Wind Power

Wind Energy in Brazil

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Abstract

This paper presents an actual overview of the electricity supply system of Brazil, the potential for wind power conversion, and considerations for the planning and operation of wind power systems connected to the electrical grid. While the presently installed capacity is 28 MW only, the PROINFA program will increase installed wind power generation capacity to at least 1,100 MW until 2006, rising concerns by the utilities in terms of grid capacity, grid stability and power quality. For most applications, modern wind converter equipment using direct-driven variable speed wind converters with four quadrant inverters, should not cause any problems - it even enables to improve the power factor of the existing grid. Nevertheless, attention should be paid to a proper layout of the system and to grid enforcements.

Index Terms— Wind energy, Wind power generation, Power generation control, Power system dynamic stability, Interconnected power systems, inverters, Power conditioning, Power system availability, Power system harmonics.

Introduction

Brazilian electric generation capacity totals 88 GW in addition to some 8 GW imported from neighboring countries. Consequently Brazil is one of the larger electricity markets in the world and by far the largest in South America, with the Brazilian total primary energy consumption being twice as large as the aggregated figures for Argentina, Bolivia, Chile, Paraguay and Uruguay. Approximately 86% (2002, [1]) of the domestic production comes from hydroelectricity (although the percentage reaches 88% when only the interconnected system – the national grid – is considered).

Non-hydro generation comes from natural gas (4.6 GW), fuel or diesel oil (4.8 GW), nuclear (2.1 GW) and coal (1.4 GW). There are two nuclear power plants in operation and a third one under consideration (since 29 years already). Coal is only used in the southern region of the country where coal reserves are available. Brazil is capable to import electricity from Paraguay (5.65 GW), Argentina (2.25 GW), Uruguay (70 MW), and Venezuela (200 MW).

Total consumption has increased from 70 to 300 TWh in the last 20 years. Currently, some 95% of the Brazilian households have access to electricity, mainly located in cities close the coast. Many rural areas still do not have electricity supply, but should be served until 2008 by governmental programs (e.g. "Light for all").

The 2001 Energy Crisis

During 2001 Brazil experienced a major electricity supply crisis triggered by a severe drought, but based on small investments in the electricity sectors in the years before. The hydroelectric power plants that had generated 94% of Brazil's electricity supply before the crisis were left with dry reservoirs, principally caused by lack of investments in the years before.

As a result, the government decided to decentralize and diversify the energy generation matrix, often carried out quite hastily. However, the Government's supplementary rationing program successfully reduced the economic impact of the crisis. Since then reservoirs returned to comfortable levels.

The new Government inaugurated in January 2003 is proceeding with the re-evaluation of the power sector policies initiated by the last administration after the 2001 crisis. One positive outcome of the crisis was the energy saving program introduced by the Government and taken up responsibly by the population, such as the consequent use of energy saving light bulbs and the ranking of electro-domestic products according to their energy efficiency (PROCEL). On return to full generation, demand did not return to the previous levels.

Since the end of the rationing period, a combination of factors such as the unprecedented shrinking in demand (electricity demand in 2002 was similar to 1998), new (albeit small) capacity added to the system, and plentiful rain, has resulted in an excess supply of 6 GW. However, the current surplus is temporary and without new investment in generation any growth in demand will result in a new crisis in the middle term. Presently the economic growth in the vicinity of 5% per annum during the last couple of years leads to an increase of energy consumption.

New Energy model

Within the new energy model state-owned power companies, precluded from investing in the sector since 1996, will now be allowed to be minority shareholders in generation or transmission projects or undertake them alone if there is no interest from private investors.

Demand grew again by 4-5% in the last two years. Industry estimates that some 30 GW will have to be added to the grid by 2015. To achieve this target, some US$ 6 billion would have to be invested in system expansion alone (US$ 3 billion in generation, US$ 2 billion in transmission, and US$ 1 billion in distribution).

There is still an estimated 226 GW of untapped hydroelectric potential in Brazil. However, most of this potential is located far away from consuming centers. There are currently discussions about two major hydroelectric projects. Belo Monte, in the Xingu River in North Brazil, is an 11 GW run of the river plant with estimated costs of about US$ 6 billion including 3,300 km of transmission lines. The other project consists of two plants in the Madeira River with a combined capacity of 7 GW that should cost around US$ 4 billion. It is envisaged that only one of the two projects will go ahead [1].

The increased availability of domestic natural gas and the construction of the Bolivia-Brazil pipeline, together with the consequences of the 2001 crisis, have led the Government to start a gas-fired thermoelectric power program with a combined output of 15 GW, but reached less. It was argued that thermoelectric power plants would constitute the fastest way to diversify the Brazilian energy matrix, decreasing its dependency on hydroelectricity, but is on the other side worsening the Brazilian greenhouse gas emission intensity for electricity generation, which used to be excellent and as low as 70 g CO_2/kWh_{el} (comparative numbers are: Japan: 439 g CO_2/kWh_{el} and Germany: 530 g CO_2/kWh_{el}) [2].

New Renewables

In 2002, the Brazilian Government established an incentive program for the development of renewable energy sources. The program is called PROINFA (Programa de Incentivo às Fontes Alternativas de Energia Elétrica, see Table 1) [3], [4]., and supports electrical generation via biomass, wind and small hydro power plants up to a maximum of 3,300 MW (1,100 MW each sector) during the first phase of the program, which ends with the full implementation of the projects by 12/31/2006. The program will especially benefit the wind sector which has been stagnant in last years (see Fig. 1). The target is to ensure that within 20 years, 10% of total electricity will come from new renewable energy sources.

A considerable number of foreign wind power companies are already installed or probing the Brazilian market, including Wobben-Enercon Windpower, Nordex Energy and Fuhrländer (Germany), Gamesa (Spain), GE-Wind (USA), Vestas (Denmark). Wobben-Enercon, in Brazil since 1996, is the only foreign operator of wind farms and manufacturer of turbines in the country.

A substantial number of projects already has been authorized by ANEEL, the electricity regulatory agency, but within the first phase of PROINFA only the selected ones by Eletrobras are supposed to be realized in 2005/06 (see Table II), with the exception of three wind parks established independently by PETROBRAS (one in Rio Grande do Norte of 1.8 MW, two in Rio de Janeiro of 3 MW each), underlining its willingness to transform itself from a fuel company to an energy supplier.

Fig. 1. Brazil's largest wind park: Prainha (30 km from Fortaleza, in the Northeast of Brazil) with 20 wind turbines of 500 kW each, representing about 40% of the country's wind power capacity presently installed.

TABLE I
The Brazilian PROINFA-Program: Tariffs

Power source	Quantity (MW)	Grid feed tariff (over 20 years) per MWh
Wind power	1,100	Depends on the capacity factor *CF*: $CF = 0.324$: R$ 204.35 [US$ 67.66] $0.324 < CF < 0.419$: R$ 204.35 – 180.18 [US$ 67.66 – 59.66] $CF = 0.419$: R$ 180.18 [US$ 59.66]
Biomass	1,100	Sugar cane bagasse: R$ 93.77 [US$ 31.05] Rice rinds: R$ 103.20 [US$ 34.17] Fire wood: R$ 101.35 [US$ 33.56] Biogas (landfills): R$ 169.08 [US$ 55.99]
Small hydro power	1,100	R$ 117.02 [US$ 38.75]

Actualizations of tariffs are based on price indicator (IGP-M/FGV).
Minimum tariff is tied to the actual consumer tariff: 90% for wind, 50% for biomass, 70% for small hydro power plants.
Values are based on exchange rates at 8/10/04: 1 R$ = 0.331 US$

Although solar power is not included in PROINFA, the Government will proceed with programs such as PRODEEM, which focuses on photovoltaic energy for remote communities via 5,000 PV-systems for school illumination, water pumping systems and health post power supply; in average each system has a size of 500 W.

Table II
Wind Parks authorized by Aneel and selected by Eletrobras after three Re-Selections

State (Region: NE: Northeast, SE: Southeast, S: South)	Number of wind parks	Power (MW)
Paraíba (NE)	13	64.850
Ceará (NE)	8	264.708
Rio Grande do Norte (NE)	2	114.000
Pernambuco (NE)	6	44.550
Piauí (NE)	1	17.950
Rio de Janeiro (SE)	2	163.050
Rio Grande do Sul (S)	5	227.562
Santa Catarina (S)	10	217.830
Brazil total	47	1,114.500

Technical Issues

Wind Power Conversion

A wind power conversion system consists of the components wind turbine, gearbox (optional, see below), generator, power-conditioner, transformer and grid connection, as shown in Fig. 2. The gearbox becomes obsolete for the case of direct-drive generators, featuring a large number of poles and a large diameter of the rotor in order to allow for adequate electrical power generation, even for the relatively low rotation speed of a large wind turbine.

Wind power converters (WPC) could be divided in two major groups defined in terms of rotation speed control: WPCs with constant rotation speed and regulation by stall and WPC with variable rotation speed with a adjustable blades at the turbine (pitch controlled WPC).

Stall controlled WPC could be also fixed to two rotation speeds by pole-switching of the generator. The electrical power from generator is fed into the grid directly or via a converter (combination of a rectifier and an inverter) and a transformer.

Variable speed WPCs allow a higher yield but always require a converter. For that case the rotation speed is determined by the frequency of the generator that is usually adjusted to maximum power output of the WPC (see Fig. 2).

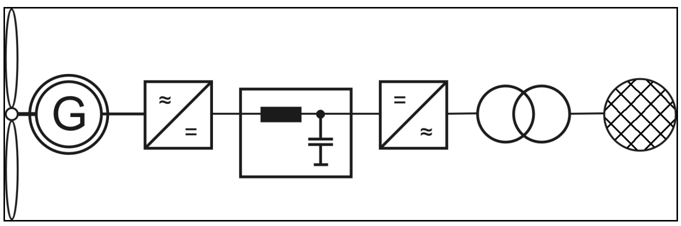

Fig. 2. Scheme of a modern gearless wind power system consisting of wind turbine, generator, rectifier, stabilizer, inverter and grid connection via a transformer.

Currently there is only one manufacturer of wind power conversion equipment in Brazil and Latin America, Wobben-Enercon, a subdivision of Enercon Germany, manufacturing just the gearless, variable speed pitch-controlled E-40, rated 600 kW (see Figs. 1, 3, 5, 6). Almost 90% of the presently installed wind power capacity in Brazil is based on that type wind energy conversion system.

Fig. 3. Final check via an online-endoscope inside a blade for a 600 kW wind turbine at Wobben-Enercon in Pecém (35 km west of Fortaleza): Still Latin America's only manufacturer for large scale wind turbines.

The turbine is variable speed pitch regulated, the generator is synchronous without gearbox, generator AC output is rectified to 700 V DC, DC is inverted to three phases, 60 Hz at 380 V and then transformed to 13.8 kV. The generators are produced in Sorocaba, near São Paulo and since 2 years turbine blades are manufactured in Pecém in the North-East of Brazil (only about 80 km away from the Prainha wind park)

Latest information [5] indicates that another player appears on the stage – Fuhrländer. It is constructing an assembly line in Pecém, in the State of Ceará, using components manufactured in the states of Santa Catarina and Minas Gerais. Until the end of 2005, 27 MW should be installed in Aracati and 25.2 MW in Beberibe. For 2006 another windpark in Canoa Quebrada with 57 MW for 142 Mio R$ is planned, so Fuhrländer intends to install ambitious 109 MW.

Grid connection

While output of the wind power converters is usually below 1 kV, due to the power electronics applied, transformers have to be used before entering the distribution grid. Voltage levels in the Brazilian distribution system are: 5 kV, 13.8 kV, 22 kV, 33/34 kV, 69 kV, 130 kV, 250 kV, 500 kV and 750 kV. Up to 69 kV are presently applied for the interconnection of wind farms. Often several wind turbines of a wind park are connected in parallel at the DC side to a common DC bus and current controlled voltage source inverters can be used to convert the DC power into AC for connection to the grid via a single, relatively large transformer [6].

Due to the relatively low cost of national transformers which are available in medium power ranges, Brazilian-made transformers are usually applied separately at every single wind conversion unit, and then interconnected on the mid voltage AC side (see Fig. 4). Costs for a national transformer from 380 V to 13.8 kV for a 500 kW wind generator are in the vicinity of R$ 10,000 (US$ 3,300).

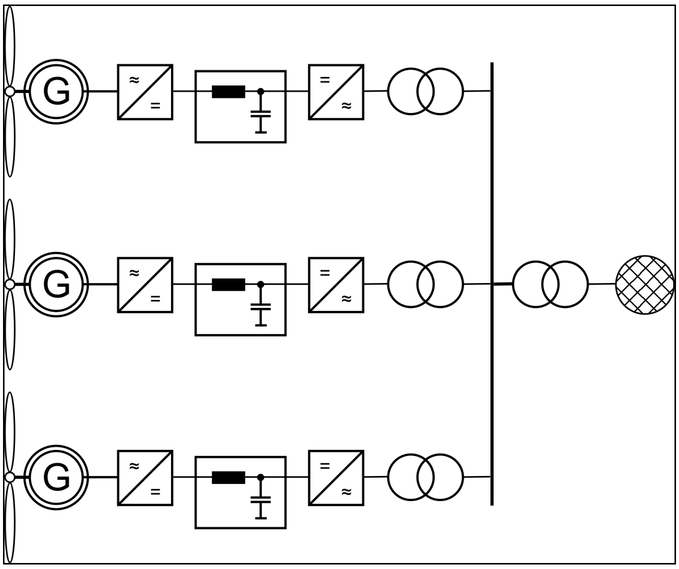

Fig. 4. Scheme of a wind park consisting of wind turbines, generators, rectifiers, stabilizers, inverters and connections to the internal mid-voltage grid of the wind park (e.g. 13.8 kV) via transformer and final grid connection via a main transformer (e.g. 13.8 kV to 69 kV).

Distortion at the grid feeding points from the wind turbines into the middle voltage grid (13.8 kV)

While the switching frequency of the inverters in the wind turbines is often limited to 2-5 kHz only, considering switching losses and cooling requirements, the current into the middle voltage grid could be quite distorted, especially for partial load conditions [7]. Voltage distortion remains within 1-2.5% at low level of the whole power range.

Actual distortion within the 13.8 kV grid.

The current distortion remains exceptionally low for relative load levels above 70%: *THD (I)* = 5% [6]. The current-distortion from different wind power converters are apparently leveling themselves out. Only at low load levels the distortion is increased and reaches 10% for relative load levels of 50%, 25% for load levels of 15% and ends up in the vicinity of 50% for very low load levels. Due to the high capacity factors of wind power conversion in NE Brazil wind turbines rarely operate in the low load range, the current distortion remains at supportable levels. Measurements at 11/25/2004, 11 a.m. at the grid-feeding point of the Prainha wind park are in accordance with the statements given above and have shown at 50% load level *THD (I)* of 1.8% and *THD (U)* of 0.5% only. Long-term measurements are on the way.

Fig. 5. A 500 kW transformer (380 V to 13.8 kV) attached to a single E 40 wind power converter.

Fig. 6. Grid connection points (2 x 5 MW, in the huts) to the public grid of COELCE (to the left) at the Prainha wind park (from the right).

At the high voltage grid feed point, where the access to the public grid occurs, the harmonics should be reduced to a negligible amount, while the grid impedance is getting lower (see Fig. 6).

Grid stability

Grid stability has been a widely discussed issue in the last years (see [8]-[13]); experiences from some federal states in Germany (e.g. Schleswig-Holstein), where wind power penetration reaches 25% in average and goes up to almost 100% of total electricity generation for the early morning hours, show the achievability of very high wind power participation levels, even for higher variability of wind velocities than in Brazil. Nevertheless adequate controlling and sufficient reserve power is required.

Human interface

To our experience communication between the wind park operator and the utility is limited: the possibility of the power electronics implemented at each of the wind turbines to achieve almost any desired cos f is hardly known by the utility responsibilities. Usually the wind park is considered as a strange black box which has to be dealt with, in a mere alienated way.

Wind power Availability

Often renewable energies are considered as less reliable than conventional energy sources. While most of the Brazilian electrical energy supply system is based on hydropower (and consequently on its seasonal availability, see Figs. 7-8), studies comparing the availability of wind and hydro power have been carried out for different locations in Brazil.

Seasonal Availability

Northeastern Brazil is one of the most promising regions for wind power use, where highest wind speeds occur precisely when the flow rate of the São Francisco River, which accounts for the power supply of major part of region, is low. Thus during this critical period, wind farms could produce electrical energy, saving water for the hydro power plants, as shown in Fig. 7. Additionally, wind farms tend to be more environmentally sound than large hydro power plants or optional fossil fuel based power plants.

Outlook for possible wind power contribution

Due to the complementary behavior, wind power could help to improve considerably the seasonal generation profile in Brazil, which is dominated by hydro availability. At 60% wind power participation the minimum of water inflow is lifted to a level that is three times higher than the original minimum for hydro generation [15].

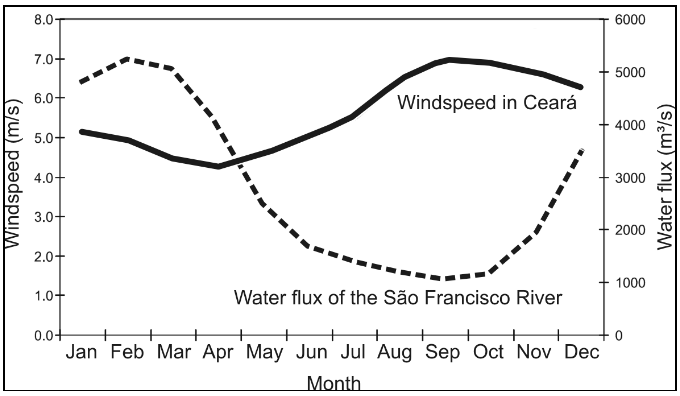

Fig. 7. Seasonal water flux of the largest river in the Northeast of Brazil in comparison to the average wind speed of the Northeastern state of Ceará (according to [14].)

Variability over the years
An additional advantage of wind power conversion in Brazil is its considerably lower variability in comparison to the fluctuations of the hydro potential, as shown by studies by [15] for the example of the Segredo hydro reservoir for the years 1983 to 1994 (see Fig. 8).

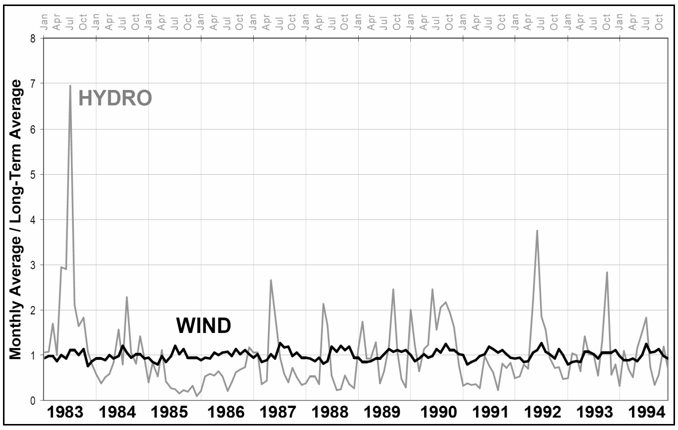

Fig. 8. Monthly fluctuations of available power sources over the years: Wind (Clevelândia) and Hydro (natural water inflow at the COPEL Segredo reservoir) [15].

Conclusion

While basic conditions are very favorable for the implementation of wind power conversion in Brazil, the country hardly used its potential. PROINFA is a first step to tap it in relevant levels. Modern wind power converters with its attached power conditioning equipment is able to even improve power quality of the connected electrical grid in terms reactive power and could be adapted to changing conditions in the future.

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