Assessing the Service Rendered by a Power Distribution Control Center

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***Abstract*—This paper presents a methodology based on queuing theory for assessing the service rendered by the control center of a power utility. Stochastic point process modeling is used for representing the sequence of events to be solved by the control center and the control center operator service times. The control center service indexes are computed by means of a procedure of sequential Monte Carlo simulation. This methodology was applied to the control center of Electricaribe, a large power distribution utility in Colombia. Results show that: *i.* In almost all the zones served by the studied control center, the input and service processes are not stationary; thus, a methodology like the proposed one, that can manage stationary and non-stationary processes, is a necessity. *ii.* The power law stochastic point process model is recommended as the first choice for representing the input and service processes because it fits even in those cases of samples with low tendency for which renewal process models could not be fitted. *iii.* The traffic intensity parameter is very helpful because it shows the pattern of utilization of the control center resources and when they will be totally occupied.**

***Index Terms*—Poisson processes, power distribution reliability, queuing analysis, reliability modeling.**

I. Introduction

THE operation of a power system is a challenging task because: *i.* It is composed by lots of components that are dispersed over wide geographical regions. *ii.* The random nature of the events that affect its operation. *iii.* Its non-linear dynamic nature. *iv.* It has to operate continuously meeting requirements of reliability, power quality, safety and security.

Fortunately, advances in communications, electronics and computing have allowed remotely supervising and controlling its operation from a control center. The history of power system control centers is presented in [1]; some visions about of their future are given in [1] and [2].

Control center operators interact with power system components and others actors of power system operation. This is depicted in Fig. 1.

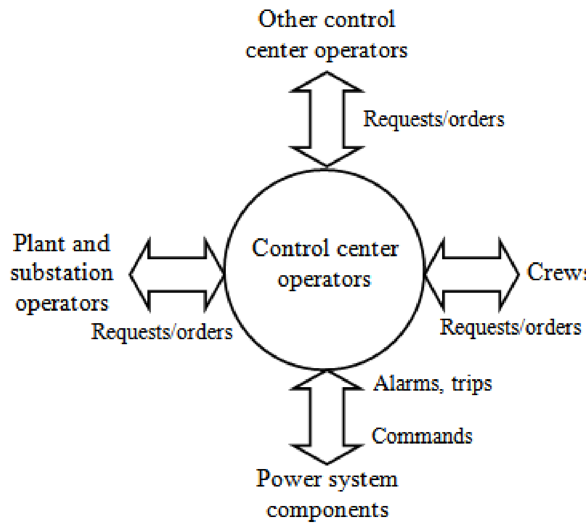

Fig. 1. Interactions of control center operators

Due to the importance of control centers on power system operation and on customer service quality, it is necessary to assess the service they render. For this purpose, a methodology based on queuing theory, stochastic point process (SPP) modeling and Monte Carlo simulation (MCS) is presented in this paper. It was previously applied to the repair process performed by crews in eight Colombian power distribution systems [3], [4].

II. Stochastic Point Processes

A SPP is a representation for a phenomenon in which events occur or "arrive" randomly in time.

Tendency of a SPP is positive if the pattern of event arrivals increase with time, negative if it decreases with time and zero if it does not increase or decrease; the intensity function $\lambda(t)$ controls the tendency of a SPP model.

A classification of SPP models is shown in Fig. 2 [5]. A RP is named after the distribution of the inter arrival times. the most famous RP is the exponential one called Homogeneous Poisson Process (HPP). While there are many NHPP models, the approach here is to use the Power Law Process (PLP) [6] because *(i)*. There are methods for parameter estimation and goodness of fit. *(ii)* It can represent a process with or without tendency.

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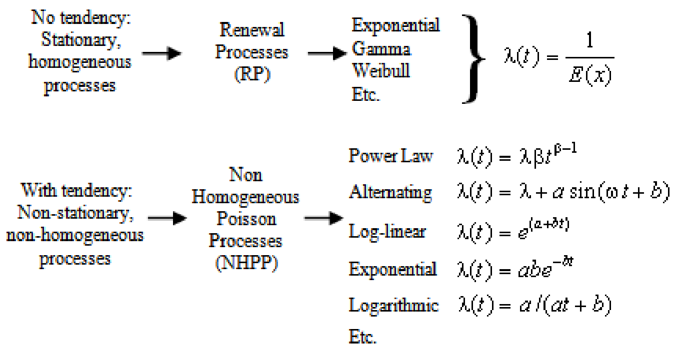

Fig. 2. A classification of SPP models

III. Methodology

A. Modeling

The service rendered by a control center in a service zone can be represented as the queuing system shown in Fig 3.

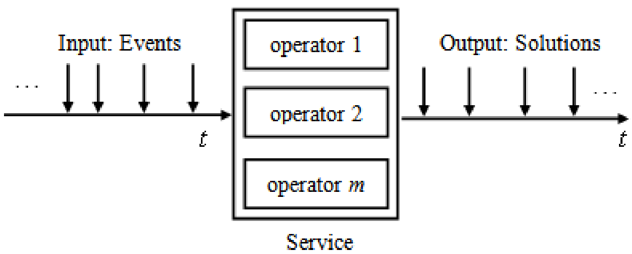

Fig. 3. Queuing model for a service zone of a control center

The input to this system is the sequence events that control center operators have to solve; these include alarms, trips and requests. It is represented by means of a SPP with intensity function $\lambda_E(t)$.

The service is a SPP with intensity function $\lambda_S(t)$ that represents the times to service (tts), i. e. the periods dedicated by the control center operators to solve the events.

The output of this system is the sequence of "solutions", given by the control center operators to the events.

B. The Traffic Intensity

The traffic intensity $a(t)$ is defined by (1).

$$a(t) = \lambda_E(t) / \lambda_S(t) \tag{1}$$

A traffic intensity higher than 1.0 (or 100%) means events arrives faster than the control center operators can solve them; thus, it has then to be less or equal to 1.0.

For the case where the input and service processes are represented by means of PLP models:

$$a(t) = \lambda_a t^{\beta_a} \tag{2}$$

$$\lambda_a = \lambda_E \beta_E / (\lambda_S \beta_S) \tag{3}$$

$$\beta_a = \beta_E - \beta_S \tag{4}$$

The service process performance will be constant if $\beta_a = 0$, deteriorating if $\beta_a > 0$ and improving if $\beta_a < 0$. t_{100} denotes the instant for which $a(t) = 100\%$.

C. Computation of Service Indexes

The service rendered by the control center is assessed by means of the following indexes: The mean waiting time ($\overline{tw}$), the mean event duration ($\overline{ted}$) and the congestion (C).

These indexes are computed by means of a procedure of sequential MCS. As shown in Fig. 4, a simulation consists of N realizations during a period T of one or more years and sub-periods dT_i (week, month, etc.).

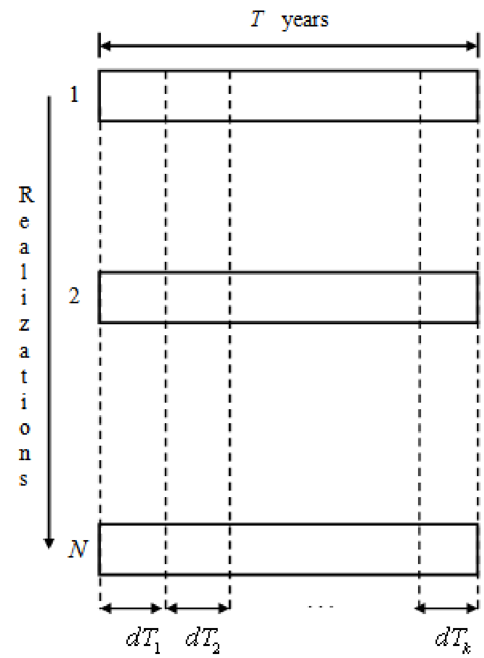

Fig. 4. General procedure of the MCS procedure

As depicted in Fig. 5, in each realization, a sequence of events e_i's and solutions s_i's are generated in order to obtain samples of tw and ted. The period an event i has to wait until an operator is free to solve it is tw_i. The total time required to solve an event is ted_i, the sum of tts_i and tw_i.

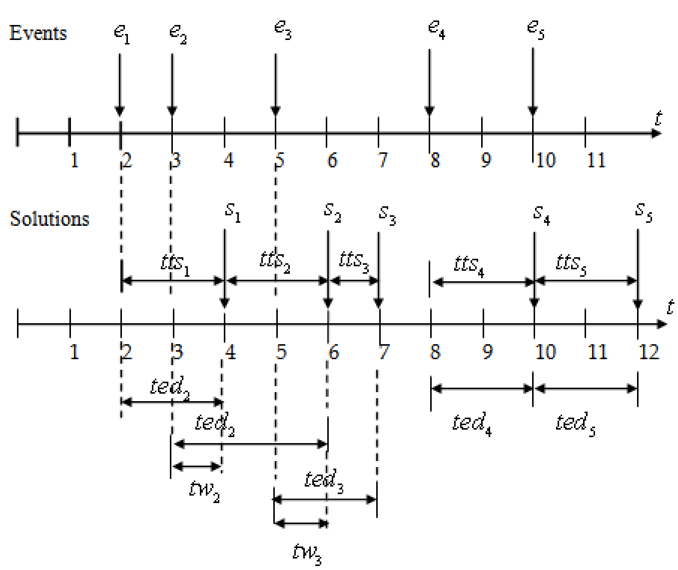

Fig. 5. A sequence of events and solutions in a realization

After performing N realizations the service indexes are computed. C is obtained applying (5).

$$C = \overline{tw} \,/\, \overline{ted} * 100\% \qquad (5)$$

IV. How to Obtain the Input and Service Models

A. Data Samples

The procedure for obtaining the samples for building the input and service models of a service zone is:

1. For a period of at least one year, take the instant of occurrence of each event; this is the sample of arrival instants of the events.
2. For each event, obtain the time to service; this is the sample of *tts* or service intervals.

If two events have the same arrival instant, displace them adding one minute to one of them.

If a control center operator requests the service of an external actor, e. g a crew, the *tts* ends when the request is given. If the external actor calls after to request something like a switching action, this request is treated as a new event.

B. Model Fitting

Fig. 6 shows the procedure applied for fitting a SPP model to a sample of size n. x_i denotes an inter-arrival interval and t_i an arrival time. More details are given in [4].

Tendency is checked by means of (6) and (7), the Laplace and Lewis-Robinson statistics which are normally distributed.

$$U_L = [(\frac{1}{n-1}\sum_{i=1}^{k} t_i) - \frac{1}{2}t_n] / [t_n\sqrt{\frac{1}{12(n-1)}}] \qquad (6)$$

$$U_{LR} = U_L * s_x / \overline{x} \qquad (7)$$

s_x and $\overline{x}$ are, respectively, the inter-arrival times standard deviation and mean.

U_L and U_{LR} are compared to $z_{\alpha/2}$, the value in the standard normal distribution for a critical probability α, in order to hold or reject the null hypothesis of no tendency.

Independency of the inter-arrival times sample is checked by means of the scatter diagram.

Goodness-of-fit to the PLP model is checked by means the TTT-plot. Goodness-of-fit to HPP, Weibull RP, Gamma RP and the Lognormal RP is checked by means of the Kolmogorov-Smirnov (KS) test.

The parameter of RP models is estimated before the application of the KS test using (8).

$$\hat{\lambda}(t) = n / t_n = 1 / \overline{x} \qquad (8)$$

The PLP parameters are estimated after the application of the TTT-plot test using (9) and (10).

$$\hat{\beta} = (n-2) / \sum_{i=1}^{n} Ln(t_n / t_i) \qquad (9)$$

$$\hat{\lambda} = n / t_n^{\hat{\beta}} \qquad (10)$$

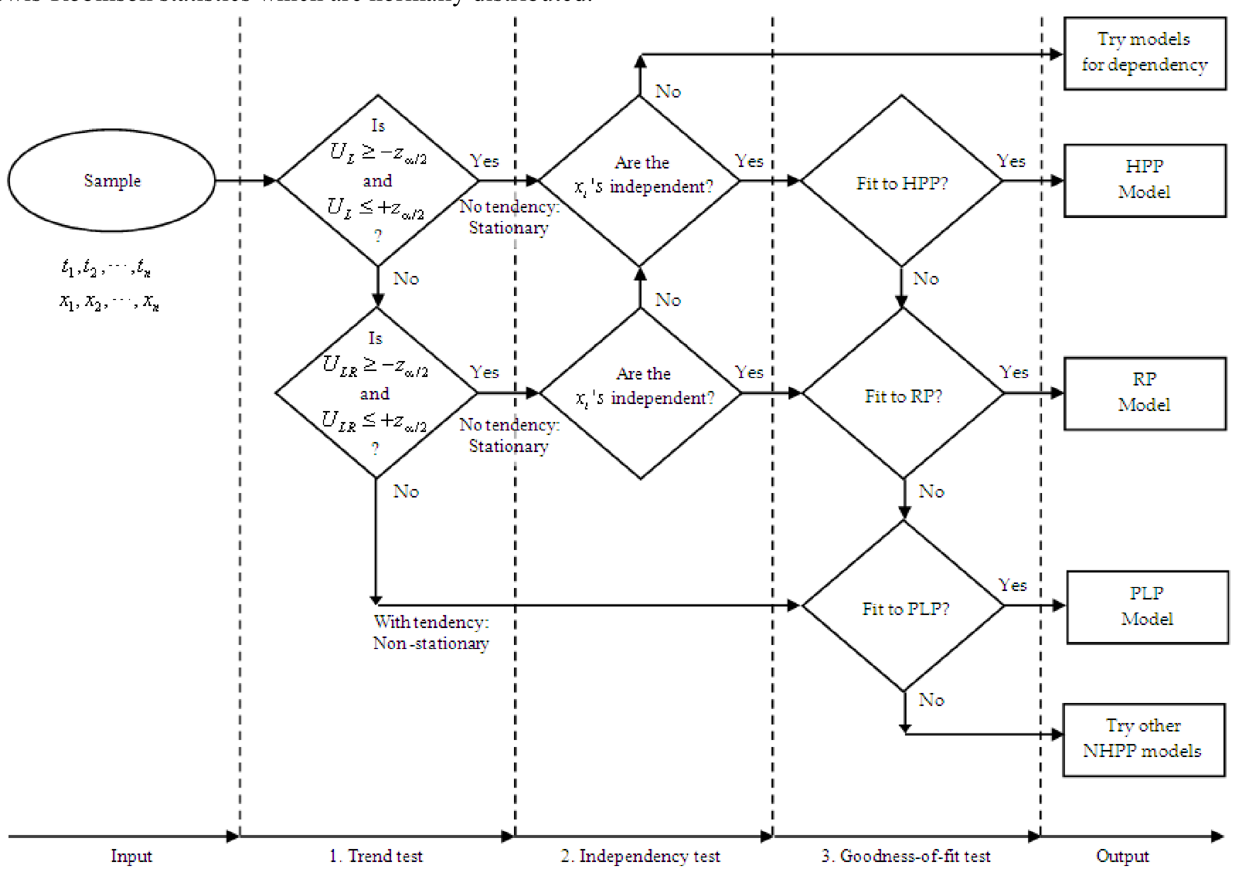

Fig. 6. Procedure for fitting a SPP model

V. Electricaribe and its Control Center

Electricaribe is a power distribution company that serves the population that lives in the Colombian Atlantic Region; this region is shown in Fig. 7. Table I shows some data about this utility.

Fig. 7. Service territory of Electricaribe

TABLE I
General Data of Electricaribe

Item	Year	Description
Service territory	2011	Departments of Cordoba, Sucre, Bolivar, Atlántico, Magdalena, Guajira and Cesar
Area of service territory	2011	132,288 km^2
Population	2005	9'677,044
Customers	2010	2'011,446
Annual energy	2010	11,222 GW-hour
% of national demand	2008	19.13%
Substations	2009	233
13.8 kV feeders	2009	590
34.5 kV feeders	2009	113
MV lines	2011	28,100 km
HV lines	2011	1600 km

Notes:
1. MV includes 13.2 and 34.5 kV
2. HV includes 66, 110 and 220 kV

Electricaribe is the third largest power distribution company in Colombia. Its control center is located in the city of Barranquilla, the fourth most populated city in Colombia (Approximately 1'800,000 inhabitants in its metropolitan area).

Table II shows a general description of the service zones defined for the control center of Electricaribe.

TABLE II
Service Zones of Electricaribe Control Center

Zone	Operators	Description	
Atlántico	1	MV system in the Department of Atlántico	Substations and feeders operating at 13.2 and 34.5 kV
Bolívar	1	MV system in Department of Bolivar	
Norte	1	MV system in departments of Guajira, Magdalena and Cesar	
Occidente	1	MV system in Departments of Cordoba and Sucre	
Caribe	1	HV system in the Departments of Atlántico, Magdalena, Cesar and Guajira	Substations and transmission lines operating at 66, 110 and 220 kV
Costa	1	HV system in the Departments of Bolivar, Sucre and Cordoba	Substations and transmission lines operating at 66, 110 and 220 kV

VI. Results

A. Input and service models

Table III shows the input and service models that were built using operating data of year 2009.

For a confidence level of 95% (Critical probability $\alpha = 5\%$), $z_{\alpha/2} = 1.967$ is the reference value to accept or reject the null hypothesis of no tendency.

As can be observed, almost all input and service processes are non stationary.

The PLP model could be fitted for all samples, even for those with low tendency.

In all cases, t_{100} is very large what means that the traffic intensity parameter will never be 1.0, i. e. the resources will never be 100% occupied.

TABLE III
Power Law Models for Input and Service

Zone	Events	Input process		Service process		Traffic intensity	
		U_L U_{LR}	Parameters	U_L U_{LR}	Parameters	Parameters	t_{100} [years]
Atlántico	12278	-19.3146 -9.7797	$\lambda_E = 58.9258$ $\beta_E = 0.9050$	-0.5984 -1.2659	$\lambda_S = 223.537$ $\beta_S = 0.9957$	$\lambda_\rho = 0.239594$ $\beta_\rho = -0.0907$	----
Bolívar	10806	+7.3399 +4.0717	$\lambda_E = 14.4262$ $\beta_E = 1.1219$	-1.9901 -4.5088	$\lambda_S = 215.1886$ $\beta_S = 0.9786$	$\lambda_\rho = 0.076857$ $\beta_\rho = 0.1433$	$1.6362e+05$
Norte	19026	+4.7185 +2.6229	$\lambda_E = 35.0032$ $\beta_E = 1.0675$	-0.3980 -1.0218	$\lambda_S = 190.7639$ $\beta_S = 0.9960$	$\lambda_\rho = 0.196662$ $\beta_\rho = 0.0715$	$2.0689e+07$
Occidente	16343	+4.6892 +2.3233	$\lambda_E = 26.8505$ $\beta_E = 1.0867$	-0.3377 -0.7526	$\lambda_S = 189.2783$ $\beta_S = 0.9886$	$\lambda_\rho = 0.155934$ $\beta_\rho = 0.0981$	$4.6186e+05$
Caribe	7845	+3.4647 +1.8835	$\lambda_E = 13.7992$ $\beta_E = 1.0752$	-0.2038 -0.4878	$\lambda_S = 176.4114$ $\beta_S = 0.9927$	$\lambda_\rho = 0.84722$ $\beta_\rho = 0.0825$	$2.7019e+10$
Costa	7929	+4.8636 +2.5715	$\lambda_E = 10.5056$ $\beta_E = 1.1232$	-0.2039 -0.4862	$\lambda_S = 197.683$ $\beta_S = 0.9949$	$\lambda_\rho = 0.059997$ $\beta_\rho = 0.1283$	$9.1464e+06$

Notes:
1. Units of the scale parameter of input and service processes are [Failures/day] and [Repairs/day], respectively.
2. Confidence level of 95%

B. Service Indexes

Table IV shows the service indexes for $T = 1.0$ year. As can be seen, the waiting time is very low in all service zones.

TABLE IV
Service Indexes for $T = 1.0$ Year

Zone	$\overline{tts}$ [Minutes]	$\overline{ted}$ [Minutes]	$\overline{tw}$ [Minutes]	$\overline{C}$ [%]
Atlántico	6.5494	7.7510	1.2016	15.5021
Bolívar	7.2867	8.5926	1.3058	15.1971
Norte	7.6879	10.6735	2.9856	27.9723
Occidente	8.0005	10.6780	2.6775	25.0750
Caribe	8.3829	9.5917	1.2088	12.6021
Costa	7.4214	8.3689	0.9474	11.3210

VII. Required Computational Time

An important aspect of every simulation method is to have an idea of the required computational time.

Table V shows required computational time for assessing the performance indexes of the service zones.

TABLE VI
Required Computational Time for Assessing the Service Indexes

Realizations	Events/year	Zone	[Hours]
150	12278	Atlántico	9.6729
	10806	Bolívar	8.9130
	19026	Norte	22.6973
	16343	Occidente	16.9846
	7845	Caribe	3.9345
	7929	Costa	5.3533

Fig. 8 shows how the required computational time grows exponentially with the number of events to be processed. This is a disadvantage of all assessment methods based on MCS; however, it is mitigated by the fact that every day computers with higher performance are more affordable.

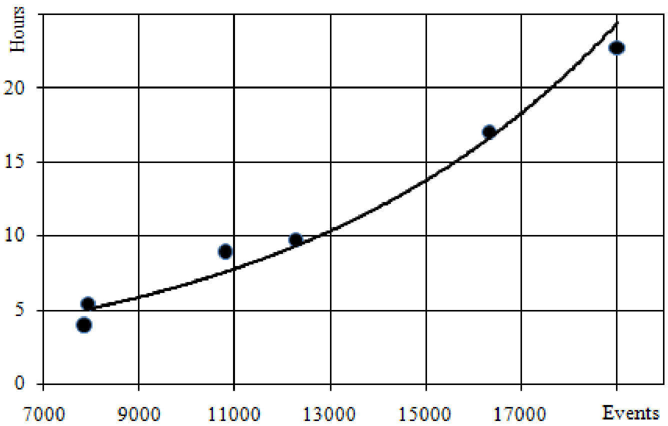

Fig. 8. Required computational time

VIII. Conclusions

1. In almost all the service zones served by the control center of Electricaribe the input and service processes are not stationary; thus, a methodology like the proposed one, that can manage stationary and non-stationary processes, is a necessity.
2. The power law stochastic point process model is recommended as the first choice for representing the input and service processes because it fits even in those cases of samples with low tendency for which renewal process models could not be fitted.
3. The traffic intensity parameter is very helpful because it shows the pattern of utilization of the control center resources and when they will be totally occupied.

IX. References

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X. Biographies

Carlos J. Zapata obtained his BScEE degree from the Universidad Tecnológica de Pereira, Pereira, Colombia, in 1991 and his MSc and PhD degrees from the Universidad de Los Andes, Bogotá, Colombia, in 1996 and 2010, respectively. From 1991 to 2001 he worked for Concol S. A, Bogotá, Colombia, where he participated in projects of power system studies, electrical designs and software development. Since 2001, he has worked for the Universidad Tecnológica de Pereira.

Johan Urrea obtained his BScEE from the Universidad Nacional de Colombia, Medellín, Colombia, in 1999 and the degree of specialist in transmission and distribution power systems from the Universidad de los Andes, Bogotá, Colombia, in 2011. Since 2000 he has worked for Electricaribe S. A.