Evaluation of Power Flow Variability on the Paraguaná Transmission System due to Integration of the First Venezuelan Wind Farm

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***Abstract*— The integration of Paraguaná wind farm imposes several challenges on the operation and control of Paraguaná transmission system. An assessment of the power system variability is imperative for the planning of the essential system reinforcements. The objective of this paper is to evaluate the variability of power flows on the Paraguaná transmission system due to the integration of the new 100MW Paraguaná wind farm. Stochastic power flow based on Monte Carlo simulations is employed to assess the variability. The stochastic system model created is based on real measurements of the loads and local generation in the Paraguaná transmission system and real wind speed data. Simulation results have demonstrated that the integration of this wind farm leads to an increase in the variability of the power flows in the system lines and to an increase in the probability of reserve power flows.**

***Index Terms*— Stochastic power flow, transmission system, variability, wind farm, wind power generation.**

I. Introduction

THE Bolivarian Republic of Venezuela has a long history of interest in developing *Renewable Energy Sources* (RES) [1]. In the 1970s *Compañía Anónima de Administración y Fomento Eléctrico* (CADAFE), one of the most important utilities in Venezuela, declared its intention of generating electrical power from non-conventionally used sources, such as coal, nuclear, geothermal and solar energy. Unfortunately, these pilot projects were abandoned due to the economic crisis of 1983. Despite this, a variety of methods were sought to encourage the use of alternative sources of energy. These have ranged from government schemes to partnerships between academia and industry but were limited to pilot projects for the most applications [3]. The need to elaborate on alternative energy sources was intensified by the *National Energy Review* in 1999, where had been decided that the existing hydropower generation should be complemented by other energy sources. The goals set by this review were to be implemented by the *Pilot Project Operative Plan of Renewable Energies* (Plan Operativo de Energías Renovables, *PODER*) which in 2004 has been substituted by the *Renewable Energy Program* (Programa de Energías Renovables, *PER*) [3]. PER was launched under the newly created *Division of Alternative Sources* (División de Fuentes Alternativas, DFA) within the Ministry of Energy and was assigned to fulfill more ambitious goals than PODER in order to meet the Venezuelan commitments arising from the Kyoto Protocol [1], [3].As part of its duties, PER aimed to promote renewable energy sources projects, which had engineered the installation of five wind farms on the archipelagoes and islands of Los Roques, Los Monjes, La Ochila, La Blanquilla and La Tortuga Island [2]. In addition to these projects three wind farms, of utility scale, are presently under development in mainland Venezuela, in La Guajira, La Peninsula de Paraguaná and Pensinsula de Macanao [1], [3].

Although a wind atlas is not currently available for Venezuela, relevant literature [2], [3] has identified some preliminary areas suitable for wind energy projects, such as the Paraguaná area and Santa Cruz de los Taques (or 'Los Taques' as known). During 2007, the wind resources in Páez, in the state of Zulia, were evaluated and a new project was set to develop a 24 MW wind farm (16 wind turbines rated at 1.5 MW each). The third project will be developed in Macanao Peninsula in Margarita Island. The first Venezuelan wind farm called *Parque Eólico Paraguaná (PEP)* will be built on Paraguaná Peninsula and will be in operation by 2012. Moreover, a second wind farm will be developed on the Venezuelan Guajira (Northwest Venezuela).

The integration of the *Parque Eólico Paraguaná* has several implications on the operation and control of *Paraguaná Transmission System*. This non-conventional generation offers a range of uncertainties and are not easily controlled. It is well established that there is nothing simple about operating a power grid penetrated by wind power [4]. The variability and uncertainty of energy resource, and wind,

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constitutes a difficult task for system operators to ensure a balance between supply and demand [5], [6]. The random fluctuating character of the wind energy causes the generation output of a wind farm to be neither continuous nor controllable. The integration of the *Parque Eólico Paraguaná* may result in voltage variations outside the regulation limits, flicker violations. Furthermore other power quality standards would change the line's transmission power and the distribution of the former power flows [7], [8].

The purpose of this paper is to evaluate the variability of transmission lines power flows on the Paraguaná Transmission System due to the integration of the new Paraguaná Wind Farm. Section II describes briefly the analysis method incorporated to calculate the stochastic power flow in the case study whilst Section III presents a description of the Paraguná power system and the wind farm characteristics to be integrated. In Section IV the results obtained are discussed by emphasizing their significance. The main contribution of this paper is the use of real data, including wind data measurements from an appropriate meteorological station, to provide a realistic estimation on the potential consequences on the transmission lines power flows due to the integration of the Paraguaná wind farm. The conclusions of this paper are presented on Section VI.

II. Stochastic Power Flow Analysis

The *Deterministic Power Flow* (DPF) is used to analyze and assess the planning and operating of a power system on a daily routine. DPF utilizes specific values for power generations and load demands on a selected network configuration in order to calculate system states and power flows [9]. The random fluctuating character of wind energy resources causes the generation output of a wind power plant to be slightly controllable but neither continuous. Furthermore, DPF analysis ignores any grid uncertainties, such as outages, network changes and load variations. For these reasons, the deterministic approach is not sufficient for the analysis of modern power systems penetrated by wind power. Consequently the results from DPF analysis may lead to quite different, contradictory, or even erroneous results. The latter may result in tremendous economic and technical impacts. In the *Stochastic Power Flow* (SPF) analysis, the power generation and the grid configurations are both considered as discrete random variables, while the load demand is considered as a continuous random variable [10], [11]. The SPF was firstly proposed in 1974 by Borkowska and Allan [12], to provide a full reflection of the influences on a range of different factors' random variations in power systems. Consequently, any uncertainties concerning the electric load, the generation (especially wind power) and grid parameters could be directly appeased through this method (SPF).

The SPF method can be subdivided in two categories: (i) *numerical approach* and (ii) *analytical approach*. The analytical approach defines a system and its inputs using mathematical expressions: i.e. using convolution techniques, with *Probabilistic Density Functions* (PDF) of stochastic variables of power inputs. That is to facilitate the calculation of the PDFs of stochastic variables of the system states and line flows. Details of this approach can be found on [12], [13], [14].

The numerical approach is to adopt a *Monte Carlo* (MC) method for the SPF analysis. This substitutes a chosen number of values from the stochastic variables and parameters of the system model and performs a deterministic analysis for each value so that the same number of values are obtained in the results [9]. Monte Carlo simulation (MCS) technique is used in [15] to solve the SPF problem including wind farms penetration by repeated simulations. The two main features of MC simulation are: (a) it provides considerably accurate results, but the computation time is consuming for large systems, (b) It can be easily combined with pre-existent DPF programs to create an easy and fast implementation of SPF. In this paper, the approach selected is a SPF based on MSC.

A. Monte Carlo Simulation on Power Flow Problem

In general, the DPF problem elaborates in finding the zero of a set of nonlinear equations emanating from an adequate initial guess. The most general form of the power flow equations is a set of *differential-algebraic-equations* (DAE) in steady-state [25]. Then, the formulation of the power flow equations is reduced to the algebraic:

$$\begin{aligned} &\mathbf{g}(\mathbf{x}) = \mathbf{0} \\ &\left[\mathbf{g}^{\mathbf{P}}(\mathbf{x}) \quad \mathbf{g}^{\mathbf{Q}}(\mathbf{x})\right]^{T} = \mathbf{0} \end{aligned} \tag{1}$$

Where **g** is the set of algebraic equations defining the power balance on network buses and **x** is the state vector. For classical formulation of AC DPF, the *inputs* or known quantities are the injected active powers (P_i) at all busbars (where P and Q or P and V are known) -excluding the slack bus-, the injected reactive powers (Q_i) at all load busbars (where P and Q are known) and the voltage magnitude at all generator busbars (where P and V are *outputs* or known).

$$\begin{aligned} P_i &= g_i^P\left(\delta_1, \delta_2, \ldots, \delta_n, V_1, V_2, \ldots, V_n\right) \\ Q_i &= g_i^Q\left(\delta_1, \delta_2, \ldots, \delta_n, V_1, V_2, \ldots, V_n\right) \end{aligned} \tag{2}$$

Where i = 1, 2, ...,n for n power buses, and non-linear voltage (V) and phase (δ) relationships. A complete explanation for the classical AC power flow can be found in [16], [17], [18].

PLF attempts to obtain *Probability Density Function* (PDF)s of state vector s and line flows for a statistically varying electrical network [19]. P_i and Q_i, are considered by their distributions, usual with binomial repartition with p_i and q_i the probability of up and down states respectively, for each unit generation $P_{g,i}$ .The PDF load $P_{L,i}$ is continuous and normal with m (mean) and σ (standard deviation) [20], [21], [22]. MCS is a method for iteratively evaluating a deterministic model using sets of random numbers as inputs [23]. SPF is solved by using MSC, which involves repeating the DLF simulation process utilising in each simulation a particular set of values of the random variables (loads, conventional and wind generation productions at each node of the considered power system).

III. Study Case: Paraguaná Transmission System

Venezuela's power system is an integrated vertical power company, called *Corporación Electrica Nacional* (Corpoelec) which covers most of the country. It is divided into several areas: north, central, west, and Guayana. It was created in 2007 by merging 10 state-owned power companies. Venezuela has among the highest electricity coverage rates in the region, with more than 94% of its population receiving electricity services. From 1998 to 2008, the installed capacity expanded with an average annual rate of 1.47%, from 19,696 MW to 22,790 MW, while the demand has climbed at an average annual rate of 4.01%, from 79,383 GWh/year to 117,670 GWh/year. Recent demand studies have shown an average year-on-year growth of 4.3% through 2027. It should be noted that the electricity grid consists of 11,747 kilometers of 765-kV, 400-kV, and 230-kV transmission lines.
Venezuela expects to have its first wind farm in-feed by the end of 2012. The 100 MW *Paraguaná wind farm* is currently under construction (November 2011, see Fig. 1), and it is located between Paraguaná populations Amuay and Los Taques in the state of Falcon (Estado Falcón). The wind farm is designed so that each wind turbine produces about 1.32 megawatts of power, resulting from 76 wind turbines with an approximate height of 70 meters per unit.

Fig. 1. Photos of the current states of Paraguaná Wind Farm.

The Paraguaná Peninsula transmission system is fed from a single circuit (230 kV) transmission line of San Isidro substation as part of the Venezuelan power pool. The average demand is 280 MW and importation by San Isidro tie line is 200 MW. Fig 2 shows the geographical distribution of the Paraguaná transmission system and Fig. 3 shows all substations, transmissions lines, static reactive compensators, and generators incorporated in this study. The Paraguaná wind farm will be connected with two transmission lines, 115kV, to the Los Taques and Judibana substations respectively. The Paraguaná wind farm will have a total installed capacity of 100 MW, which requires approximately 76 generation units with capacity 1320 kW each, MADE AE-61. Each unit consists of fixed speed wind turbines, stall regulated, with single cage induction generator at 690 V. Individual step-up transformer (0.60/34.5 kV, 1.6MVA) and static compensation of reactive power (630 kVAr) is located in each turbine. Four underground feeders (34.5kV) are used to collect the power generated by wind turbines and a step-up substation (34.5/115 kV) transmits the power generated into the Venezuelan power system through the Los Taques substation.

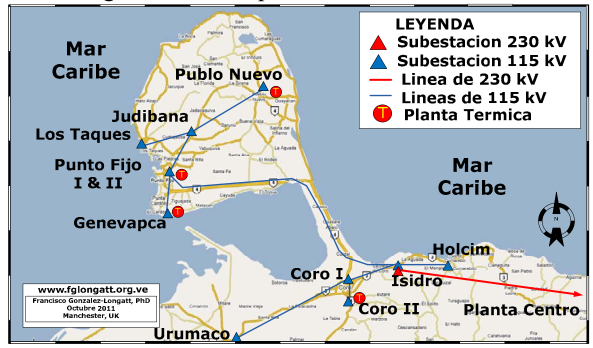

Fig. 2. Geographical map demonstrating the main components at the Paraguaná Transmission System.

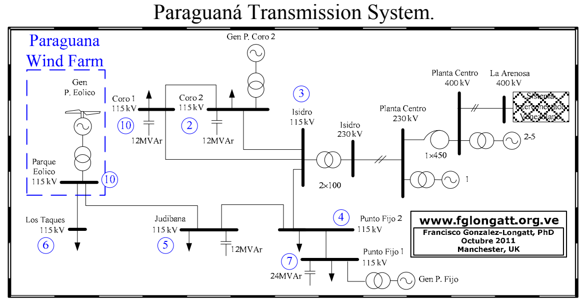

Fig. 3. On-line diagram of the Paraguaná Transmission System consideration the integration of the Paraguaná wind farm at bus 10.

IV. Simulations and Results

The incorporation of Paraguaná wind farm to the Paraguaná area power system leads to an increase in a variability of the system power flows. The assessment of this variability is necessary for the planning of the necessary system reinforcements. This section presents the main statistical analysis, simulations and results for the assessment of the variability of power flows on the Paraguaná transmission system.

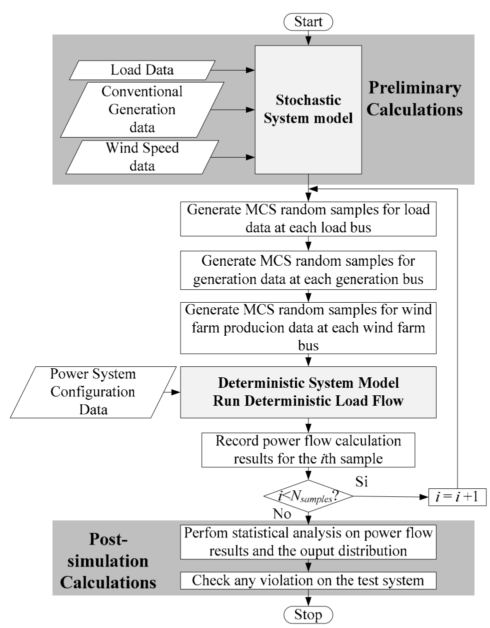

Fig. 4. Flowchart of the Assessment of Power Flows variability.

A general overview of the procedure followed for this evaluation is depicted on Fig. 4. In this paper, the preliminary calculations are used to create a stochastic model. In particular the samples generated for the MCS, and the post-simulation calculations are performed by specifically developing models (*m*-file) within MATLAB® [24] version 7.12.0.635 (R2011a 64-bit) customized for these specific proposes of this study. An interface in PowerFactory™ for the automation of power flows (deterministic) is also created by the authors using *DIgSILENT Programming Language* (DPL). All simulations are performed using a personal computer - Intel®, Core™ i7 CPU 2.0GHz, 8 GB RAM having Windows 7 Home Edition 64-bit operating system.

A. Stochastic Model

A stochastic model for the assessment of this variability is developed, as the uncertainty of the system inputs should be modeled, comprising of the stochastic nature of the system loads as well as the stochastic nature of the wind resources.

1) Stochastic Load Modeling

The load is assumed to be a random variable ($P_{L,i}$) normally distributed within each hour for a given time period [25]. Then, the PDF of $P_{L,i}$ is given by the following expression:

$$f_{P_{L,i}}\left(P_{L,i}\right)=\frac{1}{\sigma\sqrt{2\pi}}e^{-\frac{\left(P_{L,i}-\bar{P}_{L,i}\right)^2}{2\sigma^2}} \quad (3)$$

where $\bar{P}_{L,i}$ is the mean value; σ is the standard deviation.

The data for setting up the stochastic model regarding the Paraguaná transmission system loads are real measured values from six (6) substations (115 kV) located in the area: Coro I, Coro II, Punto Fijo I, Punto Fijo II, Judibana y Los Taques. The measurements were recorded over a period of one year on an hourly basis. Data validation and data recovery is performed on the data time series, and the Expectation-*Maximization* (EM) Algorithm is used for the data sets having missing values.

TABLE I. DESCRIPTIVE STATISTIC FOR LOADS IN PARAGUANÁ TRANSMISSION SYSTEM

	Coro I	*Coro II*	*P. Fijo I*	*P. Fijo II*	*Judibana*	*Los Taques*
Range	28.00	56.00	61.00	22.00	21.00	4.00
Min	25.00	42.00	61.00	14.00	20.00	6.00
Max	52.00	98.00	123.00	35.00	41.00	10.00
Mean	38.14 ±0.330	70.19 ±0.593	93.84 ±0.774	26.90 ±0.237	31.09 ±0.255	7.61 ±0.057
Std Dev	6.000	10.869	14.185	4.351	4.676	1.036
Variance	36.644	118.132	201.207	18.933	21.867	1.073
Skewmess	0.278 ±0.133	0.229 ±0.133	-0.34 +0.133	-0.686 ±0.133	-0.255 ±0.133	-0.179 ±0.133
Kurtosis	-0.478 ±0.265	-0.085 ±0.265	-0.762 ±0.265	0.157 ±0.265	-0.733 ±0.265	-1.019 ±0.265

Table I shows the main descriptive statistics for the substation load found in the Paraguaná transmission system and Fig. 5 shows the Normal Q-Q plot which is used as a graphical assessment of the normality of these data sets. It can be observed that all data points are close to the diagonal line, which implies that the data evaluated is normally distributed. Fig. 6 shows the PDFs for the measured data of each load in the Paraguaná Transmission System and their estimation on the normal distributions.

2) Stochastic Conventional Generation Modeling

The data for setting up the stochastic model of the generation installed on the Paraguaná Transmission System pertains to real measured values from two (2) power stations, recorded at 115 kV, which are located in the area: Planta Coro, Punto Fijo.

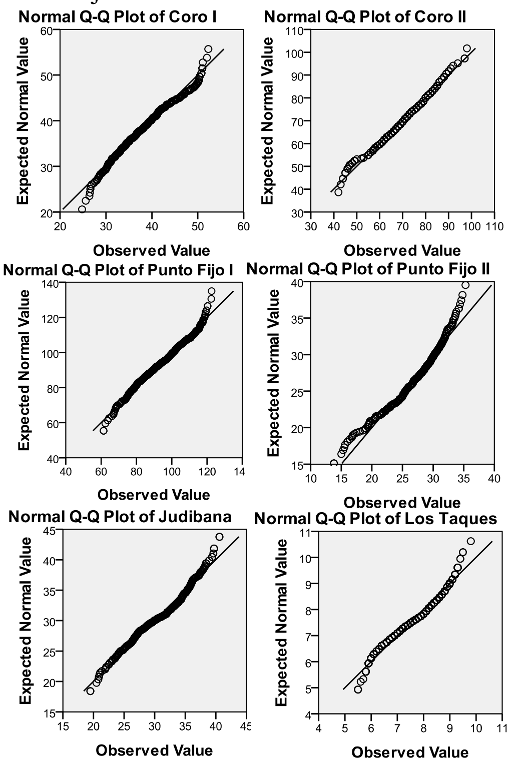

Fig. 5. Normal Q-Q Plots for Loads on Paraguaná Transmission System.

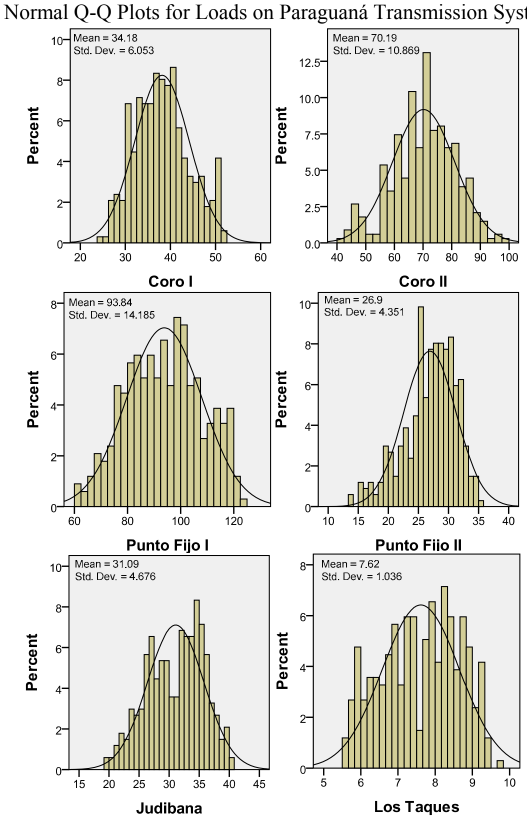

Fig. 6. PDF of the Load in Paraguaná Transmission System.

It is the authors' belief that it is relevant to show some other power flows of interest as well as data from two transmission lines (P. Centro-Isidro) and the intertie. Measurements were recorded over a period of one year on an hourly basis. The same data validation and data recovery is performed on the data time series as had been performed for the conventional generation data.

TABLE II. DESCRIPTIVE STATISTIC FOR THE GENERATION IN PARAGUANÁ TRANSMISSION SYSTEM

	P. Coro	*P. Fijo*	*Total Gen*	*P. Centro Isidro*	*P. Centro Isidro II*	*Inter-tie*	*Demand*
Range	16	151	155	142	357	396.	464
Min	0	0	2	-1	-160	-38	5
Max	16	151	157	142	197	358	469
Mean	2.21 ±0.049	66.66 ±0.232	73.94 ±0.240	90.85 ±0.207	52.42 ±0.319	232.89 ±0.515	306.83 ±0.538
Std Dev	4.169	19.889	20.530	17.718	27.332	44.083	46.035
Variance	17.365	395.556	421.479	313.928	747.027	1943.30	2119.20
Skewmess	1.387 ±0.029	0.047 ±0.029	-0.015 ±0.029	-0.115 ±0.029	-2.241 ±0.029	-0.591 ±0.029	-0.391 ±0.029
Kurtosis	-0.005 ±0.057	0.145 ±0.057	0.189 ±0.057	0.485 ±0.057	15.837 ±0.057	1.510 ±0.057	0.874 ±0.057

Table II shows the main descriptive statistics, while Fig. 7 shows the Normal Q-Q plots. Furthermore Fig 8 shows the PDFs for the measured data of each generation power plant in the Paraguaná Transmission System.

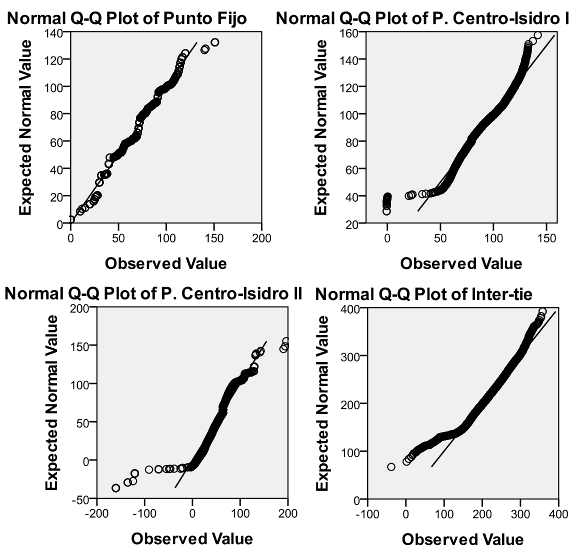

Fig. 7. Normal Q-Q Plots for Generation on Paraguaná Transmission System.

3) *Stochastic Modeling of Paragsuná Wind Farm*

For the wind power, the stochastic prime element is the wind activity modeled as a random variable following, at a specific location, the wind speed distribution which may be represented as a Weibull distribution. In this paper, the wind speed data is based on a measurement program installed on September 2002 at Paraguaná Peninsula. Initially, two measurement towers were installed, 36 m above ground, Los Taques (Mast 2) and Asubure (Mast 3). Additionally one radio antenna of 90m height in Tacuato (Mast 1) was used for measurements containing an appropriate set of measuring equipment. On January 2006 a tower measuring 69 m in height, called Mast 4, was installed in the area of the expected Paraguaná wind farm (see Fig. 9).

Fig. 10 shows the site's monthly and hourly means of wind speeds at a 50m height for a whole year. As it can be seen by Fig. 10, the monthly mean wind speed varies between 5.04 and 12.13 m/s. The maximum value of the mean wind speed was monitored in June whilst the minimum value was monitored in November and the average speed for the year was 8.69 m/s.

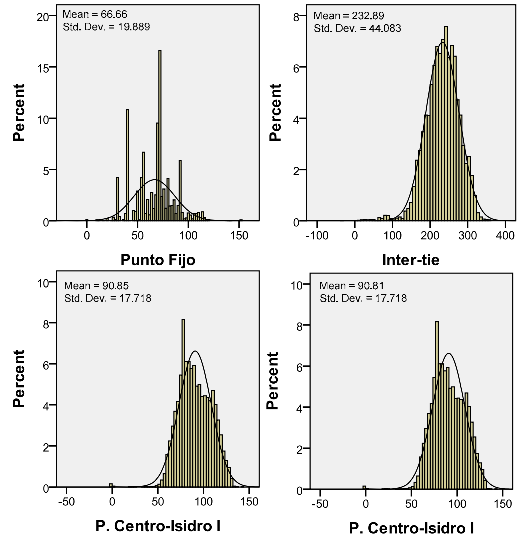

Fig. 8. PDF of the Generation in Paraguaná Transmission System.

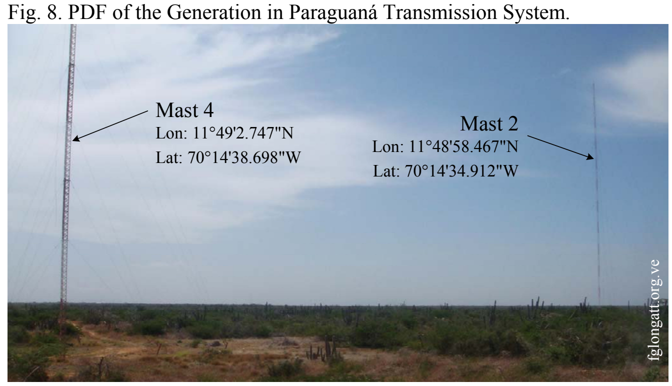

Fig. 9. Panoramic photo showing the met towers locations at the Paraguaná wind farm area (photo taken on 2006).

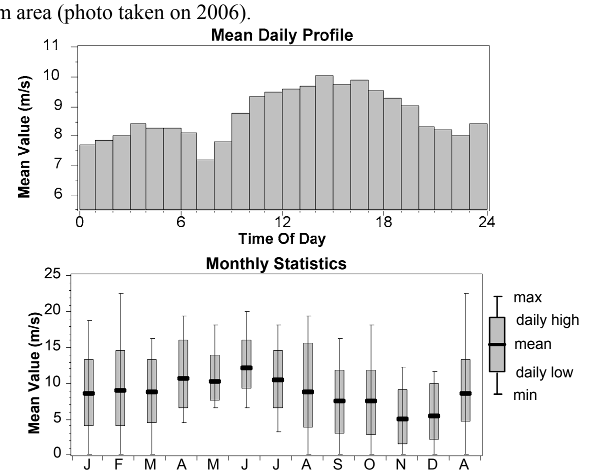

Fig. 10. Monthly statistics and daily profile for wind speed at 50m height.

The maximum wind speed recording was 22.54 m/s in February and this value appears to be below the cut-out speed of most wind turbines commercially available. The mean daily wind speed profile over the year varies between 10.04m/s and 7.17 m/s. These values were recorded on 15:00 and 8:00 hours respectively. Fig. 11 shows the Weibull probability distribution with the estimated parameters derived from the observed data. The *wind turbine* (WT) power curve of the power output and wind speed for Made-AE-61, used for the Paraguaná wind farm, is shown by Fig 12.

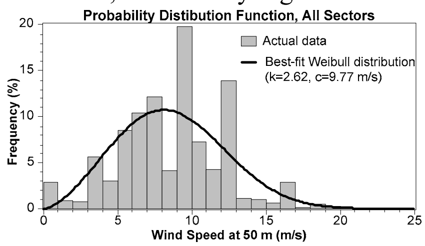

Fig. 11. Wind speed frequency distribution in the site assessed.

Furthermore, operational limits were included in the characteristic with cut-in ($v_{w,in}$), nominal and cut-out wind speed ($v_{w,out}$) values of 3.5, 14 and 25 m/s, respectively. The wind speed data was corrected from the measurement height to the hub height (70m) using a Hellmann exponential profile.

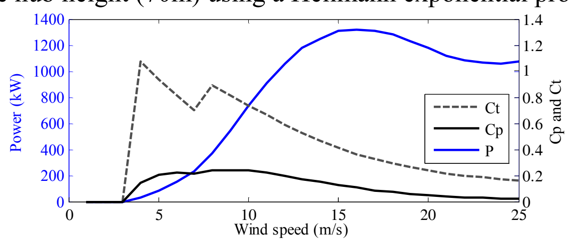

Fig. 12. Wind Speed-Power Characteristic for MADE AE-61. P: Power (kW), Cp: Power coefficient (-), Ct: thrust coefficient (-).

In this paper, the MCS samples are based on the PDF for wind speed. Once the wind speed (v_w) is known, the power injected into the grid can be calculated by the means of it. Fig. 11 illustrates the results of a 10,000-sample MCS for the output power distributions for the WT presented in Fig. 13.

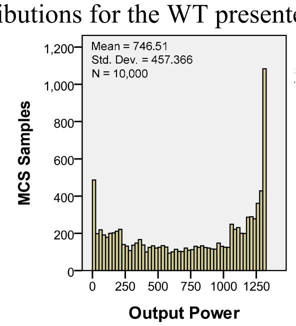

Fig. 13. WTG output power distribution ($P_{g,WF}$).

The corresponding WT output power distribution obtained is highly *non-normal* presenting a concentration of probability zero, ($v_w<v_{w,in}$, $v_w>v_{w,out}$), and a nominal output power ($v_{w,in}<v_w<v_{w,out}$) due to the effect of the non-monotonic WT characteristic.

4) *Evaluation of Variability on Paragunà Power System*

In order to proceed to the MCS analysis of power system variability due to the integration of Paraguaná wind farm two scenarios are evaluated in this section: *Case I*: Paraguaná Transmission System operating without the integration of Paraguaná wind farm, and *Case II*: considers the integration of the wind farm. The bus number '10', named *'Parque Eolico 115 kV'*, corresponds to the wind farm step-up substation. It is connected through a transmission line to the substation Los Taques, '6' and one more transmission line Judibana, '5' (see Fig 3). On the other hand, a single transmission line between Los Taques and Judibana '5-6', is considered only for *Case I*. The number code shown in Fig 3 is utilized in the analysis presented by this paper. The SPF described in previous sections is used to calculate the power flow distribution on the Paraguaná Transmission System. Table III and Table IV show the descriptive statistics for the power flows on the transmission lines involved in the Paraguaná Transmission System for Case I and II respectively.

Moreover, the integration of the Paraguaná wind farm leads to an increase in the standard deviations of the power flow distributions. It is evident on the case of the transmission line Punto Fijo II-Judibana, '4-5', where the standard deviation of the power flow changes from 4.903 to 34.77 MW. This is a 6 km long overhead transmission line, having a conductor type of ACAR 350 kcmil, 12/7 and its rated current is 0.451kA. The expected power flow for this particular line after the integration of the Paraguaná wind farm remains below its thermal rating. The results obtained demonstrate that the presence of a stochastic generation on the Paraguaná Transmission System results in highly bidirectional power flows. In many cases, the incorporation of wind power leads to higher reverse power flows than direct ones.

Fig. 14 and 15 show histograms of the MCS power flows through transmission lines of the Paraguaná Transmission System for the Case I and II respectively. As it is evident on Fig. 15, the power flow distributions extend in both positive and negative axis (bidirectional power flows) for the case of the transmission line Punto Fijo II-Judibana, '4-5'. This indicates a probability of reserve power flows. It should noted that higher reverse power flows than direct ones are expected on '4-5'.

TABLE III. DESCRIPTIVE STATISTIC FOR POWER FLOWS ON PARAGUANÁ TRANSMISSION SYSTEM: CASE I

	P1-2	*P2-3*	*P1-3*	*P3-4*	*P4-5*	*P5-6*	*P4-7*
Range	21.77	82.77	24.1	211.67	39.08	7.75	231.67
Min	7.78	54.79	14.72	55.26	18.43	3.51	-11.71
Max	29.55	137.56	38.82	266.93	57.51	11.27	219.98
Mean	18.33	93.39	27.64	**133.31**	38.862	7.6244	65.10
	±0.028	±0.106	±0.031	**±0.209**	±0.049	±0.010	±0.192
Std Dev	2.888	10.643	3.169	**20.936**	4.903	1.043	19.290
Variance	8.344	113.282	10.044	438.349	24.044	1.09	372.11
Skewmess	0.051	-0.005	-0.027	0.188	0.235	0.238	0.043
	±0.024	±0.024	±0.024	±0.024	±0.024	±0.024	±0.024
Kurtosis	0.065	0.002	-0.066	-0.768	-1.396	-1.447	0.087
	±0.049	±0.049	±0.049	±0.049	±0.049	±0.049	±0.049

TABLE IV. DESCRIPTIVE STATISTIC FOR POWER FLOWS ON PARAGUANÁ TRANSMISSION SYSTEM: CASE II

	P1-2	*P2-3*	*P1-3*	*P3-4*	*P4-5*	*P5-10*	*P4-7*	*P6-10*
Range	22.06	81.13	26.05	261.52	126.36	105.72	184.69	7.98
Min	6.99	52.37	15.16	-60.29	-74.65	-94.85	-1.67	-11.62
Max	29.05	133.5	41.21	201.22	51.7	10.89	183.01	-3.65
Mean	18.31	93.37	27.62	**76.69**	-17.54	-48.76	65.98	-7.6125
	±0.294	±0.107	±0.032	**±0.402**	±0.347	±0.345	±0.194	±0.103
Std Dev	2.94	10.77	3.21	**40.22**	34.77	34.52	19.1415	1.034
Variance	8.65	116.20	10.34	1617.7	1207.41	1192.30	366.398	1.07
Skewmess	-0.005	-0.005	-0.027	0.188	0.235	0.238	0.043	-0.008
	±0.024	±0.024	±0.024	±0.024	±0.024	±0.024	±0.024	±0.024
Kurtosis	-0.073	0.002	-0.066	-0.768	-1.396	-1.447	0.087	0.008
	±0.049	±0.049	±0.049	±0.049	±0.049	±0.049	±0.049	±0.049

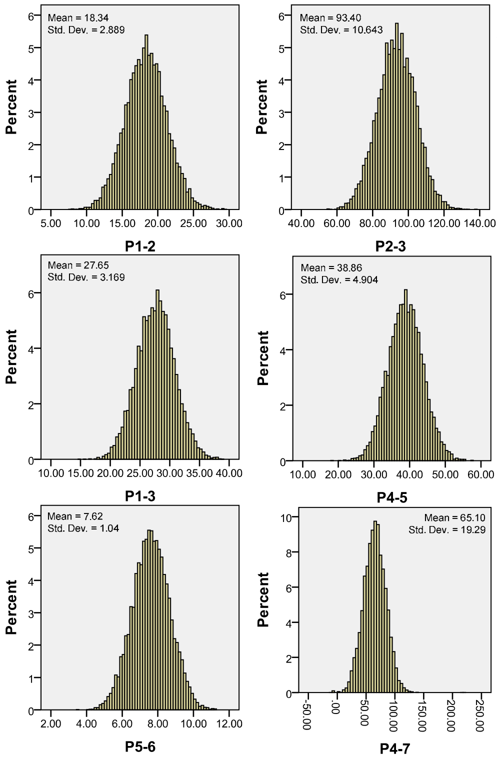

Fig. 14. Histogram of the power flows (P_{ij}) through transmission lines in Paraguaná Transmission System: *Case I.*

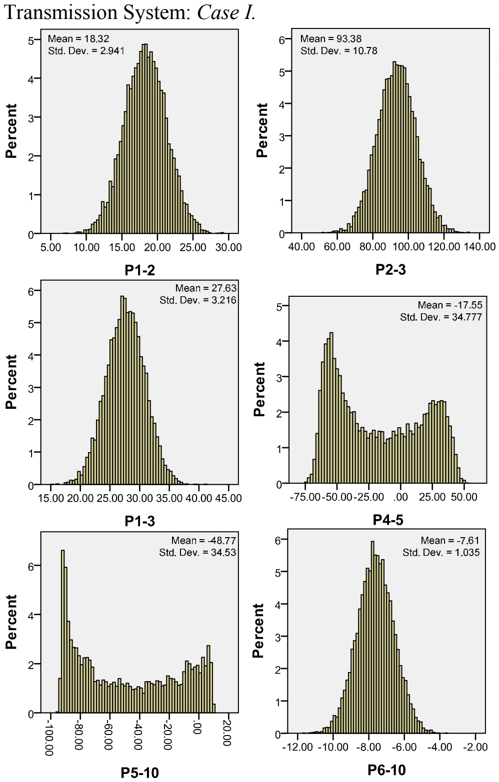

Fig. 15. Histogram of the power flows (P_{ij}) through transmission lines in Paraguaná Transmission System: *Case II.*

The probability for the reverse power flow to occur at '4-5' reaches its maximum around 65.3MW. A very positive impact resulting from the integration of the Paraguaná wind farm is an important reduction of the power flow transfer through the El Isidro-Punto Fijo II, '3-4' transmission line (86 km, cooper 350 kcmil, 0.584kA). It can be therefore stated that although the variability of power flows in this transmission line is expected to increase, the expected value of the power transfer is considerably reduced (see Fig. 16). Fig 17 and 18, illustrate the box-plots for the power flow distributions in the system lines. It is evident that the integration of the Paraguaná wind farm leads to an increase of the variance of the power flow distributions for lines '3-4', '4-5' and '5-10'. Nevertheless, the power transfer through Parque Eolico-Judibana '5-10' transmission line, requires further analysis, as the histogram of Fig. 15 demonstrates a possible situation for overload.

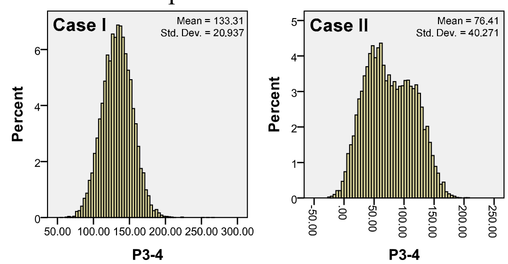

Fig. 16. Histograms of the power flows (P_{ij}) through the transmission line El Isidro-Punto Fijo II, '3-4': *Case I* and *II.*

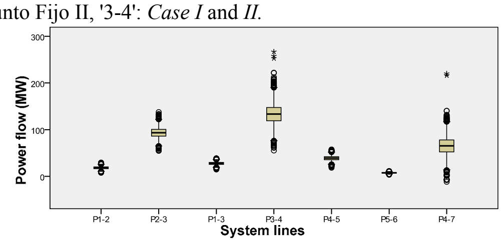

Fig. 17. Box-plot for the power flows (P_{ij}) through transmission lines on Paraguaná Transmission System: *Case I.*

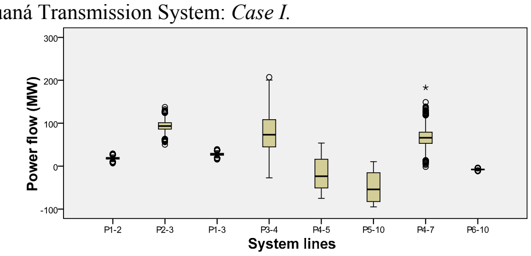

Fig. 18. Box-plot for the power flows (P_{ij}) through transmission lines on Paraguaná Transmission System: *Case II.*

V. Conclusion

The assessment of the power system variability is imperative for the planning of any possible system reinforcements. This paper presents a practical example case for such an assessment resulting from the integration of the Paraguaná wind farm into the Paraguaná Transmission System in Venezuela. This paper is quite novel because it uses real measurements regarding the loads , the conventional generation in the Paraguaná Transmission System and real wind speed measurements to develop a stochastic system model. The simulation results have demonstrated that the integration of this wind farm leads to an increase in the variability of the power flows in the system lines and further increases the probability of reserve power flows. Future work may include further statistical analysis in terms of the stochastic system modeling. Finally further investigation is needed on the power transfer through transmission line Parque Eólico-Judibana, incorporating overloading probability.

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VI. BIOGRAPHIES

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