

Sag Performance of some Brazilian Network Busbars

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Abstract – The Brazilian electric energy market can be characterized as a functionally unbundled model, which implies that generation, transport – transmission and distribution – and commercialization activities are segregated. Considering the ample institutional experience in Brazil, ONS – the exclusive Brazilian Independent System Operator (ISO) – has been working diligently to bring into force all the previous concerns with respect to the question of Power Quality. To this end and with the support of ANEEL – the Brazilian Electric Energy Regulating Agency – ONS has been stimulating a broad debate which market players that require access to the transmission system, government organs, universities and research centers have been taking part in.

Regarding voltage sags and swells, it has been clearly observed that the amount of information readily available in Brazil was not sufficient as to permit conclusions to be safely made. For that reason, a pilot project, a measurement survey, has been initiated. This project has as its prime motivation the quality of power at the end consumer and has striven to achieve the immediate objectives of identifying the main causes and mechanisms of sag and swell propagation in the system, as well as to subsidize the definition and characterization of the phenomenon and its indices.

The main results of the project have made clear that the performance of an homogeneous family of bars follow a log-normal statistical distribution, as the present paper intends to show.

Keywords – Power quality, sag performance, statistical distribution

I. INTRODUCTION

The project has foreseen the selection of survey points spread over Brazil and the installation of measurement instruments. The information thus obtained was supplied to ONS and treated statistically on two levels. Technical analysis of the results have had broad divulgation and were aggregated in order to not permit the identification of the locations involved. On a more detailed level, only the companies involved in the subsystem have had access to the complete information.

The aim of this general program, whose finality was to improve the quality of electrical energy received by the end-consumer, was to reach the following objectives:

- To promote a better understanding of the concepts involved and a leveling among the Brazilian electrical community;
- To subsidize the definitive characterization of the phenomenon;

- To define the adequate indices for the phenomenon, and to recommend reference standards;
- To define the adequate methodology for obtaining these indices;
- To identify the main propagation causes and mechanisms of the phenomenon in the same voltage level and between different voltage levels;
- To publish the performance results on the transmission system bars.

Additionally, by the end of the pilot monitoring program, one intended to reach decisions concerning the statistical sampling criteria; the bus performance analysis and propagation analysis.

The project was divided in areas and each area in subsystems. In each subsystem, bars were selected for measurement. The project covered seven Brazilian states, 28 subsystems, 19 companies and 85 bars, including voltage classes of 11, 13.8, 34.5, 69, 88, 138, 230, 345, 440 and 500 kV.

II. MAIN DEFINITIONS

All the main definitions and recommendations are included in the Grid Procedures. These Procedures contain a set of documents elaborated by ONS together with the agents and whose final version must be approved by ANEEL. They establish the procedures and technical requirements for the implementation, use and operation of the transmission systems and define the responsibilities of ONS and all other players.

According to the Module 2 of Grid Procedures – Performance Standards and Minimum Requirements for the Transmission System – voltage sags and swells are collectively called short voltage variations and are defined as a significant voltage amplitude deviation during short intervals of time. The amplitude is defined as the extreme *rms* voltage value during the variation in pu of a reference voltage at the point considered. The duration of the short voltage variation is defined as the time interval measured from the instant at which the *rms* value in pu crosses a certain pre-established voltage limit up to the instant at which the same variable crosses again the same limit.

In order to better relate the variation to its causes a division of the phenomenon in different band durations has been adopted. Momentary voltage variations are events shorter than or equal to 3 seconds, while temporary voltage variations are events longer than 3 seconds up to and including one minute. In momentary and temporary interruptions all three voltages must be below 10 % of the

nominal voltage.

Taking these considerations into account, the phenomena have been classified as per Table I.

Table I Brazilian classification of the short voltage variations

Classification		Duration d	Amplitude a
Momentary voltage variations	Interruptions	$d \leq 3$ s.	$a < 0,1$ pu
	Sags	1 cycle $\leq d \leq 3$ s.	$0,1$ pu $\leq a < 0,9$ pu
	Swells	1 cycle $\leq d \leq 3$ s.	$1,1$ pu $< a$
Temporary voltage variations	Interruptions	3 s $< d \leq 1$ mn.	$a < 0,1$ pu
	Sags	3 s $< d \leq 1$ mn.	$0,1$ pu $\leq a < 0,9$ pu
	Swells	3 s $< d \leq 1$ mn.	$1,1$ pu $< a$

III. CHARACTERIZATION OF A BUSBAR PERFORMANCE

The parameters duration and amplitude were used to characterize the severity of a certain short voltage variation. The performance of a busbar with reference to this phenomenon was quantified by the frequency of occurrence of pairs amplitude-duration in a given period of time during which the bus has been monitored. These were divided in bands.

In order to make it possible to evaluate the propagation of the phenomenon over the system, the waveforms were recorded, so that the data could be manipulated according to different criteria in the future.

IV. STATISTICAL UNIVERSE

The total survey period was one and a half years. The survey universe for the pilot project comprised 745 point.months, divided as shown in Table I

Table I Survey universe

Voltage class	Points	Point.months
11-34.5 kV:	24	21
69-88 kV:	20	182
138-161 kV:	21	159
230 kV:	12	115
345 kV:	4	48
440-500 kV:	4	10

V. AVERAGE SAG AMPLITUDE OCCURRENCE DISTRIBUTION

Fig. 1 presents the absolute frequency distribution in occurrences/month of sag amplitudes detected by voltage class. The frequency distribution for the busbars with voltage less than 230 kV correspond to the average of the 65 busbars included in the survey, while the distribution for the busbars with voltage equal to or greater than 230 kV correspond to the average of the 20 surveyed. To illustrate, busbars with voltage less than 230 kV presented in aver-

age about 1.7 sags of amplitude below or equal to 0.7 pu per month, while busbars with voltage equal to or greater than 230 kV presented in average approximately 0.7 sags of amplitude below or equal to 0.7 pu per month.

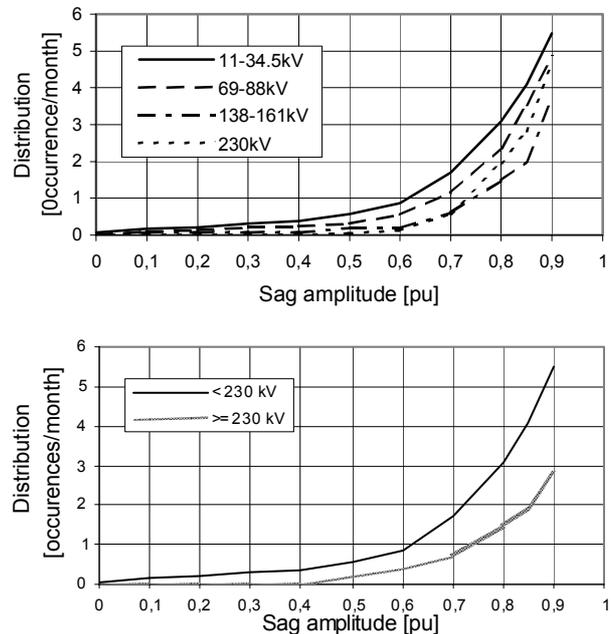


Fig. 1: Average sag amplitude occurrence distribution

VI. MONTHLY OCCURRENCE FREQUENCY

Fig. 2 presents the monthly frequency of occurrence of sags of amplitude equal to or below 0.9 pu. The seasonal behavior is almost the same, independently of the voltage class.

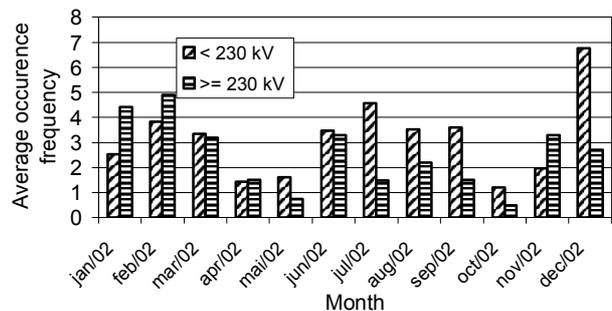


Fig. 2: Average monthly frequency of occurrence of sags of amplitude equal to or below 0.9 pu

VII. DISTRIBUTION OF THE ADJUSTMENT

As said before, each point of the distribution presented in Fig. 1 correspond to the average of a set of busbars (65 < 230 kV and 20 \geq 230 kV). Nothing can be said of the dispersion of this information among the set of busbars.

It has been shown that the outage frequency of a set of transmission lines may be adjusted by a log-normal distribution [3]. Fig. 3 shows a comparison of the actual distribution values and the theoretical log-normal distribution

for 230 kV transmission lies. This results corresponds to five year Brazilian survey. Based on the fact that the probabilistic distribution of the outage frequency of transmission lines follows a log-normal distribution, it was to be expected that the sag performance of busbars came to follow also a log-normal distribution, since the busbar performance is a combination of the performance of the transmission lines. Among the functions tested the one fitted with the least square error was the log-normal distribution.

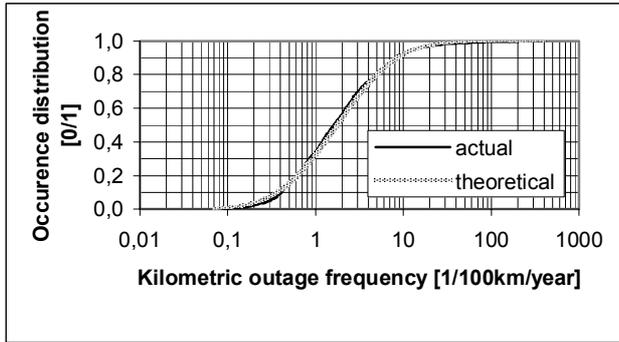


Fig. 3: Comparison of the actual kilometric outage frequency distribution and the adjusted lognormal distribution for 230 kV transmission lines [3]

Figure 4 shows the quadratic minimum value adjustment of a log-normal distribution to the observed sag performance distribution for amplitudes less than or equal to 0.7 pu for the set of busbars surveyed with voltage equal to or greater than 230 kV. decimal logarithm of the indicators corresponding to 230 kV transmission lines. Based on these curves, it can be said that the adjustment has an acceptable margin of error. It was admitted, therefore, that a log-normal distribution adequately represents the individual behavior of a set of busbars.

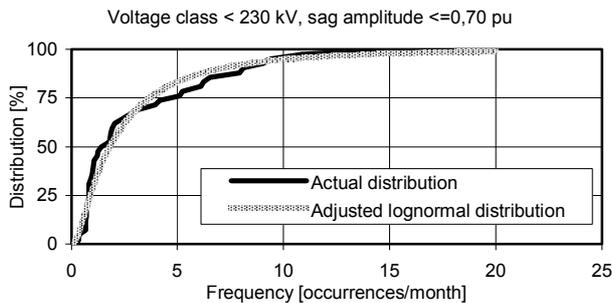


Fig. 4: Comparison of the actual frequency distribution and the adjusted distribution of the performance of busbars

A random variable X has a log-normal probability distribution if the natural log of X has a normal distribution. That is, if the random variable Y defined by $Y = \ln X$ has a normal distribution then the random variable X has a log-normal distribution. This definition is base independent, since the logarithm of any give base a can be represented as a natural log by the application of the relation $\log_a x = \ln x / \ln a$.

The density function of X has the form shown in (2)

$$f_x(x) = \frac{1}{\sqrt{2\pi}\xi} \exp \left[-\frac{1}{2} \left(\frac{\ln x - \lambda}{\xi} \right)^2 \right] \quad (2)$$

for $0 \leq x < \infty$, where $\lambda = E(\ln X)$ and $\xi = \sqrt{\text{Var}(\ln X)}$ are, respectively, the average and the standard deviation of $\ln X$, and are parameters of the log-normal distribution.

Based on the equation above, the probability that X , for $0 \leq x < \infty$, will assume a value in the interval (a,b) is

$$P(a < X \leq b) = \int_a^b \frac{1}{\sqrt{2\pi}\xi x} \exp \left[-\frac{1}{2} \left(\frac{\ln x - \lambda}{\xi} \right)^2 \right] dx \quad (3)$$

The relation between parameters λ and ξ of the log-normal distribution and the average μ and the standard deviation σ of the original distribution is given by the equations below.

$$\lambda = \ln \mu - 0.5\xi^2 \quad \text{and} \quad \xi^2 = \ln \left(1 + \frac{\sigma^2}{\mu^2} \right).$$

Table II presents the parameters λ and ξ (average λ and standard deviation ξ of the logarithm of the values) for the statistical distribution of the sag performance of the set of busbars surveyed divided into two voltage classes: below 230 kV and above or equal to 230 kV. For each voltage class the table indicates the parameters for sag amplitudes: inferior or equal to 0.5 pu, 0.7 pu and 0.85 pu. Based on these parameters, Figs. 5, 6 and 7 present the frequency distribution of the sag performance of a set of busbars.

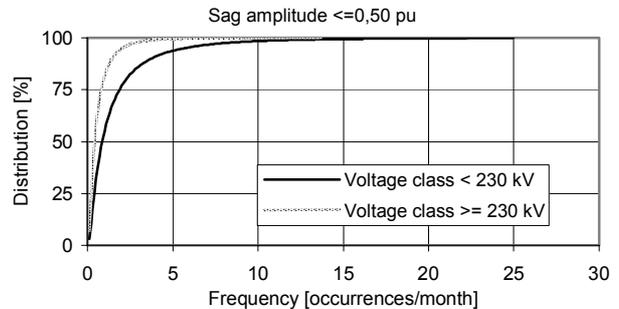


Fig. 5: Theoretical frequency distribution of the sag performance for amplitudes less than or equal to 0.5 pu of a set of busbars

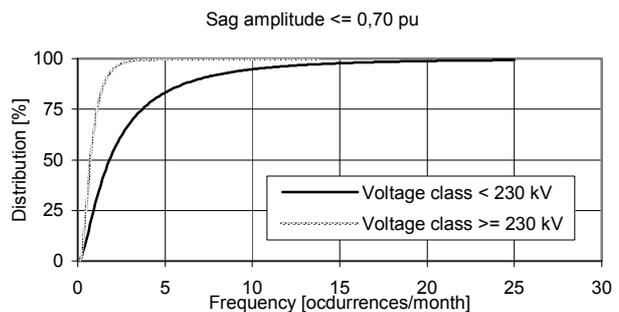


Fig. 6: Theoretical frequency distribution of the sag performance for amplitudes less than or equal to 0.7 pu of a set of busbars

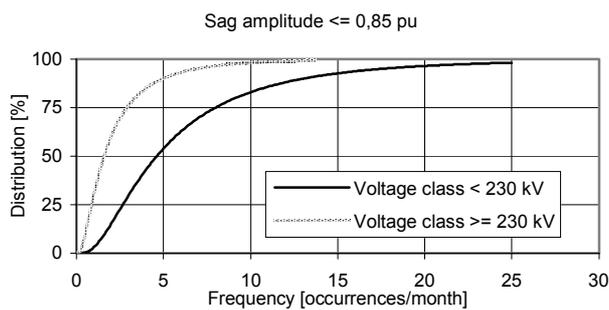


Fig. 7: Theoretical frequency distribution of the sag performance for amplitudes less than or equal to 0.85 pu of a set of busbars

VII. CONCLUSIONS

A log-normal distribution adequately represents the expected behavior of the sag performance of a set of busbars. The parameters in this distribution are the average of the logarithm and the standard deviations of the logarithm of the original values. They can be estimated starting from the average usual parameters and the standard deviation of the original values.

Table II Statistical parameters of the busbar performance

Amplitude [pu]	Parameters			
	Voltage class < 230 kV		Voltage class \geq 230 kV	
	λ	ξ	λ	ξ
≤ 0.50	-0,15	1,15	-0,87	0,97
≤ 0.70	0,60	1,05	-0,34	0,64
≤ 0.85	1,53	0,82	0,46	0,90

In order to better qualify the performance of a given busbar, it is possible to compare its behavior with the distribution of the set it is included. For instance bars included in the first quartile of the distribution can be considered as having an adequate behavior while bars included in the fourth quartile should have its performance seen in more detail.

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IX. REFERENCES

- [1] G.J. Anders. *Probability Concepts in Electric Power Systems*. New York: John Wiley & Sons, 1990.
- [2] D.M. Correia, and D.O.C. Brasil "A Pilot project for the survey of sag performance of the Brazilian transmission system". 10th ICHQP – International Conference on Harmonics and Quality of Power, 6th-9th Oct., 2002, Rio de Janeiro, Brazil.
- [3] D.M. Correia, D.O.C. Brasil, and D.C. Lima. "A Proposal for the evaluation of transmission line performance in a competitive market". 2002 Cigré Session, 25th-30th Aug., 2002, Paris.
- [4] R.J.R. Gomes, D.O.C. Brasil, and J.R. Medeiros. "Power Quality Management as a Goal of ONS - Operador Nacional do Sistema Elétrico - The Brazilian Transmission ISO". 9th ICHQP – International Conference on Harmonics and Quality of Power, Oct. 1-4, 2000, Orlando, Florida USA.
- [5] ONS – Operador Nacional do Sistema, "Procedimentos de Rede, Módulo 2.2 – Padrões de Desempenho e Requisitos Mínimos para as Instalações da Rede Básica (Grid Procedure, Module 2.2 – Performance Standards and Minimum Requirements for the Basic Grid Installations)", Rio de Janeiro, Nov. 1999.