to be purged consist of those in which there was the occurrence of long-lasting interruptions or short-term voltage variations. The set of measurements to generate the product steady-state quality indicators may have the registration of 1008 valid measurements.

Calculation

Once the value of the measurement voltage has been obtained it may be classified, based on the distance of the reading value in relation to the reference value (in the case of the state of Rondônia 115 or 127 Volts), in three categories: adequate, precarious or critical, as presented in Figure 1. The reference voltage is determined by ANEEL standards for clients connected to the secondary network, or directly with the customer through the contracted voltage for clients connected to medium voltage.

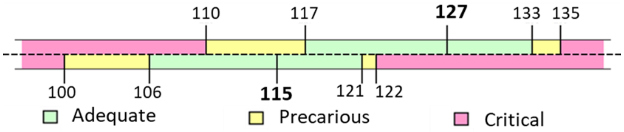

Figure 1:Voltage ranges relative to reference voltage(115/127 V)

Indicators and compensations

Once all the measured values that makes up the set of valid readings are classified, the relative duration of the transgression for precarious voltage (DRP) and for critical voltage (DRC) index are calculated. These indices correspond to the percentage of time, among the 1008 readings, in which the steady-state voltage remained in precarious and/or critical levels, respectively. For measurements involving more than one phase, must be considered the worst values, in other words, which are closest to the critical range.

The exceed of the appropriate voltage limits results in the payment of compensations by the Distributor, as well as other disadvantages. The limits established for the DRP and DRC, in PRODIST, are 3% and 0.5%, respectively.

DATABASES

Aneel voltage measurement (Voltage complaints)

To ensure that the steady-state voltage limits are being adequately serviced, the Distributor has the obligation to carry out steady-state voltage measurements in a random sample of customers, within the continuous period of about a week each, defined by ANEEL. In addition, customers who complain of voltage problems, usually motivated by the malfunction of an equipment, require the visit of a technician to proceed with the following steps: realization of measurement with the multimeter, if confirmed the problem or by requirement of the costumer, a meter must be installed to perform the continuous measurement. The calculations of the DRP and DRC indicators are carried out, even if they have appropriate voltage levels, and the consumer is reimbursed if necessary. It's possible to visualize the regions with higher complaints, where the DRP and DRC indexes were above the limits allowed, in the heat map of Figure 2.

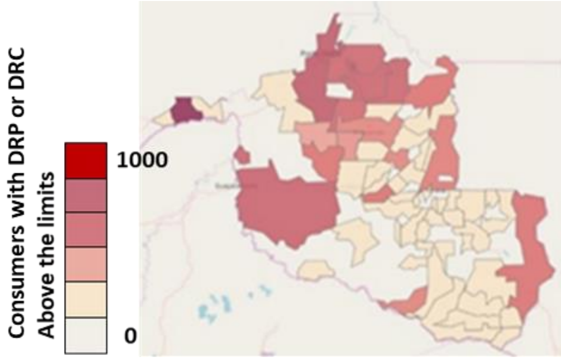

Figure 2: Voltage complains - voltage indexes above the limits.

Measurement campaign for load curve

The measurement campaign is an action carried out by the Distributor once every tariff review cycle of the company, required by the regulatory agency ANEEL, in order to obtain typical loads curves of the company, which will allow the establishment of appropriate tariffs and used as a model for the planning activities. The measurement campaign focuses on obtaining levels of active and reactive energy data. For this, customers are chosen randomly, from various ranges of consumption, in order to enable, through methods of grouping and selection, the creation of typical load curves. In an innovative process, the measurements of the campaign were used, which contained jointly the measuring voltage levels, to evaluate the steady-state voltage, with the benefit of the randomness of the sample. Performing the individual calculation of quality indices (DRP and DRC), it is possible to have an overview of the regions with the highest occurrence of steady-state voltage problems (DRP and DRC index above the limits) of a random sample of consumers, as illustrated in the heat map of Figure 3.

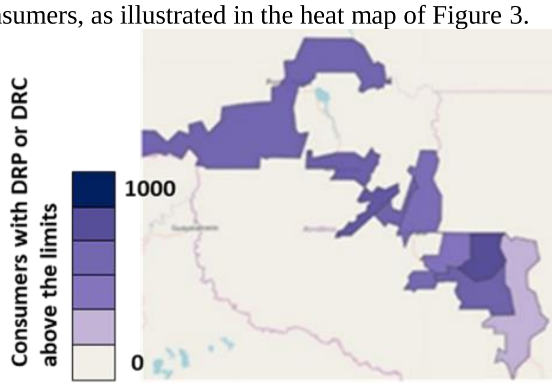

Figure 3: measurement - voltage indexes above the limits.

IBGE

In order to improve the steady-state voltage analysis, the great relevance of socio-economic was found in the project, using statistical tools and machine learning. The database of the 2010 census was used, carried out by the IBGE, with Rondônia. This is the most recent census conducted so far. Due to this interval of time, information contained in the census may be different from the current situation, but it was noticed that this difference can be beneficial, pointing to the growth of the region. The objective was to obtain information as geographically refined as possible and, thus, information was used at the census sector[1]level such as: household income; proportion of households without electricity; with electric power but without meter; with open-pit sewage; with sewage connection to the general network, septic tank or other "alternative" forms of sewage; streets without public lighting; and without streets paving.

Electrical network databases

It is common for Distributors to possess databases containing detailed technical data of their electrical networks, each company with its format. In the case of the state of Rondônia this database contains information on more than 500,000 consumer units under the company's distribution. It provides information on the electrical distribution network, such as cable length, resistance, transformers, etc. These data are used for the creation of simulated network, calculation of power flow, voltage levels, etc. Among the variables relevant on the subject addressed, can be quoted the number of total consumers (by feeder) and the extension of the electrical network.

Power Flow

From the electrical databases it is possible to create the simulated electrical network for calculating the power flow. With the result of this calculation, a relevant variable is the one related to the demand and simulated indicators of DRP and DRC, based on the simulations of voltage levels. The calculation of power flow is carried out several times, each with specific alterations, described later.

Corporate database

Power distribution companies need to have databases containing, mainly, monthly energy consumption information, invoicing, and correlation with the consumer. However, in practice these databases have a much greater level of detail about the consumers. Among these various information, three aspects are important for the analyses, being two crucial to improve the estimation of precarious regions in the subject matter of voltage wave quality: georeferencing, historical consumption (measured energy and monthly invoicing), in addition to information that ensures a greater detail of each individual consumer, such as class of consumption, among others.

Feeders metering

Most of the distribution substations have individual measurements for each feeder and/or at least measurement after the distribution transformer. These measurements are useful for comparing the energy that came out of the substation with that provided to consumers, plus electrical losses. Any differences are indicators of errors, like registration (from the distribution network or consumers), or measurement. However, in Brazil the reality of energy losses due to theft is significantly high in some regions.

STATE ESTIMATOR

To refine the simulations, both for power flow and voltage levels, it is necessary to adjust the flow of energy along the distribution feeders as close as possible to reality, since there are no measurements along the feeders or MV/LV transformers. On one side there are measurements of demand and energy from the distribution substations, on the other there are consumer energy measurements for cycles of approximately a month. However, each consumer has initial dates of these measurement cycles, different from the substation. It creates an impasse due to the difference in cycle dates. The solution used is already a topic of study of previous R&D project in Rondônia [1], where a module was developed for: definition of typical load curves of the electrical system; adjustment of the energy for each consumer to the same measurement cycle, using typical load curves of each consumption class, called pro-rata calculation; State Estimator and demand adjustment to adjust in a more realistically way the measurements of the substation with the sum of the measurements of all the loads that it supplies.

SIMULATIONS

The registrations, in the corporate system, of the network equipment and consumers are satisfactory and close to reality, but information more detailed as TAP of the MV/LV transformers and voltage regulators are not usually faithful to the reality observed in field. In addition, different systematic registration errors impact significantly the identification of customers with voltage problems, such as a secondary voltage register different from practiced in the field. These errors usually have little impact for planning of the future electrical network, however for the study of voltage become critical. A reliable simulation of the voltage levels of all consumers is far of being a reality of Brazilian distributors.

Furthermore, the Brazilian reality of commercial losses, arising from the energy theft, is fairly high in some regions, creating one impasse for voltage simulations, as it is not possible to identify, at the level of the MV/LV transformers, where the power thefts are occurring, based solely on the register. By circumventing these problems, there were tested four approaches to perform simulations of voltage levels. For this it was used the simulation and planning software Sinapgrid, which has already incorporated the module of state estimator developed in the previous project of Rondônia [1]. The initial four approaches, and their descriptions, are listed below:

• Network database directly extracted from the company's corporate system and performed simulations: the

1 Census sector is a territorial unit for collecting census operations, defined by IBGE, with identified physical limits, in continuous areas and respecting the political-administrative division of Brazil. Source: IBGE.

prediction results were not satisfactory, and it was observed that the registration of energy billing consumers is not realistic, since there are several inconsistencies such as zeroed measurements or duplicate measurement. In addition, there are several critical registration errors to voltage analysis that have never been noticed, since they do not influence the common uses of planning and operation of the company;

• Use of pro-rata calculation in the alignment of consumer energy measurements, and state estimator to adjust this energy of consumers (increasing them) based on measurements of the distribution substation: these adjustments did not bring improvements to the prediction of consumers with voltages levels problems. Although these adjustments incorporate in the network the surplus energy measured in the substation, if existent, it cannot be done with the level of detail required for low voltage analysis, due to the absence of more detailed information for such. It is important to emphasize the difference between adjustments for voltage analysis from network planning, which is common to use the maximum energy level and demand, but not necessarily the voltage problems occur at maximum energy and demand levels;

•Use of the billing energy data of the commercial/corporate base for the elaboration of average energy measurements, from 8 to 12 months, depending on the existing period: the characterization of voltage should check a longer space of time, so that any non-common measurements do not compromise the analysis, either due to a consumption abnormally low or high. This approach was possible due to the low seasonality present in the measurements observed in Rondônia. The pro-rata and the state estimator calculations with these new average consumption energy values, extracted from de commercial base, were remade. It is noticed an improvement in the results after this correction, after all, eliminates some measurement errors (which generate, in the simulation, a result contrary to reality).

• Correction of registration errors, impacting the voltage analysis, cited above: there were noticed the presence of typical errors, such as registered voltage different from that practiced in the field (e.g. 440 volts instead of 220 volts, which would drastically reduce the indices of voltage problems in these secondary networks). Moreover, other punctual errors were observed, such as type of MV/LV transformer different from the field. Corrections are important to exclude from the quadrant of simulated problems consumers who in practice have never fled the proper voltage range.

Exploring more of the various errors or inconsistencies in the values of energy imported from corporate systems, the main systematic errors can be listed:

• Outdated registration, where the energy value refers to months or years of difference;

• Energy zeroed due to impossibility of measurement in the previous month. This is a common scenario, for some consumers in the Brazilian environment, due to manual energy measurement, where in the impossibility of reading the meter (due to the difficult access, such as when the internal meter is the blocked, or as rural regions where neither it is always possible to arrive due to rivers and/or closed forest), the reading is postponed to the next month;

• Energy doubly invoiced, due to the impossibility of measuring in the period, described in the above scenario, the energy value is double-registered;

• Big difference between the sum of the energies and all the loads (plus electrical losses) compared to substation measurements. In some regions this scenario occurs due to the energy thefts.

Referring only to energy adjustments through pro-rata calculations and state estimator for the first three cases described above, the energy distribution histograms of all consumers are presented, in Figure 3, to: electrical network imported directly from the corporate system without fixes [A]; this network adjusted with substation measurement [B]; and this network with refinement through the average consumption of the commercial base [C].

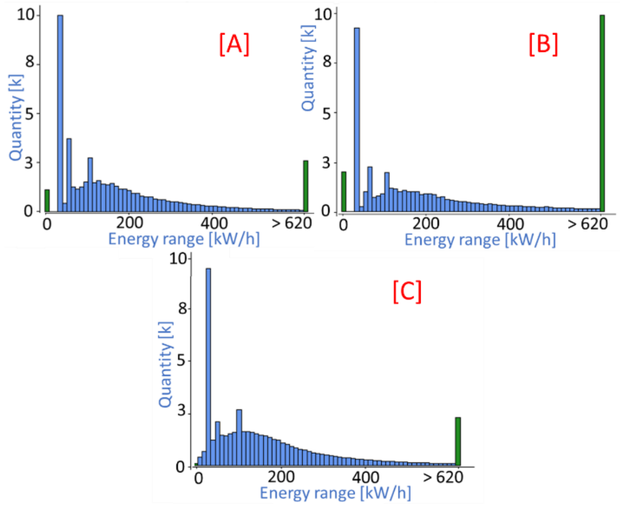

Figure 4: Quantity of consumers per consumed energy range.

It is possible to notice, in all charts, a large number of consumers in a small consumer range, highlighting visually, characterizing the consumers of public lighting that remain connected only in the night period. The first two charts do not use average values of consumption and observe both large quantities of customers without consumption, and a "bumpy" distribution of these consumptions. It is also observed that when the energy is adjusted through the output measurements of the substations some problems are generated, such as loads that already had a high consumption are higher still (shifting the curve to the right), represented by the green column to the right for average consumption higher than 620 kWh/month, resulting in unrealistic values of consumption, in some cases even impossible to close the calculation of the power flow. For the network adjusted only on the consumer side, with the current average billed energy of the commercial database, there is a general improvement in the distribution of the quantity of consumers per consumer range, fixing some of the errors.

STATISTICAL PROCESS

A different approach was studied to estimate regions and/or consumers with probable voltage problems, using machine learning techniques, fleeing the conventional use of only power flow tools, since it did not present satisfactory results, especially for LV consumers. For such, electrical variables (from the distribution network), results from the calculation of power flow and, in an innovative way, socioeconomic variables originated from the census conducted by IBGE, are used to train the model. Through these techniques it is possible to obtain a forecast of the amount of DRC indicator expected for the consumers in the simulated region, called LUZ model.

The Table 1 compares the ability to correct predict the voltage problems by 4 models, where in this simulation there are 50 consumers with steady-state voltage problems (DRC is above the limits). The idea is to predict consumers with voltage problems, where when chosen “n” consumers it is expected to return every consumer with problem of these “n” consumers. That is what happens on the ideal model, where the number consumers returned from the prediction, which really have voltage problems, is equal to the number of chosen consumers, limited by the number of problems in this simulation (50 consumers). The random model is the worst predictive case, hitting only the expected for randomness. Prediction from power flow simulations, with the corrections described in this article, is slightly better than the random model. Finally, the LUZ model shows a much better predictive capacity, where it hits at the beginning approximately 80% of the consumers with voltage problems.

Table 1: comparison of the predictive capacity of the 4 models.

Clients chosen:	Prediction model:			
	Ideal	**Random**	**Power Flow**	**LUZ**
10	10	2	2	8
50	50	10	14	22
100	50	20	23	31
150	50	30	34	38
200	50	40	42	45
250	50	50	50	50

It can be observed that the LUZ model is significantly superior form the power flow prediction, even with correction and optimization of this simulations described in this article, where for the first 10 predictions LUZ forecast model assimilates to the ideal forecast model, leaving great space for research in this field, but the initial results are already surprisingly positive, considering the impact of these social variables and social dispersion (geostatistics) in the calculation of electrical quantities.

POWER FLOW PREDICTION RESULTS

Using the ANEEL complaints database to "train" the prediction, power flow simulations were performed, using all the appropriate methods described in this article, for three substations with approximately 80,000 consumers. Among these, the complaints base indicates 200 individuals in these substations, which 64 have indicators above the limits (this proportion is similar to the complete area of Rondônia). The simulations indicate 37 consumers exceeding the limits of DRP, hitting 14% of those contained in the complaints database. As for DRC, 9 consumers are indicated, hitting 5% of the complaints.

An advance was observed in the quality of steady-state voltage prediction, after the improvements mentioned in the article. It is noteworthy that this ANEEL complaints database is referring to the last campaign, so there is a time interval up to the present time of the study, and some voltage problems have probably been solved, besides complaining of atypical problems.

CONCLUSIONS

The prediction of regions with voltage problems in MV through power flow methods presents a satisfactory accuracy, however for LV some problems restrain this method from being so assertive. This is due to high sensitivity of the quality of electrical data such as TAP of MV/LV transformers and voltage regulators, which have poor registration, not faithful to reality. Thus, this article addressed the use of several databases to perform improvements in the simulations, which some were used in a pioneering way in Brazil. These are used to adjust the energy, correct registration errors, and even used as a control group to train/improve the model. Subsequently, load curves for each consumption class (pro-rata calculation), State Estimator and demand adjustment were used to perform power flow simulations. This process proved to be essential, indicating improvements in the number of assertiveness of consumers with voltage problems, such as the decrease in the number of consumers erroneously indicated as problematic.

Furthermore, it can noticed that in the lack of data it is possible to enrich the analysis with socio-economic data, improving the prediction of steady-state voltage problems. These data, together with statistical and machine learning techniques, presented satisfactory initial results, indicating not only the possibility of using "non-electrical data" to predict voltage problems, but also the need to improve the means used to predict voltage problems, especially for LV, leaving a great space for future studies in this field.

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