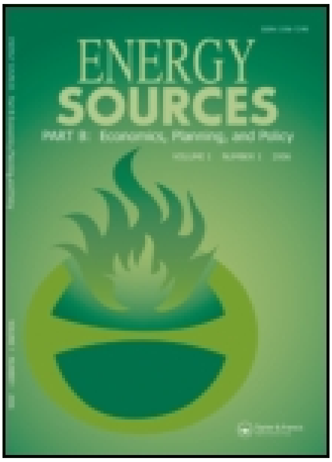

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New Renewable Energy Sources for Electric Power Generation in Brazil

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Abstract *Producing electricity from wind, biomass and solar sources (WBSS) is a promising alternative from a sustainability perspective. Considering that the increasing insertion of WBSS into the Brazilian National Grid is an irreversible trend, it is essential to go deeper into the debate on the resulting impacts. Will it be possible to service the growth in load using WBSS and to what extent? Which strategy should be adopted to foster the inclusion of WBSS while retaining security of supply? The main objective of this article is to discuss the problems that surround these questions under the focus of full load servicing.*

Keywords electricity supply, energy policy, expansion planning, renewable sources, security of supply

1. Introduction

The characteristics of seasonality and variability in the production of electricity from wind, biomass, and solar sources (WBSS) result in a need for additional measures, in both the long- and short-term view, such that the load can be supplied with maximum security and reliability. ("Security" should be considered as being associated with the availability of supply and "reliability" with the quality of supply). A number of solutions may be applied with the aim of mitigating these problems. The complementarity of other sources, as well as energy storage, emerge as promising paths. Complementarity may be brought into operation with hydro, thermal, and nuclear power stations; without them it is not possible to fully meet the load requirements. Looking more specifically at hydropower and comparing the characteristics of this type of generation with those of WBSS, natural complementary associations can be found. In addition to this, the incorporation of WBSS into the generation mix, as a complement to hydroelectric power, allows for the diversification of the power system and increases the flexibility of the use of water resources. The energy policies should set objectives and priorities on which the power system planning will be based (Doukas et al., 2008).

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2. Load Supply

One way to analyze load behavior is by using the daily load curve and the load duration curve. The former has a daily time horizon and is more detailed in terms of those aspects related to variation and levels, while the latter, with the usually adopted annual horizon, allows a better assessment of base generation. Two significant factors can be evaluated with the help of these curves: the generation response given variations in load and the sustained maintenance of the base generation. Generation at the base consists of operating by supplying a particular power value during time thresholds over the course of an analyzed period and preferably when there is little modulation in generation values. In 2004, in the load curve for the Brazil Southeast-Midwest subsystem, there was a power level (24 GW) whose corresponding generation should service the load for 8,760 h of the year. It should be emphasized that there are no margins for error in this generation base, i.e., it is imperative to supply 100% of the load (in this instance 24 GW) 100% of the time. Consequently, the generation expansion and operation planning have to meet this requirement. In this regard, the generation mix is of paramount importance.

Another important issue to note is the behavior of the load over the course of a day. In a typical daily load curve, the variations observed are quite peculiar, especially the elevations known as "load ramps." These ramps are characterized by large increases in the amount of load in a relatively short period of time. The most critical ramps can be observed at the beginning of the first "average" load period and at the beginning of the heavy load period. Load periods in Brazil are light (midnight to 6:59 a.m.), average 7 a.m. to 5:59 p.m. and 9 p.m. to 11:59 p.m.) and heavy (6 p.m. to 8:59 p.m.). As an example, take the daily load curve of the Brazil Southeast-Midwest subsystem that corresponds to a typical working day. The ramp at the beginning of the average load is less accentuated, though the amplitude is greater. It starts between 5 a.m. and 6 a.m. and lasts until between 10 a.m. and 11 a.m. This ramp corresponds to an approximate variation of 10 GW at an average rate of 30 MW/min. The ramp that occurs at the start of the heavy load shows a smaller amplitude, but involves a far shorter time interval in comparison with the average load ramp. The start occurs between 5 p.m. and 5.30 p.m. and lasts until between 6 p.m. and 6.30 p.m. The variation in this case is approximately 5 GW at an average rate of around 80 MW/min. The point addressed in this discussion is that the power generation system must be able to service immediately these sharp variations, keeping the generation/load balance during all the time.

3. Generation of Electric Power From WBSS

3.1. *Wind Power*

The operation of wind power plants is characterized by the intermittency and variability of the primary energy source employed and the difficulty of predicting the production levels (Chompoo-Inwai et al., 2005). Moreover, the growing share of this type of generation causes impacts both for the operation of the power systems, and also for the electrical energy market (Brekken et al., 2010).

As far as predictability is concerned, the example of the Brazilian wind generation farms of Rio do Fogo, Índios, Osório, Sangradouro and Praia Formosa is meaningful. The National System Operator observed the following average absolute deviations between forecast and actual production of these farms: 29.2% in the week of January 2 to 8, 2010; 42.5% in the week of March 6 to 12, 2010; 20.3% in the week of June 5 to 11, 2010;

68.8 % in the week of September 4 to 10, 2010; and 51.2% in the week of December 4 to 10, 2010.

When looking at the intermittency issue, there is an example out of Germany where the proportion of the wind power source reached 14% in 2005, with an average capacity factor of 17% (IEA, 2007). A situation occurred where the company responsible for supplying electric power to a large part of this country, E.ON Netz, faced variations in the supply of wind power that reached as high as 80% of the installed power for this source. This event gave rise to serious difficulties with the load supply (Boyle, 2007).

As for the aspect of variability and the possibility of falling in the cut-off region of the turbines, the example of the wind measurement station of São João do Cariri (in the Brazilian state of Paraíba, data at intervals of 10 min—at 50 m—between July 1 and 3, 2006) is quite instructive. The frequency distribution of the wind speed in this station produced the following results for a total of 1,152 samples: less than or equal to 3 m/s (36.7%), greater than 3 and lower than 4 m/s (16.7%), greater than 4 and less than or equal to 5 m/s (15.9%), greater than 5 and less than or equal to 6 m/s (15%), greater than 6 and less than or equal to 7 m/s (8.6%), greater than 7 and less than or equal to 8 m/s (4.9%), greater than 8 m/s (2.3%). It should be pointed out that, in this location, according to the 2001 edition of the Brazilian Wind Potential Atlas, both the quarterly average (March through May) and the annual average wind speed are above 6 m/s.

3.2. Biomass as a Source of Electricity

Despite the fact that it cannot be considered as intermittent, nor does it present the same levels of fluctuation as wind power and solar energy, the generation of electric power from the bagasse of sugar cane, the input most frequently used as biomass in Brazil, does possess seasonal variations. Outside of the harvesting period, which in the case of the state of São Paulo, the main producing region in Brazil, extends from May to November, the production of electricity is practically nil. Therefore, the impacts of this seasonal behavior in the system where this form of generation is connected should be considered in the long- and short-term planning studies, as well as in the power dispatch (Pignatti, 2007).

According to data made available by the energy research company EPE, a state-owned company responsible for expansion planning studies in the electricity sector in Brazil, in the months of January, February and March, electricity generation is declared as nil for all the thermoelectric power plants (TPPs) that consume sugarcane bagasse. In December, only one of these TPPs declared any availability of energy, and the value was well below the average production for the plant. In April, the availability of these TPPs is well down in comparison with their production at full capacity.

3.3. Solar Energy

Solar energy may be considered as less random than wind power due to the fact that the forecast of availability of this source is more accurate. Nevertheless, factors associated with microclimate which are difficult to forecast, such as cloud cover and the percentage of water vapor in the air, introduce a considerable degree of randomness in the short term. This makes planning difficult in this time horizon, which leads to the need for complementary sources of power (Phoon, 2006).

Data obtained from the weather station at Caicó (daily data from October 1 to 7, 2004, at discrete intervals of 1 min.), in the Brazilian state of Rio Grande do Norte, provide an example of the typical behavior of global solar radiation intensity. The frequency distribution, for the period from 8:10 a.m. to 8:23 p.m. is as follows: less than or equal to 200 W/m^2 (24.9%), greater than 200 and less than or equal to 400 W/m^2 (20.3%), greater than 400 and less than or equal to 600 W/m^2 (16.3%), greater than 600 and less than or equal to 800 W/m^2 (12.3%), greater than 800 and less than or equal to 1,000 W/m^2 (10.4%), greater than 1,000 and less than or equal to 1,200 W/m^2 (15.3%) and greater than 1,200 W/m^2 (0.5%).

The nighttime period is not represented, due to solar radiation being nil. This meteorological station is situated in a location where, according to the Brazilian Solar Energy Atlas (CEPEI, 2001; INPE, 2006), the energy originating from average global solar radiation, taking the quarter from September through November, is in the range from 5.9 to 6.3 kWh/m^2. This variability can be found within a day and between days. One fact of crucial importance is the reduction in solar radiation beginning at 5 p.m. and reaching 0 by around 9 p.m. It is precisely during this period, at 5 p.m., that the heavy load period ramp occurs, where consumption of electrical energy is most pronounced. The peak load occurs between 5 p.m. and 6 p.m., shifting to between 6 p.m. and 7 p.m. during the Brazilian summertime. Besides, solar radiation intensity is significant from 8 a.m. while the load ramp of the early morning begins around 7 a.m.

3.4. Small Hydroelectric Power Plants

Small hydroelectric power plants (SHPs) are undertakings installed in small river basins. They are usually subject to large fluctuations in the river flows and they do not have enough capacity in their reservoirs to store the large surplus flows, available during the wet seasons, in order to produce power during the dry seasons. The majority of SHPs are run-of-the-river plants with, at most, daily or weekly regularization of their reservoirs' incoming streamflows (Fill et al., 2006).

Let's take the example of the SHPs at Queluz and Lavrinhas. Both have an installed capacity of 30 MW and a physical guarantee of 21 average-MW, and are situated on the Paraíba do Sul river (in the Brazilian state of São Paulo). The variability of the streamflows (daily average rates in 2007) is revealed in the frequency distribution: less than or equal to 100 m^3/s (1.6%), greater than 100 and less than or equal to 150 m^3/s (13.2%), greater than 150 and less than or equal to 200 m^3/s (59.7%), greater than 200 and less than or equal to 250 m^3/s (16.2%), greater than 250 and less than or equal to 300 m^3/s (4.4%), greater than 300 and less than or equal to 350 m^3/s (3.0%), greater than 350 m^3/s (1.9%).

As these plants do not aggregate regularization capacity, their production is subject to the streamflows where they are installed. The latter have a seasonal component and a random one, cause by rainfall variations in the river basins. So, the same happens with the electric power generated by the plants. Moreover, there exists an additional constraint for the operation of SHPs, namely sanitary flow, i.e., the minimum streamflow that must be maintained in the river, regardless of the inflows to the turbines.

4. The Insertion of WBSS Into Brazil's Electric Power System

The biggest limitation of most renewable energy sources is their intermittent nature (Kaygusuz, 2007). The decentralized production of electricity leads to problems of stability for the associated electric systems and requires technological solutions that can mitigate these problems. These solutions are essential elements, as far as security and reliability of supply are concerned, when there is a significant inclusion of renewable energy sources in the generation mix (Ibrahim et al., 2008).

The participation of the WBSS in a power system requires, in proportion to their share in total generation, more flexibility in the system, as well as "backup" sources and energy storage mechanisms, considering time horizons ranging from a few seconds to several days. Storage systems offer additional advantages, namely: mitigation of transmission constraints, the possibility of temporal reallocation of power generation so as to match supply and demand, attenuation of the agents exposure to short-term market prices due to the predictability of generation, maintenance of system stability at times of sharp falls in generation from renewable energy sources, and compensation for the typical fluctuation of these sources (Chen et al., 2009).

The hydro plant reservoirs act as virtual electricity storage systems (Mason and Williamson, 2010), with the water stored in these reservoirs being available for prompt and immediate use for power generation whenever necessary (Demirbas, 2007; Bakis, 2007). Hydro power plants with reservoirs respond rapidly to load ramps. They are easily dispatched (Mason and Williamson, 2010) and can provide spinning reserve at low cost (Mason and Williamson, 2010). These characteristics make the hydropower stations (HPS) a suitable solution for offsetting the variability and intermittency of the power produced from WBSS. Such integration provides more flexibility to an electric power system containing WBSS (Evans, 2009).

The firm power provided by hydro power stations with reservoirs can offset fluctuations and seasonality arising from WBSS at amounts proportional to the reservoirs' regulation capacity (Jaramillo et al., 2004). In a study conducted by Mason and Williamson (2010), one of the conclusions highlights a constraint of great importance: the maximum share of wind power in a power system that is predominantly water based, as is the case in Brazil, is directly dependent upon the available storage capacity in this system.

A HPS with a large accumulation reservoir has a high level of controllability, both when meeting base load and when needing to respond rapidly to load ramps. Limitations in the stock of water lead to consequent service-related restrictions in both cases (Twidell and Weir, 2006).

Projects for the generation of electricity from hydraulic power are relatively flexible in terms of the scale of production and adaptation to the area of implementation. A vast scale of installed power can fall within the scope of hydroelectric projects, ranging from a few kW up to tens of GW. No other form of electricity generation has such a breadth of scale and adaptability (Kaygusuz, 2009a).

The planning and construction of only run-of-the-river hydro power plants, something which has been occurring in Brazil in recent years, have the following consequences: reduced capacity to regularize the hydroelectric system, leading to a lower efficiency of the system (simulations show a reduction, in Brazil, from 41% in 2010 to 32% by 2020), the need to build thermal power plants based on fossil fuels in order to compensate the loss of regularization capacity of the HPSs (the share of such type of thermal power plants in Brazil rose from 7% in 1998 to 14% in 2008, assuming firm power), the dispatch of the thermal power stations (TPSs) is required earlier and earlier, as the regularization capacity diminishes (simulations suggest the need to bring forward the dispatch of the TPSs in Brazil by 14 months, assuming a 30 month cycle). Obviously, another consequence is the increase in CO_2 emissions, resulting from the larger use of TPSs consuming fossil fuels to meet the power demand in the country (Brito et al., 2009).

Bezerra et al. (2010) found out in a study that, if the government forecasts for generation expansion planning in Brazil will come true, the picture for 2020 will be far from favorable to the environment. Restrictions on new projects for HPSs with significant storage capacity will require a lot more TPS dispatch. This will lead to a rise of 203% in CO_2 emissions in 2020, in relation to the current level of emissions. By that year, regularization capacity will have dropped 12%. The study also concludes that, for each 1% loss in regularization capacity, there is a 19% rise in CO_2 emissions. However, this unfavorable picture can be reversed if the plan not to build more HPSs with reservoirs is re-evaluated.

In global terms, electric power generated from hydro power plants avoids the burning of 120 million tons of coal, or 83.3 million cubic meters of fuel oil (Demirbas, 2007). Hydroelectricity goes on providing a clean energy opportunity both for Brazil and for other countries that still have significant untapped water resources. Most of the environmental impacts produced by HPSs are local; so they are easier to mitigate (Komurcu and Akpinar, 2010). Their greenhouse gas emissions are significantly lower than those of TPSs burning fossil fuels. In addition, emissions of particulate matter are practically nil, which is not the case with fossil fuel sources. In this regard, the contribution to public health is undeniable and has positive repercussions (Balat, 2006).

The water stored in the reservoirs of hydro power plants can be used for other purposes besides power generation (Komurcu and Akpinar, 2010). In a developing country, such as Brazil, water supply for communities, flood control, irrigation, better conditions for navigation and waterborne leasure activities are multiple uses of the water from theses reservoirs that can be very valuable in fostering local and regional development. Unfortunately, in Brazil these multiple uses of the water from HPS reservoirs have not been developed to the extent they could be, because hydroelectricity has been, by far, the dominant use of water, with well-organized companies exploring this activity. The other uses of water, with far-reaching local benefits, usually have lower priorities and are badly organized. This picture should change significantly if the current strong environmental resistance to the building of large storage reservoirs in the country is to be overcome in the future.

The technologies involved in building and operating HPSs have been fully mastered in Brazil for over 50 years. This alternative presents the lowest operating costs and the longest useful life amongst all the electricity generation options. Moreover, there exists, also, the possibility of extending the useful life of HPSs by means of rehabilitation. The process of converting energy in this type of power station is one of the most efficient (around 95%), providing excellent returns on investment (Yüksel, 2009).

The characteristics and potential benefits of hydro power plants make them a key element in the implementation of sustainability in the process of electric power production (Kaygusuz, 2009b). According to IHA (2003) and Kaygusuz (2009b), this assertion is supported by the following facts: HPSs use a renewable source of energy, their reservoirs can provide backup power for other renewable energy sources, they are very valuable in terms of security of supply, the price of electricity produced in HPSs is stable, the water stored in the plants' reservoirs can be used for several purposes with many local benefits, they assist in combating climate change, they avoid the emissions of air pollutants, and they can help promote local or regional development.

5. Conclusions

The production of electricity from renewable energy sources brings numerous benefits, both for the environment and the economy, to society in general and the electricity sector itself inasmuch as it stimulates the opening up of new areas of scientific, economic and social development, and contributes to the diversification of the generation mix.

They should not, however, be regarded as alternative but rather complementary sources, since by virtue of their characteristics of intermittency, variability and predictability, they cannot be the only nor the primary option for the expansion of the electric power supply.

One interesting solution that meets the required prerequisites of security of supply and sustainability is the integraton of renewable energy sources with electric power storage systems. While not losing sight of technical, economic and socio-environmental feasibility, HPSs with storage reservoirs are a promising alternative in this regard.

HPSs with reservoirs, in addition to favoring a growth in the incorporation of WBSS, particularly in the case of Brazil, can assure security and reliability in load supply with low environmental impacts, particularly in what concerns the emission of greenhouse gases. In addition, they can bring infrastructure and factors that stimulate socio-economic development in deprived regions, particularly when the multiple uses of the water contained in the plants' reservoirs are fully exploited for the benefit of local and regional populations. This is applicable not only to Brazil, but also for several other developing countries with abundant water resources.

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