Connection of Wind Power Plants at Brazilian Integrated Power Grid

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ABSTRACT

Since the late 90s, with the unbundling of the Brazilian electricity sector, generation, transmission, distribution and trading of power were separated into distinct segments, with centralized planning being carried out by the Energy Research Company (EPE, *Empresa de Pesquisa Energética in Portuguese*). Despite the fact that EPE is a single company, generation and transmission planning are two different tasks, fulfilled by different teams, leading to global solutions that may not be optimized. Due to the large geographical area of Brazil, power plants are often allocated far away from the load centers, what leads to high costs for the expansion of the transmission system due to constant increasing distances. Due to the characteristics of wind generators of being random and unstable over time, the electric system needs the maintenance of hydraulic and/or thermal plants operating in the base, as well as heavy investments in voltage and frequency control equipments. As the granting of the generation and the transmission system are different processes, it is possible to start operating in different dates, what leads to generation without transmission sometimes or transmission without proper use.

Wind power generation has had a strong growth over the past decade due, in part, to tax incentives and other subsidies from national, regional and municipal governments. In 2018 Brazil had 589 wind power plants totaling 14,5 GW of installed capacity [1]. Besides those, there were others 194 granted projects to add more 4,3 GW to the National Interconnected Grid (SIN, *Sistema Interligado Nacional in Portuguese*). The transmission system is not intended only to the dispatch of those plants. Indeed, Brazil has auctioned more than 10,000 km of transmission lines and 50 new substations, directly or indirectly associated to connect wind power plants.

In this paper, a comprehensive analysis is carried out, regarding wind generation plants already granted and in the final planning stage, as well as the necessary transmission facilities for the power flow of this potential. The greatest potential for wind generation are in the Northeast and Southern regions, while the higher load concentration is in the Southeast, where São Paulo and Rio de Janeiro are located. The real price of energy is compared with others alternative energy sources, such as hydraulic and thermal power generation with less transmission lines associated. Moreover, the effects on the SIN and the overcost to the consumer due to the mismatching of transmission and generation are analyzed. There are concession contracts in which the generator has been guaranteed payment for energy, whether the necessary transmission system for their dispatch starts operating on the contracted date or not. This situation has been commonly due to environmental and real estate acquisition difficulties for the construction of transmission lines.

The conclusion is that an integrated energy planning is needed, as well as to consider the cost of different generation sources with the corresponding expansion cost of the transmission system and its actual period of construction, considering all of its construction difficulties. Here are submitted some proposals for joint bidding of generation and transmission in order to avoid the mismatch in those facilities operation starting date. In addition, it is recommended the production of economic regulation that allows the massive introduction of equipment for the storage of energy and the joint operation of storage and several generation sources, such as wind and photovoltaic, among others, to improve the electrical performance of these source sets and increase assured energy. It is, also, necessary to rethink the state subsidies, which often discourage the optimal allocation of the generating sources.

Keywords – wind power generation, power transmission system, integrated planning, joint operation, joint bidding.

RESUMO

Desde o final da década de 90, quando houve a desverticalização do setor elétrico brasileiro, geração, transmissão, distribuição e comercialização foram separadas em seguimentos distintos, com planejamento centralizado a cargo da Empresa de Pesquisa Energética (EPE). Em que pese a EPE ser uma única empresa, o planejamento da geração é feito separado do planejamento da transmissão, o que pode levar a uma solução não otimizada do ponto de vista global. Dada a dimensão continental do País, muitas vezes as plantas de geração são alocadas distante dos centros de carga, o que acarreta uma elevada expansão do sistema de transmissão. Devido a característica aleatória e instável dos geradores eólicos, há a necessidade de manutenção de plantas hidráulicas e/ou térmicas operando na base, assim como pesados investimentos em equipamentos de controle de tensão e frequência. Como as outorgas de geração e transmissão são distintas, é muito comum a entrada em operação em datas diferentes, deixando por vezes geração sem transmissão ou transmissão sem uso adequado.

A geração de energia elétrica a partir de fonte eólica teve um forte crescimento ao longo da última década, devido, em parte, aos incentivos fiscais e outros subsídios dos governos nas três esferas executivas: federal, estadual e municipal. Em 2018 o Brazil tinha 589 plantas de geração eólica, totalizando 14,5 GW de potência instalada. Além desses, haviam mais 194 empreendimentos outorgados para agregar mais 4.3 GW ao sistema interligado nacional (SIN). O sistema de transmissão não se destina unicamente ao escoamento dessas usinas, no entanto, foram licitados mais de 10.000 km de linhas de transmissão e 50 novas subestações, associados de forma direta ou indireta ao escoamento de plantas eólicas.

Neste trabalho faz-se uma análise global das plantas de geração eólicas já outorgadas e em fase final de planejamento, bem como das instalações de transmissão necessárias para o escoamento desse potencial. Os maiores potenciais para geração eólica estão nas regiões nordeste e sul, enquanto a maior concentração de carga está na região sudeste, onde se localizam as maiores cidades do País, São Paulo e Rio de Janeiro. Levanta-se o preço real dessa energia e compara-se com alternativas de geração hidráulica e/ou térmica com menos transmissão associada. Além disso, são feitas análises dos efeitos para o SIN e do custo para o consumidor devido ao descasamento da transmissão com a geração. Há contratos de concessão em que o gerador tem garantia de recebimento pela energia, caso o sistema de transmissão necessário para o seu escoamento não esteja pronto na data contratada. Situação frequente devido as dificuldades socioambientais e fundiárias para a construção de linhas de transmissão.

Conclui-se que há necessidade de um planejamento energético integrado, que considere o custo das diversas fontes de geração com a correspondente expansão do sistema de transmissão e seus prazos reais de construção, já considerando as dificuldades socioambientais e fundiárias a serem vencidas. Ao final são apresentadas algumas propostas para licitação conjunta de geração e transmissão de forma a minimizar o risco de descasamento na entrada em operação desses empreendimentos. Adicionalmente recomenda-se a produção de regulação econômica que viabilize a introdução massiva de equipamento destinados ao armazenamento de energia e a operação conjunta de diversas fontes, como eólicas e fotovoltaicas, entre outras, com armazenamento, para melhorar o desempenho elétrico desses conjuntos de fontes e aumentar a energia assegurada. Há que se repensar os subsídios, que muitas vezes desincentivam a alocação ótima das fontes geradoras.

INTRODUCTION

The electric power generation in Brazil is predominantly hydraulic and accounted for approximately 85% of installed capacity by the end of the 90s, when the unbundling of the sector took place, which separated it in four distinct segments Generation, Transmission, Distribution and Energy Trading. In the early 2000s there was a long drought and the country underwent an energy supply crisis, which led the Federal Government to take several measures such as rationing of consumption and encouraging alternative sources of generation. In July 2001 the Management Chamber of Electric Energy Crisis created the Emergency Program for Wind Energy [2] in order to deploy 1,050 MW by the year 2003. Even with incentives such as the purchase of the total energy generated 120% overpriced, the program failed and ended up with not a megawatt from wind generators installed. Amidst the supply crisis and trying to diversify the energy matrix, the Federal Government established the Incentive Program for Alternative Sources of Electric Energy (PROINFA) through Law nº 10,438/2002 [3]. PROINFA aimed to add more 3,300 MW from alternative sources. Of these, 1,100 MW should be from wind farms, and the purchase of energy provided through contracts awarded by Centrais Elétricas Brasileiras SA (Eletrobras), within 20 years from the date of entry into operation defined in the contract. Enterprises must demonstrate a nationalization degree of equipment and services in an amount not less than 90%.

Law nº. 10,438 was regulated in March 2004, when finally the Eletrobras could open the Public Call to hire electrical energy from alternative sources, including wind farms. The first signings of Eletrobras increased the installed capacity of 27 MW in 2005 to 235 MW in the next year. In 2009, when the first auction for contracting energy from wind farms took place, Brazil had already contracted 600 MW of wind energy through PROINFA. Since then the Brazilian wind power sector has grown exponentially with an expectation to reach 20 GW by 2025, "Fig. 1"[4]. By the year 2018 Brazilian National Electricity Agency (ANEEL - *Agência Nacional de Energia Elétrica in Portuguese*) held 21 auctions where energy from wind source was purchased in a total more than 20 GW installed power in parks located in the Northeast and Southern regions, with delivery expected energy between 3 and 5 years from the signatures of contracts. In terms of photovoltaic energy, Brazil has contracted 3,8 GW, with 2 GW already in operation at the end of 2018. There was no energy storage connected to the SIN in operation by the end of 2018.

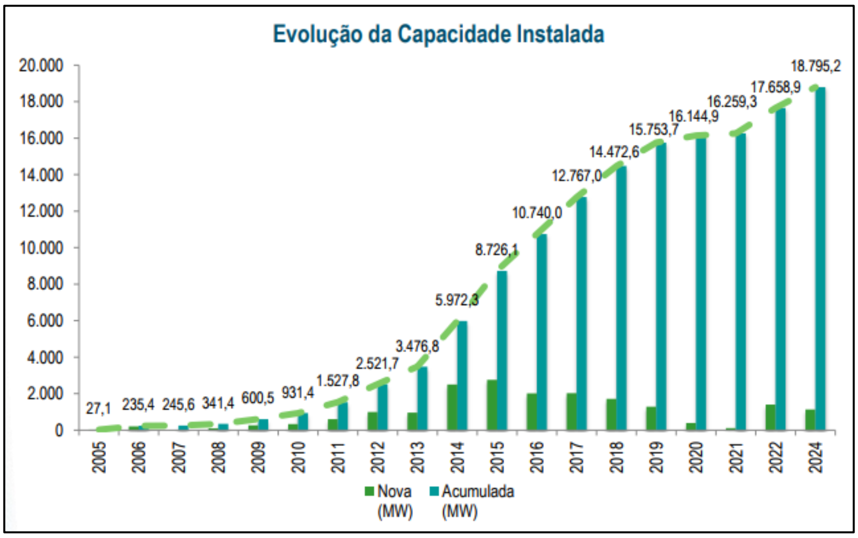

Figure 1 - Power Capacity Evolution of Wind Power Plants in Brazil

RELATED TRANSMISSION WITH WIND POWER PLANTS

The most significant wind power plants were contracted via PROINFA by 2009, with pre-defined flow conditions in the existing network. Thus, studies were undertaken to determine the remaining capacity of the national interconnected grid at probable connection points of wind farms. Many small parks were contracted due to this condition, all of them connected to the distribution system at lower voltages to 130 kV. The largest wind farms contracted by Eletrobrás was the Osório, in the southern state of Rio Grande do Sul, with 150 MW installed and the Formosa Beach in Camocim city, in the northeastern state of Ceará, with 104 MW. Interestingly, each one located at opposite ends of the country, south and northeast, in areas of greater intensity winds on the country, “Fig. 2”. Both parks are connected to existing substations at 230 kV, Osório and Sobral, who would later be expanded due to entry of new generators in these regions.

The first reserve energy auction took place in 2010, for energy supply in 2012. In that event 1,800 MW were auctioned, divided among 71 parks with installed power between 6 and 50 MW, located in the states of Bahia, Ceará, Rio Grande do Norte, Sergipe and Rio Grande do Sul. The large number of small wind farms is due to tax breaks for small power plants. The average energy price of these parks was R$ 148.39 per MWh. Then there was the second reserve auction and an auction of alternative sources, both of them to start operation in 2013, totaling 2,078 MW. The physical guaranty of the enterprises of these three auctions is 1,800 MW.

In the same year 5 transmission lines and 5 substations associated with the dispatch of these power plants were tendered, auctioned with an Annual Allowed Revenue (RAP, *Receita Anual Permitida in Portuguese*) around 20 million of reals.

Energy is paid in reals per MWh, while the transmission is paid by the availability of facilities in reals per year. To compare both, one must put them on the same basis. Thus, we transform R$/MWh to R$/year in the following equation:

$$EP_y = EP * FG * 8760h \quad (1)$$

Where:
EP_y: energy price in reals per year;
EP: energy price in R$/MWh;
FG: physical guaranty of all wind power plants;

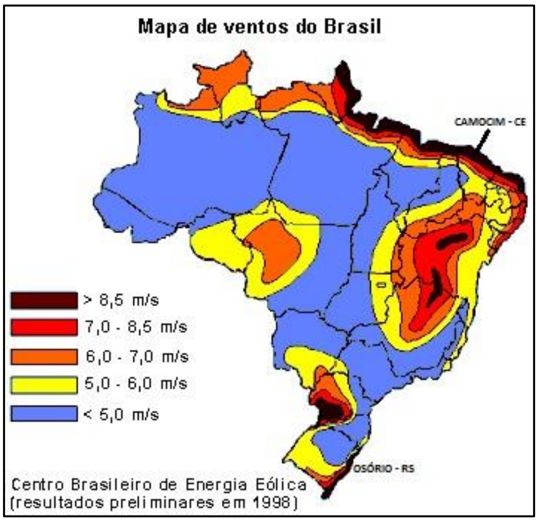

Figure 2 – Brazil wind map

In our case, splitting the cost of transmission by the annual average of assured energy, the cost of the transmission system is less than two reals per megawatt assured, or about 1% real increase in the energy price. This same reasoning is used for other wind farms auctioned by 2015, "Tab. I", and their associated transmission systems.

Between 2011 and 2016, 19 auctions for the contracting of public service of electrical transmission took place. Of them, 85 lines and 49 substations are associated with wind farms flow, "Tab. II". In this case, using the equation "(1)", we will have an increase of 37.5 reals per megawatt generated, increasing the average price of electricity from these wind farms to R$ 162.00. This price is similar to the average price of energy from thermal power plants powered by natural gas, which is the cheapest fuel in Brazil. That is, the price is not relevant in the choice between remote wind farms of load centers and thermal power plants to natural gas close to the load centers.

TABLE I. WIND POWER PLANTS AUCTIONS BY 2015

Auction	**Farms**	**Power (MW)**	**Energy (avr. MW)**	**Price (R$/MWh)**
02/2011	44	1.070	485	102,07
03/2011	34	860	429	99,61
07/2011	39	976	479	102,18
06/2012	10	282	152	91,25
05/2013	66	1505	700	110,51
09/2013	39	868	380	124,43
10/2013	97	2338	1.083	120,30
03/2014	22	551	275	126,18
06/2014	36	926	436	136,11
08/2014	31	769	333	142,90
02/2015	3	90	42	177,47
04/2015	19	539	252	181,09
09/2015	20	548	285	202,86
TOTAL	460	11.322	5.331	124,27[1]

Surce: ANEEL [1]

[1] weighted average by the physical guaranty

TABLE II. LINES AND SUBSTATIONS AUCTIONED FOR WIND POWER FLOW

Auction	**Lot**	**Lines**	**Substations**	**Revenue (R$x106/ano)**
01/2011	A	4	3	31,9
	B	1	1	4,1
	C	1	2	7,8
04/2011	L	4	2	68,9
06/2011	A	4	1	49,4
03/2012	B	3	2	12,1
	C	3	2	18,2
05/2012	A	4	3	77,4
07/2012	A	6	2	145,6
	E	1	2	31,9
	G	3	0	5,9
01/2013	A	1	0	34,6
	B	2	2	9,7
	C	2	4	12,9
	G	1	0	18,8
02/2013	C	6	5	31,6
	E	1	1	4,9
07/2013	E	2	2	24,5
13/2013	D	1	1	7,8
01/2014	D	2	2	45,6
	E	4	0	48,8
04/2014	A	15	5	336,0
07/2014	A	6	2	144,6
13/2015	A	4	4	404,9
	E	2	0	121,6
	I	2	1	48,5
TOTAL		85	49	1.748

PROBLEMS FACED AND PERSPECTIVES FOR THE FUTURE

Although it was able to operate in 2012, the wind complex Alto Sertão I, with an installed capacity of 295 MW, was out for nearly two years unable to generate power for lack of a transmission line linking the city of Igaporã to the substation of Bom Jesus da Lapa where it would then be connected to the SIN. The lack of generation have costed fifteen million reals monthly, totalizing around 360 million, excluding the expenses incurred with the use of energy from other sources, passed on to consumers.

Built by the Hydroelectric Company of São Francisco (Chesf), the line necessary to connect Igaporã to Bom Jesus da Lapa "Fig. 3" was finally completed in 2014 and inaugurated on June 18th of that year. Chesf is a mixed capital company managed by the federal government with similar objectives to private companies. The search for profit leads the company to choose the best opportunities to raise funds in the financial market and make investments, which contributed to the delay in the implementation of the lines necessary for the flow of the wind farms in the northeastern region of the country, where Chesf operates. Beyond the economic problems, environmental licensing have become more difficult since 2010, when the demand for new transmission facilities grew sharply.

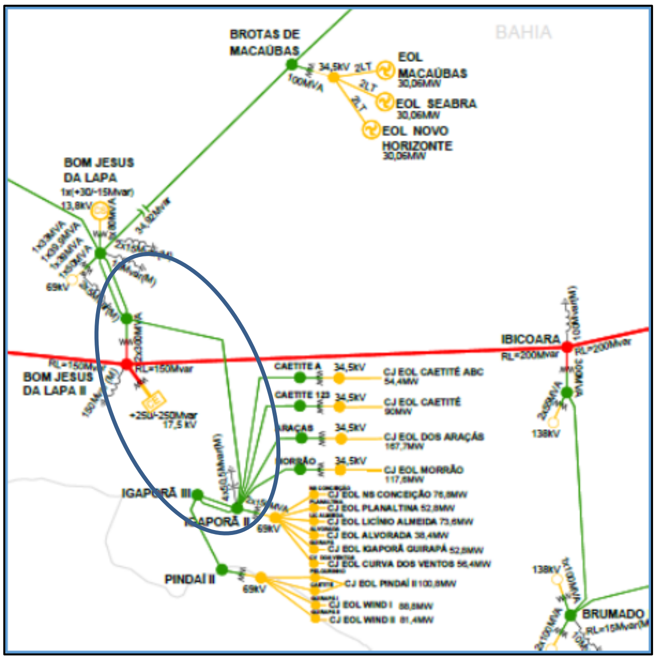

Figure 3 - Wind power plants conections at SE Igaporã

A similar problem has happened with other substations and lines auctioned to Chesf, such as substation João Câmara, where about 1,500 MW of wind power were connected and Aracati II with 500 MW of wind farms "Fig. 4". The RAP of these three projects groups was 19.2 million reals a year, much less than the damage caused by the delay in the entry into operation. Thus, any penalty imposed on transmission company is insignificant if compared to the cost of the lack of generation. In addition, if the transmission company was liable for the damage it caused, it would mean its bankruptcy. Even so, in September 2012, ANEEL decided to pursue legal action to repair damages caused by the delay in the entry into operation of two transmission companies responsible for delayed transmission projects.

From the first delays in transmission systems, ANEEL started signing generation contracts without guarantee of payment if there were delays in the necessary transmission, thus transferring the risk to generation entrepreneurs. Of course, the transmission delays have continued and the solution was to extend the deadlines for implementation of transmission facilities, increasing the gap between operation dates of generation and transmission. Generation auctions for delivery in 3 and 5 years were realized in 2015 and 2016, meanwhile, on the transmission auctions the operation starting date was predicted to be in five years.

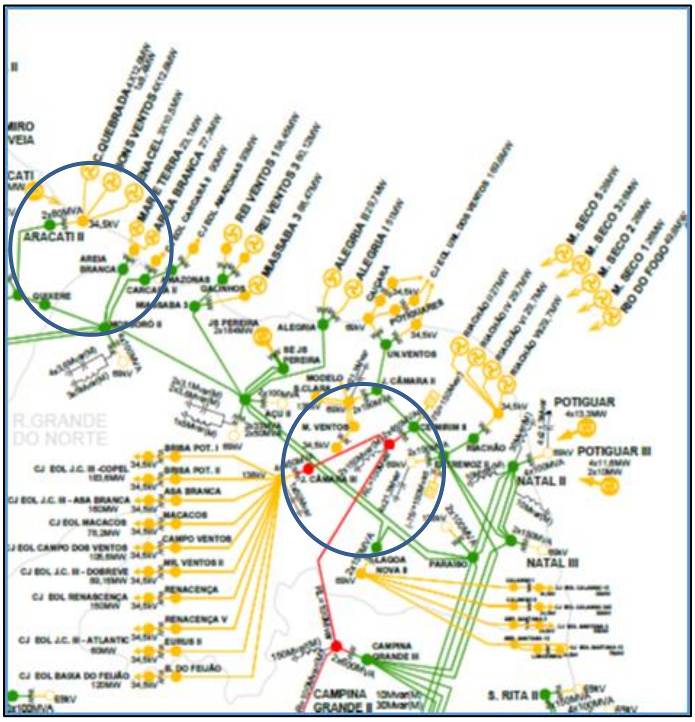

Figure 4 – Wind power plants conections at SEs Aracati II and João Câmara

The same did not happen in the south of the country, in part due to other planning flaws. There is an over dimensioned transmission system in the west of Rio Grande do Sul state. It is composed by a 500 kV system, installed in the early 2000s during the energy crisis in Brazil, dimensioned to import up to 2,200 MW from Argentina, which never happened due to lack of supply in the neighboring country. The system operates intermittently with an exchange of 500 MW, leaving a gap at up to 1,700 MW on the system. In other hand, the 230 kV system was reinforced, at the same time, to drain the energy of the thermal power plant in Uruguaiana, with installed capacity of 600 MW, which operated for a short period until the supply cut of natural gas from Argentina. This system is used in part by the wind farm of Cerro Chato, with installed capacity of 217 MW and will be used in a few years by other wind farms auctioned to that region.

In the Rio Grande do Sul coast, the winning entrepreneurs in wind power plants auction were the same, in most of the cases, that alone or associated to thirds entrepreneurs, won lots of transmission, so that there was no significant delay in entry into operation of the transmission systems in relation to entry into operation of wind farms.

CONCLUSIONS

According to the Ten Year Plan for Energy Expansion (PDE 2024, *Plano Decenal de Expansão in Portuguese*) [8], the expansion of power generation for the ten-year horizon must be carried out sustainably, meeting the economic criteria and security of supply for the electric power system. Planning for the expansion of electricity supply is carried out based on standards established by the National Energy Policy Council (CNPE, *Conselho Nacional de Políticas Energéticas in Portuguese*). CNPE is an advisory body of the President to formulate energy policies and guidelines, which determines that the marginal cost of operation (CMO, *Custo Marginal da Operação in Portuguese*) must be equal to the marginal cost of expansion (CME, *Custo Marginal da Expansão in Portuguese*). In addition, the maximum risk of deficit allowed, of any magnitude in each year of planning, must be less than 5% in each SIN subsystem, considering all hydrological scenarios. We verify that the costs of transmission are not among the parameters used for planning the generation expansion.

In recent years, the contracts signings of wind generation were around 18,500 MW, occurred, as shown in “Fig. 5”, being the majority located in the Northeastern and Southern Brazil. In the same period, we have contracted 3,600 MW in solar photovoltaic power plants, which is around 20% of wind. This percentage are growing fast and, in a few years will be significant compared with wind farms. These two sources of renewable energy, operating together need some storage system to improve their assured energy and avoid voltage and frequency control equipments.

There is a pressing need to expand the transmission system in the Southern and Northeast regions in increasingly short deadlines, due to the growing trend of contracting these types of renewable energy sources. Energy Research Company (EPE) have been conducting specific studies, called Prospective Studies, in order to expand the transmission system to enable integration of the alternative renewable sources potential, not identified yet.

On this way, this prospective potential, estimated based on last energy auctions, includes the integration of wind and solar power projects, given the excellent results obtained from these source in recent auctions. However, the expansions proposed in prospective studies could be used to the flow of energy from all types of sources.

On the other hand, the aim of the Basic Network expansion studies for transmission facilities, which comprises voltages equal to or higher than 230 kV, are made to allow market participants to have free access to the network, enabling an environment for competition in the generation and trade of electric energy in the SIN.

In addition to the local market connection, the transmission system plays an important role in linking the electricity sub-markets, allowing the equalization of energy prices by minimizing bottlenecks between submarkets, resulting in an optimized dispatch of the generating units.

The development of transmission expansion studies in the ten-year horizon is based on projections of electric load and generating plan, with the use of applicable planning criteria. The power grid initial studies are done by performance analysis on a permanent basis in various load levels and generation dispatch scenarios through power flow simulations in normal condition and no simultaneous contingency of the network elements (n-1 criteria). The analysis to the expansion of the transmission system planning follow a minimum performance criteria, and the selection of alternatives conducted under perspective of the electrical performance equalization and the minimum overall cost approach. These studies considers, in addition to costs relating to electrical system losses, the investments for the necessary expansion of the

Basic Network, in other transmission facilities (voltage level below 230 kV) in the distribution network and the facilities of the restricted use of each enterprise.

ANEEL and the government must develop regulations to encourage large-scale mixed power plants, with wind, photovoltaic and energy storage operating together.

Although the increase in energy prices, due to transmission expansion, is negligible as we see on this paper, there are other reasons, such as the need for matching the deadlines for starting operation of generation and its transmission, which could be improved with a generation and transmission joint bid. Such thoughts lead us to look for an integrated energy planning, to consider the cost of different sources of generation with the corresponding needed expansion of the transmission system and its actual scheduling times of construction. In these deadlines, one cannot forget the environmental licensing processes and the land release for granted, which usually are responsible by a significant delay in the operation start of transmission lines and power plants.

Joint bid auctions for generation and transmission, can be carried out without changing both current models. Three ways of implementation of the auctions are suggested.

A. *Auction G & T*

With a single price, where the transmission facilities costs would be added to the energy price. As we have previously seen, the energy price increase is not significant, what would maintain the competition between the various sources with their restricted interest transmission networks. There would be a single G & T contract with the possibility of segregation of transmission. The laws and regulations allow that, after completed, the transmission facilities can be transferred, free of charge, to a transmission company, following certain rules.

B. *Auction G + T (1)*

With the price of energy and transmission revenue distinct and a single buyer. In this case, we use the score auction concept with weights to put the discounts in energy price and RAP at the same base (Equation 2) to get the lowest overall cost for users that will define the auction winner. There will be a single G & T contract with the possibility of partial disposal, only the transmission or only the generation. The sale will take place through direct sale of the facilities, from an entrepreneur to another with technical and economic qualification accepted by ANEEL.

$$SB = \frac{G_{\%} * G_{\$} + T_{\%} * T_{\$}}{G_{\$} + T_{\$}} \qquad (2)$$

Where:
$G_{\%}$ is the energy price discount in percent;
$G_{\$}$ is the energy price in R$/MWh;
$T_{\%}$ is the transmission revenue discount in percent;
$T_{\$}$ is the transmission revenue in R$/year;

C. *Auction G + T (2)*

With energy prices and transmission revenues distinct and one or two buyers. It applies the same previous methodology to define the winner of the auction. There will be two contracts, one of generation and another of transmission with cross default clauses to transfer the risk of delay between each other, ie, if one company finishes the work before the other will not be entitled to payment until the entry in operation of the other.

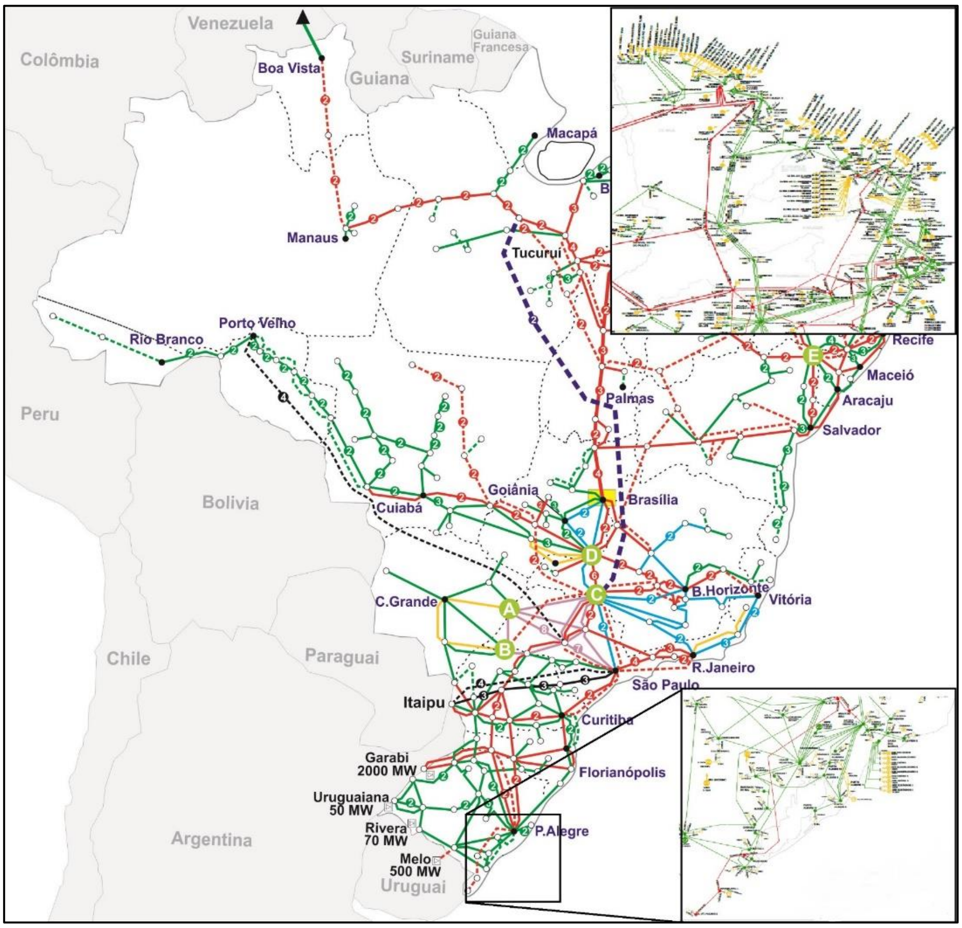

Figure 5 – Main location of wind farmes

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