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PARAMETRIC STATISTICAL CONTROL APPLIED TO INSTALLED ELECTRIC POWER CAPACITY IN BRAZIL

André Luiz Marques Serrano
Universidade de Brasília, Production Engineering Department
University Campus: Darcy Ribeiro, Asa Norte, Brasília, Federal District
https://orcid.org/0000-0001-5182-0496

Lucas Oliveira Gomes Ferreira
Universidade de Brasília, Faculty of Economics, Administration and Accounting
University Campus: Darcy Ribeiro, Asa Norte, Brasília, Federal District
https://orcid.org/0000-0002-8734-4740

Abstract: The present research investigated the installed capacity of electric energy in Brazil, seeking a pattern of behavior and thus verifying the need to implement or even propose improvements to the production process. Performance was analyzed using some statistical techniques recommended in quality programs, such as descriptive measures, graphs and hypothesis tests. The results showed that the installed energy capacity of Brazilian regions is related to performance and production. Due to the influence of the months, during a period of 9 years (2012-2020), not a single point was detected that extrapolates the control limits. Even with the subjectivity involved in the process, the results found indicated the constant need for monitoring, providing subsidies for improving the process. Thus, the statistical process control can identify to energy distributors if the generators of the system are supplying and have the installed capacity with variables in a state of statistical control.
Keywords: Parametric statistical control, Installed capacity, Electricity, Brazil.

INTRODUCTION

Considering the economic and social importance regarding energy production in Brazil, public and private initiatives were fundamental for the increase and expansion of the energy matrix, with the feasibility of new projects, construction of new production units, expansion of installed capacity and, finally, the consolidation of bodies linked to the segment, with planning and regulation finalities (Serrano et al, 2021). With this aim, attention has been increased in the economy regarding the continuous demand for the parameter "installed capacity of electric energy", this parameter applies to all plants generating this input and represents the largest amount of power that a plant can supply.

According to the literature, installed capacity is defined as measured in MW (megawatts) and has in its projects, plants that are based on the installed capacity to dimension the necessary equipment for its assembly and production. For example, the hydroelectric plants of Itaipu (14,000 MW), Belo Monte (11,233 MW) and Tucuruí (8,535 MW) have the highest installed capacities (Aneel, 2020).

However, this efficiency is considered to be the maximum available power, but as inferred by the National System Operator - ONS, a plant rarely provides its installed capacity, this is due to the brakes imposed by the ONS itself. In addition, electricity transformation processes have losses and technical stops, which also prevent plants from providing their maximum power (Serrano et al, 2021).

Accordingly, the path to excellence has been traced through more elaborate production processes with reduced operational losses (Serrano et al, 2021; Portilho, 2021). With the incessant search for efficiency, there is the competence of the process, which must recognize the level of utility necessary to satisfy the expectations of both consumers and firms, with the purpose of maximizing profitability (Vaccaro, Moraes, CAM, Richter, C.; Fink, D., & Scherrer, 2011; Serrano et al, 2021).

From the understanding of the installed capacity, it must be understood that this instrument is used to refer to the maximum power that can be generated by a certain fuel in a certain country or region. As an illustration, we mention that the sum of the installed capacity of all hydroelectric plants in Brazil accounts for approximately 63% of all installed matrix in the year 2020. With a view to a level of efficiency and quality, it is necessary to recognize the production processes that enable energy generating organizations to decide what to do to meet consumer expectations through reliable and stable processes (Parmar & Deshpande, 2014; Portilho et al, 2021).

Therefore, one of the biggest challenges that organizations that generate and distribute energy have is the dynamic nature of quality, since consumers are increasingly demanding. This forces generators to be innovative in order to maintain productivity and competitiveness, producing inputs with the lowest possible operational loss in order to ensure survival in the market (Belisário, Bahiense, & Oliveira, 2003). Given the context presented, the Statistical Process Control (CEP) aims to discuss the use of a statistical approach to analyze the quality of electricity generation and installed capacity in Brazil, which is considered the best quality tool available to meet the demand. This implementation must be linked to measures to quantify process improvement (Schaeffer, Cohen, Almeida, Achão, & Cima, 2003).

With the objective of confirming the CEP as a tool for verifying how the quality of the installed energy capacity in Brazil has behaved, the parametric Shewhart (1931) charts were searched via Wilcoxon's signposted test. That said, according to the real values of variables for energy production up to the point of maximum power that can be generated by a certain fuel, the different effects of parametric control charts on the data were investigated. Thus, for this study, parametric tests were performed for which the values of the variables studied must have a normal distribution.

The text is structured in five sections, including this first one, which introduces the work. In the second section, a non-exhaustive, but very comprehensive analysis of the theoretical framework that deals with statistical process control, capacity indices and Shewhart's charts (1931) is elaborated. In the third, there is the methodology, where the adopted procedures are highlighted. The fourth section presents the analysis of the study. Finally, in the fifth section, some general conclusions are presented, summarizing the main results of the work. It is noteworthy that this research aims to contribute to the qualification of the service provided, focusing on the potential for cost reduction in production levels without reducing the established quality standards.

LITERATURE REVIEW

Faced with the concept of production quality, there is a process of constant evolution of the characteristics of products and services, which can lead to lower expenditures and increased productivity. Thus, for a given product in the economy to be competitive, it is necessary to have efficiency applicability and a lower production expense, which is obtained through quality control, which can be applied to all sectors of a company, industry or services (Serrano et al, 2021).

However, from the understanding of the applicability of quality in specific segments of the economy, the importance for the energy production sector will be given. Energy, in turn, is considered one of the most relevant inputs for the development and economic growth of a nation. Nowadays, the progress of a State can be directly related to the flexibility of energy generation and installed capacity. The availability of this good implies changes that result in improvements in not only economic, but also social, environmental and institutional dimensions (shaeffer, 2003).

STATISTICAL PROCESS CONTROL *APPLIED TO THE ENERGY SECTOR - INSTALLED CAPACITY*

Statistical techniques have been used in several areas of knowledge, aiming at the optimization of economic resources and production processes, directly related to increasing quality and productivity in research linked by sampling (Backes & Pacheco, 2017). Thus, it is worth noting that the hydroelectric source has been the main source of generation in the Brazilian electrical system for several decades, both for its economic competitiveness and for the abundance of this energy resource at the national level. In the case of Brazil, there is a generating system with an installed capacity of more than 150 GW, predominantly hydroelectric.

This predominance stems from the country's extensive land area, with many plateaus and mighty rivers. The Brazilian hydroelectric potential is estimated at 172 GW, of which more than 60% has already been used. Of the untapped potential, approximately 70% are located in the Amazon and Tocantins - Araguaia hydrographic basins. It is a mature and reliable technology that, in the context of greater concern with greenhouse gas emissions, has the additional advantage of being a renewable source of energy generation (Aneel, 2020; Serrano et al, 2021).

From the point of view of electrical operation, hydroelectric plants are flexible resources, capable of providing a series of services, such as automatic generation control, voltage and frequency control. Many hydroelectric plants have accumulation reservoirs, which make it possible to regulate the flows into the rivers, transferring water from wet to dry periods and, in some cases, from wet to dry years. In addition, its reservoirs can promote different uses of water, such as: flood control, irrigation, industrial processing, water supply for human consumption, recreation and navigation services. The capacity to regulate the reservoirs, given the growing system, has been decreasing in recent years, due to the notorious difficulties in expanding the reservoirs.

Thus, the currently widely used unit of electrical energy is the kWh (kilowatt-hour) or the MWh (megawatt-hour). These are units used to indicate the "power per unit of time" that a power generation plant can produce in a specified time. This production of electrical energy can occur through several sources of generation, among them: thermoelectric, wind, hydroelectric, photovoltaic, thermonuclear, among others. The total installed power in Brazil, as the name says, makes up the sum of the power of enterprises that generate electricity from all sources currently explored. The knowledge of the dispersion of installed generation capacity in the national territory is a relevant topic. Thus, the National Electric Energy Agency (ANEEL) provides the list of the "Installed Capacity per Federation Unit" in Brazil.

It must be noted that plants located on state borders are considered in the total capacity of the state itself. In the case of this research, the table below shows the installed energy capacity in its entirety within the matrices available for the generation of this input between 2012 and 2020, considering the aggregated data and table 1 with the more regionalized aggregated data.

It is worth mentioning that the data are relevant to scientific production applied in different areas of knowledge, among them are linked to the energy production process, metallurgy, engineering and others (Backes & Pacheco, 2017). In industries it is common for engineers to use statistical techniques to monitor the quality control of products within a certain level of acceptance (Ignacio, 2011). However, the number of publications for the segment referring to electrical production is low in terms of quality control. This way, it is concluded that an extensive area exists that has not yet been addressed and needs to be deepened in future research.

	2012	2013	2014	2015	2016	2017	2018	2019	2020
Total	120.975	126.743	133.913	140.858	150.338	157.112	164.503	170.118	174.737
Hydroelectric Power Plants	79.956	81.132	84.095	86.366	91.499	94.662	98.287	102.999	103.027
PCH	4.101	4.620	4.790	4.886	4.941	5.020	5.157	5.291	5.429
CGH	236	266	308	398	484	594	695	768	816
Natural Gas	11.439	12.300	12.550	12.428	12.965	12.980	13.359	13.385	14.927
Oil derivates	7.228	7.515	7.888	8.828	8.845	8.792	7.549	7.670	7.696
Coal	2.304	3.389	3.389	3.389	3.389	3.324	2.858	3.228	3.203
Nuclear power plants	2.007	1.990	1.990	1.990	1.990	1.990	1.990	1.990	1.990
Biomass	9.771	11.449	12.183	13.069	13.913	14.289	14.569	14.703	15.011
Wind Power Plants	1.894	2.202	4.888	7.633	10.124	12.283	15.378	15.378	17.131
Sun	2	5	15	21	24	935	2.473	2.473	3.287
Others	2.035	1.874	1.816	1.850	2.163	2.243	2.188	2.234	2.221

Table 1 - Installed electricity generation capacity in Brazil (MW).

Source: Prepared by the authors (2021).

A BRIEF DISCUSSION ON QUALITY APPLIED TO THE ELECTRICITY SECTOR

Statistical Process Control (SPC) is a quality control approach based on statistical methods with the aim of monitoring processes and thus ensuring that they are running stably and efficiently, producing a greater percentage of compliant products and services with less waste (Subbulakshmi, Kachimohideen, Sasikumar, & Bangusha Devi, 2017). This method works as a preventive rather than corrective mechanism by detecting problems early (Montgomery, 2009; Serrano et al, 2021).

Various scientific studies have implemented different statistical tools and techniques to improve production systems in different industries and sectors such as construction, energy sector, healthcare, manufacturing and so on. In the meantime, CEP is defined as an online quality control system that can be defined as a strategy and methods to improve systems and their results based on the theory of variation due to common and special cause events, as reported by Montgomery. (2009), a reduction in process variability is obtained, allowing monitoring and estimation of parameters, it is also mentioned, the continuous search for efficiency aiming at reducing production problems and guaranteeing diagnostic information (Suman & Prajapati, 2018; Serrano et al, 2021).

In this correspondence, there are common and special cause events, which must be detected and monitored to bring the process back to its control state. Organizations that are CEP-oriented achieve higher levels of performance metrics as an integral component of the quality management system (Albliwi, Antony, & Arshed, 2015). This way, the level of success regarding the implementation of statistical control depends on the congruent planning of the immediate actions taken to solve the problems. With a view to immediate actions to resolve weaknesses in the process, the Statistical Process Control (SPC) uses control letters that support the identification of common or special causes in a process (Awaj, Singh, & Amedie, 2013; Serrano et al, 2021).

Thus, there is a tool that allows an institution to evaluate and thereby systematically reduce the variability of a technique, contributing to continuous improvement and ensuring high reliability results (Ribeiro & Caten, 2012). Thus, it can be applied at all stages of the production and distribution process, thus enabling constant monitoring of quality and identification of variables that negatively destabilize the expected results. It is worth mentioning that several researchers do not mention disadvantages in the application of statistical control, they only point out that the mechanism must be well implemented, because then the financial return that the firm will have will be evident and the side effects will be practically imperceptible, since the main cause of failure in the deployment of statistical tools is linked to wrong execution (Subbulakshmi, et al., 2017).

Specifically, the energy segment, there is the understanding that the statistical control of the process can be the mechanism to minimize possible transversal effects, both in the production and in the distribution of this input to other segments of the economy. Thus, there is a need to use the seven quality tools that will guarantee the improvement of productive capacity in an economic sector that demands large public and private investments (Adinyira, Ayarkwa, & Aidoo, 2014). With these tools, electric power generators and distributors will be able to analyze, control and improve their processes to achieve exceptional business results. The continuous implementation of quality tools has an effect on human capital, as they become better able to think, generate ideas, plan and solve problems.

The seven quality tools play significant roles in monitoring through problem detection and troubleshooting for any production system in order to achieve organizational performance excellence (Montgomery, 2009; Neyestani, 2017). The propositions referring to the quality devices can be implemented with the management tools in an integrative aspect. These tools were implemented in order to reduce defects in the process. Through this effectuation, you can reduce overall defects to a significant level. Consequently, one of the most important devices used is the cause and effect diagram, as it helps to find the causes of defects and eliminate them (Memon et al, 2019).

It is worth noting that some of these quality devices can be used under different phases of the six sigma approach (design, measure, analyze, improve and control) to optimize processes in order to obtain the best level of quality (Lim, Priyono, & Mohamad, 2019). There are also control charts as one of the quality tools that are also considered as tools of the six sigma framework that are used for quality monitoring in all organizational units extensively (Gohel & Sarkar, 2017). In the meantime, these devices help to improve the internal and external environment, as well as the generation and distribution of energy, aimed at both consumers and companies, and this way, there are basic requirements for the adoption of Total Quality Management (TQM) (Magar & Shinde, 2014).

This way, the search to improve the efficiency and autonomy of the installed energy capacity in Brazil, made the country promote structural reforms in its form of operation, considering the influence of the doctrine of the minimal state. As a result of these reforms, the energy generation, transmission and distribution segments are now separated, being managed and operated by different agents (Abradee, 2022). In which, the predominant idea was that free competition could prevail wherever possible, relegating the role of regulation to the state where necessary (Abradee, 2022). Thus, the generation and distribution segments were characterized as competitive segments, given the existence of many agents and the fact that the input, electricity, is homogeneous, as a commodity (Joskow & Schmalensee, 1983).

In turn, the energy transmission sector is considered a natural monopoly, as its physical structure makes competition between two agents in the same concession area economically unfeasible (consumers would pay higher tariffs, a fact that would go against the concept of affordability). tariff) (Abradee, 2022). With regard to electricity generation, it is the segment of the electricity industry responsible for producing electricity and incorporating it into transport systems (transmission and distribution) so that it reaches consumers (Abradee, 2022) and firms. In the Brazilian case, the generation segment is considered dispersed, with 7,250 generating enterprises (Aneel, 2020). A large part of these projects, 3,004, are medium-sized thermoelectric plants, powered by natural gas, biomass, diesel oil, fuel oil and mineral coal (Abradee, 2022). Despite that, practically 64% of the installed capacity in the country is of clean hydroelectric origin, and which produce 63% of the energy generated, with 217 large enterprises, 428 small hydroelectric plants (SHPs) and 696 micro hydroelectric plants (Aneel, 2020). ; Serrano et al, 2021).

With regard to electricity distribution, this is the segment that requires the greatest managerial effort and concentrates most of the innovations in progress in the electricity sector (Santos & Ghirardi, 2003). Additionally, it is characterized by a distribution system that consists of a physical low-voltage transmission network, connected to high-voltage transmission lines or directly to generating plants (Santos & Ghirardi, 2003). The distribution segment interfaces with consumers and represents retail in the captive electricity market (Joskow & Schmalensee, 1983). This system is characterized by: i) each system is a unit, geographically separated and delimited by the locations served; ii) it is composed of thousands of identical pieces, arranged in an appropriate way to the aspects of location; iii) operates in restrictive environments; iv) has direct and immediate contact with consumers; vi) provides multi-products as a function of spatial and temporal variations in demand and the reliability levels of the supplied energy; vii) has characteristics of a natural monopoly due to the existence of economies of scale and asset specificity (Godina, Matias, & Azevedo, 2016).

Therefore, as the demand and geographic range of the serviced area increase, the distribution company obtains economies of scale in the actions necessary to guarantee stability to the system (Santos & Ghirardi, 2003). The main measures are associated with the use of substations, primary distribution lines with higher voltage, maintenance of equipment, interconnections with low and high voltage networks and reduction of administrative costs (Joskow & Schmalensee, 1983). Advances in the area of information and communication technologies prove to be strategic, especially in the activities of monitoring load fluctuations, commercialization divisions and operations management (Santos & Ghirardi, 2003).

STATISTICAL PROCESS CONTROL: PARAMETRIC CHARTS

The parametric tests are based on interval measurements, and the use of these tests requires that some requirements are met, which are normal distribution and homogeneous variance of the data, in addition to continuous and equal intervals. Considering the premise that the frequency distribution of sampling errors is normal, the variances are homogeneous, the effects of the variation factors are additive and the errors are independent. This way, it is very likely that the sample is symmetric, having only one maximum point, centered on the class interval where the mean of the distribution is, and its frequency histogram will have an outline that will follow the bell-shaped design of the normal curve. Therefore, the fulfillment of these requirements condition the choice of using parametric statistics, whose tests are generally more powerful (Hu, 2015; Grover et al., 2017; Díez et al., 2017).

Shewhart's Statistical Process Control defines that the mean and variance of the variables follow the behavior of normal distributions, and that they are independent (Ribeiro et al, 2018). Thus, xi is the data matrix observed in the year: *i*, with p variables in the columns and n*i* observations in the lines and 1 a vector composed of *n*. So, $\hat{\mu}_i$ the vector of averages of the day: i and $\hat{\sigma}_i^2$ the vector of variances of the year: *i* (Ribeiro et al, 2018):

$$\hat{\mu}_i = X_i^t \mathbf{1}\left(\frac{1}{n_i}\right) \tag{1}$$

For the variance and standard deviation vectors: δ_i^2 e δ_i:

$$\hat{\sigma}_i^2 == diag\left(\frac{1}{n_i - 1}\left[x_i^t x_i - \left(\frac{1}{x_i}\right) x_i^t x_i\right]\right); \tag{2}$$

$$\hat{\sigma}_i == \sqrt{\hat{\sigma}_i^2} \tag{3}$$

Therefore, the standard deviation matrix: $M\hat{\sigma}$ and the vector of means of standard deviations: $\hat{\sigma}_{imed}$ are described by:

$$M\hat{\sigma} = [\hat{\sigma}_1; \hat{\sigma}_2; \hat{\sigma}_3; \hat{\sigma}_4; \ldots \ldots \hat{\sigma}_n]; \quad \hat{\sigma}_{med} = M\hat{\sigma}1\left(\frac{1}{n_i}\right) \tag{4}$$

Later, after creating the vector of constants: d3 (*n*) e :

$$d3(n) = [d3(n_1), d3(n_2), \ldots, d3(n_n)]; \quad n_i = [n_1, n_2, \ldots, n_n] \tag{5}$$

Concurrently, the matrix of lower control limits for mean (LIC_{med}) and upper control limits for the mean (LSC_{med}) are checked as follows:

$$(LIC_{med}) = \hat{\mu}_i + \hat{\sigma}_{med} \oplus 1 * \left[\frac{z\alpha/_2}{d_3(n)\sqrt{n_i}} 1\right]^t \tag{6}$$

$$(LSC_{med}) = \hat{\mu}_i - \hat{\sigma}_{med} \oplus 1 * \left[\frac{z\alpha/_2}{d_3(n)\sqrt{n_i}} 1\right]^t \tag{7}$$

With regard to the lower and upper control limits of standard deviations, respectively (LIC_{med}) and (LSC_{med}), are found in the following matrix form:

$$(LSC_{dp}) = \hat{\mu}_i - \hat{\sigma}_{med} \oplus \left[\frac{z\alpha/_2}{d_3(n)\sqrt{n_i}} 1\right]^t \tag{8}$$

$$(LIC_{dp}) = \hat{\sigma}_{med} - \hat{\sigma}_{med}\ z\alpha/_2 \oplus 1\sqrt{\left(\frac{1 - d_3(n)}{d_3(n)}\right)} \tag{9}$$

Therefore, for the central lines of the control charts for the variance, the vector of average variances is used: $\hat{\sigma}_{imed}$,and for the lower and upper limits, considering the sample sizes, we have the matrices: LIC_{DP} e LSC_{DP}, respectively. Thus, the points on the graphs represent the mean values and variances of the data. The central line represents the mean of the mean and the variance. The probabilities of values occurring above the upper limit and below the lower limit of the cards are low. So, since the data are independent, any trend can indicate changes in the system, as well as points outside the control limits (Ribeiro et al, 2018).

METHODOLOGY

Annual samples of installed electricity capacity in Brazil were analyzed according to regions (North, Northeast, Midwest, Southeast and South) between the years 2012 to 2020. As soon as the energy is generated, information on maximum power can be be generated and computed by the national system operator, for a given region of the country, a sample is taken for analysis of the different matrices in random months.

Therefore, the sample size (rational subgroup) also varied monthly. In this

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unbalanced case, the control charts must have a lower control limit (LIC) and upper control limit (LSC) calculated according to the sample size of each month. As there are five monitored regions, a CEP matrix approach was chosen.

The process was considered to be in the initial phase (phase I). According to Qiu (2014), it is in this phase that characteristics that represent the process are verified and it is checked whether these variables are under statistical control. If they are not, actions must be taken to correct the process and new analyzes must be performed to verify that the actions were sufficient to bring the process under statistical control. In phase I, Shewhart control charts are recommended, as they are simpler to make and are relatively capable of verifying large displacements of variables (Qiu, 2014). Therefore, Shewhart control charts, in their parametric approach, were adopted in this work.

The normal distribution has great importance in Statistics, both in practical and theoretical terms. Therefore, if a variable follows a normal distribution, even approximately, the inference about this variable is easily performed, and this is no different for control charts (Qiu, 2014). In the case of controlling means, if these follow a normal distribution, which is predicted to happen by the central limit theorem when the sample size is large enough, control charts via parametric tests must be preferred, as they are more sensitive than tests that are not. parameters (Qiu, 2014).

However, there are several cases where normality cannot be assumed for certain variables. In these cases, several authors report that parametric tests are not reliable. There are indications that when a variable does not follow a normal distribution and standard Shewhart control charts are used, the intervals between out-of-control stops (ARL0) are much smaller than they must be, which is to say that a lot of effort is spent on when the process is under control. In these cases, there are several non-parametric methods that can be used. If the variables have symmetry, a way to delimit LIC and indicated LSC is the sum of flagged ranks (Qiu, 2014).

Therefore, upper and lower control limits of the mean and standard deviation were developed in matrix operations for parametric Shewhart control charts and non-parametric limits, both sensitive to the sample size, the first being indicated for variables that present normality or approximate normality and the second for when the distribution of the variable has not been verified.

Due to the difficulties encountered by the authors in locating the matrix formulas for the matrix control limits, they were defined for scientific dissemination purposes according to topic 2.3 discussed in the theoretical framework.

RESULTS

Normality tests were carried out for the consolidated data over a period of 9 years for the Brazilian regions (North, Northeast, Midwest, Southeast and South), considering a significance level of 5%, for the simulation, the test of Shapiro-Wilk (SW) based on Shapiro and Wilk (1965) which can be applied to samples of size $4 \leq n \leq 2000$. Thus, the S-W normality test assumes the following hypotheses:

H0: the sample comes from a population with N distribution (μ, σ);

H1: the sample does not come from a population with N distribution (μ, σ).

It was verified in table 2 that, for some variables, the data presented p-value above the considered significance level, which is an indication of normality already expected by the central limit theorem, with the average sample size of the sample being approximately 480.

Small values of W_{cal} indicate that the distribution of the variable under study is not normal. Unlike most tables, this table provides the critical values of W_c in which P ($W_{cal} < W_c$) = α (for a one-sided test on the left), which allows us to conclude, at the 95% confidence level, that the sample is obtained from a population with a normal distribution. For the null hypothesis H0 to be rejected, the value of the statistic W_{cal} must belong to the critical region, i.e., $W_{cal} < W_c$; otherwise, we do not reject H0. We do not reject H0 if P >0.05, as shown in the normality test presented in Table 2 below.

In addition, regarding the proof of normality, figure 1 details the test, by Brazilian region.

The skewness coefficient can be used to check whether a data series is symmetric. In Table 3 are absolute values of the skewness coefficient, where values close to zero are signs that the data come from a symmetrical distribution. The symmetry assumption was not fully met. It can be verified that for all variables, at least one region presented an absolute value of the asymmetry coefficient close to 1. This way, Kurtosis and bias are "shape measures" in the distribution of a data series.

Kurtosis and bias are measured as a series of data to which a probability distribution is fitted. Bias or skewness in a data distribution is a measure of the extent to which the data are not symmetrical about the mean. According to Montgomery (2009) the value of asymmetry reveals information in the way the data are distributed. If the skewness coefficient is zero, this indicates that the data are perfectly symmetrical, like the normal distribution. On the other hand, a positive bias "+" indicates skewness to the right, while a negative skewness value "-" is a sign of left bias.

Figure 2 presents the control charts for the means of the variables of interest and figure 3 for the Deviations control charts. It can be verified in the Figure, that apparently, all the variables were controlled.

Therefore, to verify if the samples come from equal or unequal population means, a two-sided test is performed. If the value of the statistic belongs to the critical region, that is, if Tcal < −tc or Tcal > tc, the test offers conditions for rejecting the null hypothesis. On the other hand, if −tc ≤ Tcal ≤ tc, we do not reject H0.

Ho - the sample comes from equal population means; Pv>0.05

H1: the sample comes from unequal population means. Pv<0.05

Next, Figure 4 presents the tests to confirm population means.

Thus and according to the results found (such as p-value North = 0.992; p-value Northeast = 0.995; p-value Southeast =0.875; p-value South =0.999; p-value Midwest =0.997), we found that all Brazilian regions have similar population averages.

CONCLUSIONS

This research investigated the installed capacity of electricity in Brazil, as well as sought evidence of a pattern of behavior of the installed capacity that would make it possible to implement or propose improvements and monitor their effects on the production process. The performance of statistical techniques recommended in quality programs was also analyzed, such as descriptive measures, graphs and hypothesis tests, considering them satisfactory, in line with the research by Gautério and Mattos (2014).

The results showed that the installed energy capacity of Brazilian regions is related to performance and production. Even so, due to the influence of the months during the 9-year period (2012-2020), not a single point was

Variables	Notes	W	V	z	Prob>z
North region	12	0.926	1.225	0.395	0.346
Northeast Region	12	0.914	1.437	0.707	0.239
Southeast region	12	0.892	1.794	1.138	0.127
South region	12	0.889	1.941	1.293	0.098
Midwest region	12	0.940	1.120	0.221	0.412

Table 2 – Shapiro-Wilk normality test.

Source: Prepared by the authors (2021).

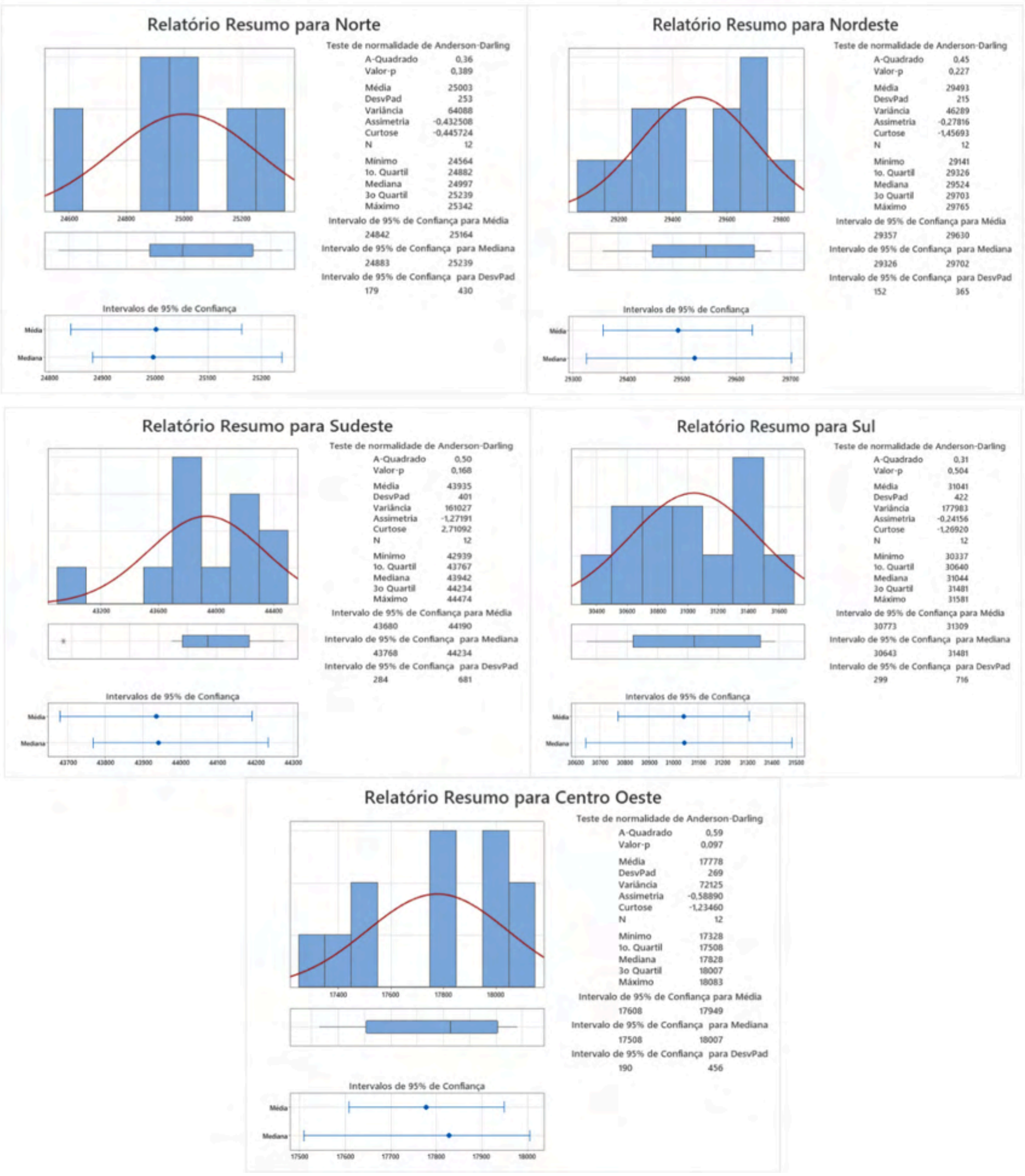

Figure 1 – Graphic test to prove normality; pv> us.

Source: Prepared by the authors (2021).

Variables	Pr (Skewness)	Pr (Kurtosis)	adj chi2(2)	Prob >chi2
North region	0.4801	0.8343	0.57	0.7528
Northeast Region	0.6482	0.1194	3.15	0.2075
Southeast region	0.0487	0.0682	6.42	0.0404
South region	0.3394	0.2313	2.78	0.2488
Midwest region	0.6917	0.2113	2.0	0.3680

Table 3 – Kurtosis Test - Values of the asymmetry coefficients evaluated.

Source: Prepared by the authors (2021).

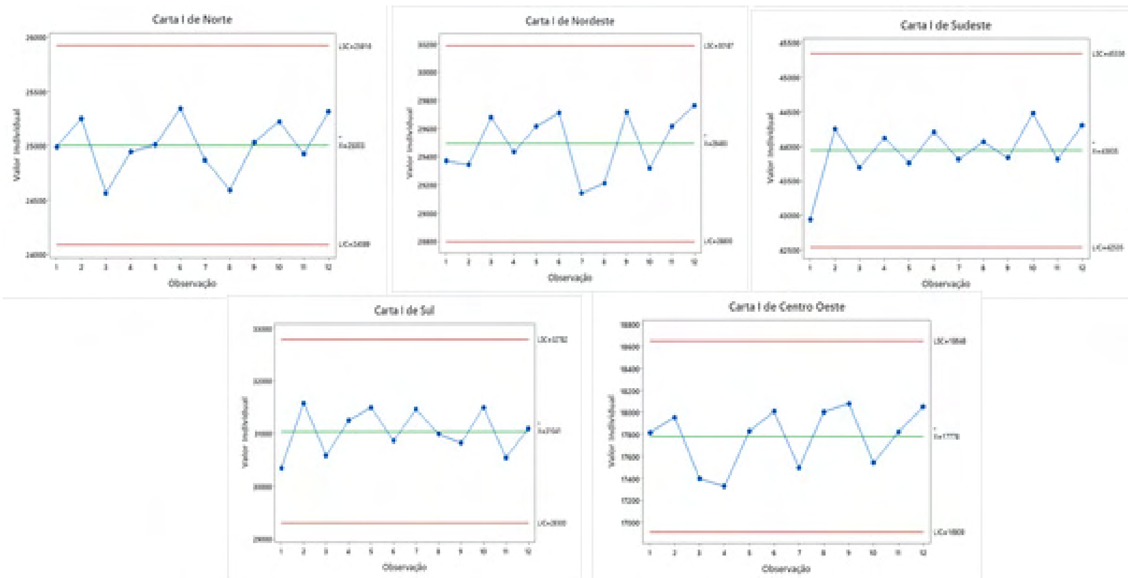

Figure 2 – Test of the average control charts of the variables.

Source: Prepared by the authors (2021).

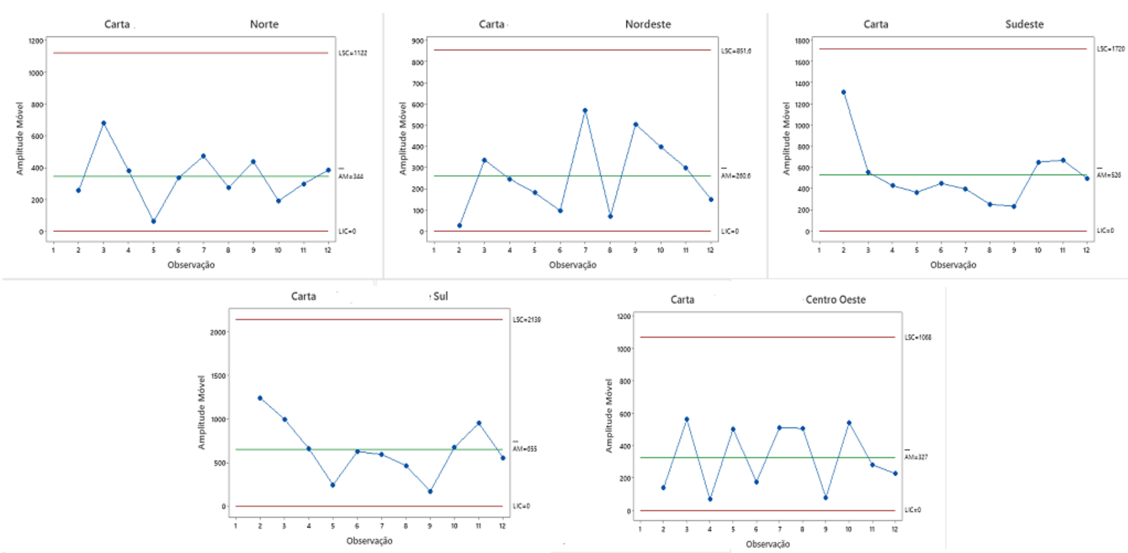

Figure 3 – Test of control charts for deviations.

Source: Prepared by the authors (2021).

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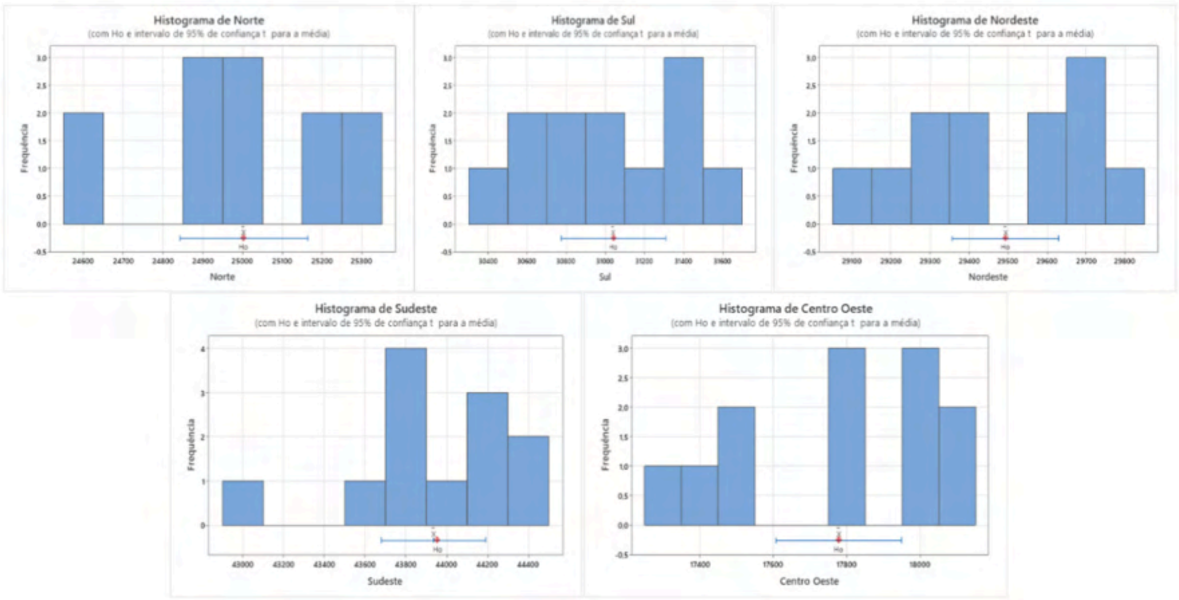

Figure 4 – Test to verify population means.

Source: Prepared by the authors (2021).

detected that extrapolates the control limits. In the individual value and average amplitude control chart, for example, no values were found that extrapolated the control limits. Even with the great subjectivity involved in the process, the results found indicate the constant need to monitor them, providing subsidies for process improvement.

It is concluded with this work, that the statistical process control can identify to the energy distributors if the generators of the system are supplying and have the energy installed capacity with variables in a state of statistical control, in case it is not, they can take actions together with the generators, to bring the variables that describe the installed capacity into statistical control. Here, only five variables were used, north region, northeast region, southeast region, south region and central-west region. The authors suggest the application of control charts as a tool to control the installed capacity of electricity in Brazil, divided by regions, and if normality is verified, the use of parametric tests must be preferred.

According to Montgomery (2009), control charts are considered to be very important tools for CEP, which are based on a surprisingly simple idea: if you follow the production tracks, you can see how it must and must not. behave. Thus, it is considered that these extremely simple ideas, involved in monitoring and control activities, may have been one of the determining factors of the success of quality control. Although many sophisticated techniques have been developed, the use of simple procedures seems to have a satisfactory result (Gautério & Mattos, 2014).

It must be noted that, in order to achieve improvement and control of installed capacity, it is necessary to consider quality from a holistic perspective, executing public and private actions that seek efficiency. Finally, in line with the results of Gautério and Mattos (2014), although the control charts used in this study were considered useful, the possibility of using graphs of accumulated sums for future research is suggested.

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