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The Role of Natural Gas Power Plants in Mitigation of High Variability of Renewable Energy Sources in the North and Northeast of Brazil

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Abstract: The increasing penetration of renewable energy sources in Brazil's north and northeast regions indicates economic development, employment generation and income, as well as several other environmental externalities. However, in terms of electric system operations, this situation raises concerns, mainly due to the entry of new wind farms and of the incipient but growing portion of photovoltaic solar generation. In this paper, we discuss the use of natural gas to provide greater flexibility and resilience to the electric system and thus mitigate the impact of the great variability of generation in the region where they preferentially occur. Gas turbines are characterized by rapid response ramps to generation-load changes, and can be used in the gas-to-power success model.

Keywords: variability, natural gas power plants, gas-to-power, and flexibility.

1. INTRODUCTION

Latin America, and especially Brazil, present exceptional conditions for the generation of electric energy from a variety of renewable sources (Vargas, et al., 2016). In the country, these opportunities have a strong presence in the northeast region. This scenario - still a dynamic condition - shows the energy dimension as an important vector of regional development and strengthening regionalization.

However, with increasing Wind Power Plants (WPP) participation (and more recently Photovoltaic Power Plants – PVPP), there is an increase in generation and load uncertainty, implying a need for additional flexibility to maintain the generation-load balance.

In the case of WPP, flexibility refers to the ability of the system to deal with variability and uncertainty in primary source. From the economic point of view, flexibility adds another cost to mitigate variations and uncertainties in energy production by this type of source. This cost should be limited within a reasonable range (Pinto, et al., 2017).

Flexibility is provided by reserves of generation with capacity/speed of response to changes of generation of the units compatible with the variability compensate. These are candidates for this function: hydraulic pumps, gas plants and large battery banks, among others (Ferreira, et al., 2011) (Ren, et al., 2015) (Holttinen, et al., 2012) .

1.1. The Interconnected System

For purposes of electrical-energy planning, Brazil's National Council for Energy Policies (CNPE) subdivide the Brazilian Interconnected Power System (SIN) in subsystems. The subsystems are defined according to the hydrological homogeneity of the regions, so that the simulation of the electroenergetic operation can be performed considering the aggregated or individualized representation of the reservoirs and the inflows, without presenting significant distortions. Currently CNPE divide SIN into four subsystems (Fig. 1): North, Northeast, Southeast/Center-West and South. From this point of view, Maranhão is part of North subsystem.

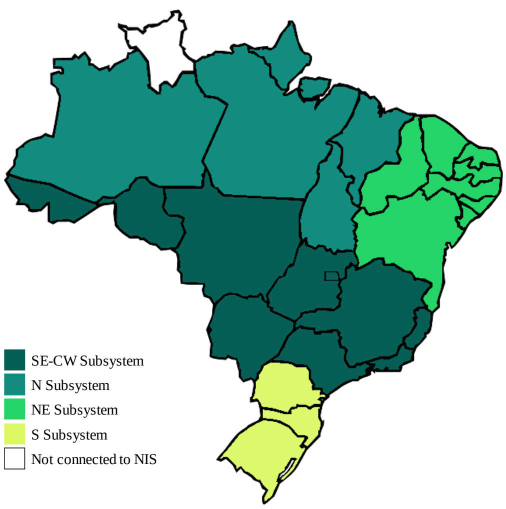

Fig. 1. Brazil's territorial division accordingly to SIN

1.2. This Paper

This paper discusses the opportunity to use natural gas as a mitigation of the generation variability in the region, where the expansion of wind and photovoltaic power plants continues to occur. The use of natural gas facilitates the installation of Thermoelectric Power Plants (TPP) with rapid response ramps to the generation/load changes, which can be used in the gas-to-grid successful model.

The paper is organized as follows: Section 2 presents analysis of electrical energy generation data at N and NE subsystems. Section 3 presents the perspectives of generation expansion in N and NE subsystems. Section 4 presents a brief analysis of Power Transmission System in Maranhão. Section 5 presents the scenario of Natural Gas in Maranhão.

2. ELECTRICITY GENERATION

Maranhão is in a transition region, playing an important role in the political, economic and energy contexts in two geographic regions of the country: North and Northeast. Therefore, at the planning level, it is important to consider it in investment decisions in both regions.

The State of Maranhão started the production of electricity for the Brazilian Interconnected Power System (SIN) in its territory in 2011 (ONS, 2020), when started the commercial operation of Estreito HPP. Since then, there have been several investments in generation in the state, mainly in Thermoelectric Plants and, more recently, Wind Power Plants. Fig. 2 (ONS, 2020) shows the increase of generation capacity in Maranhão since 2010.

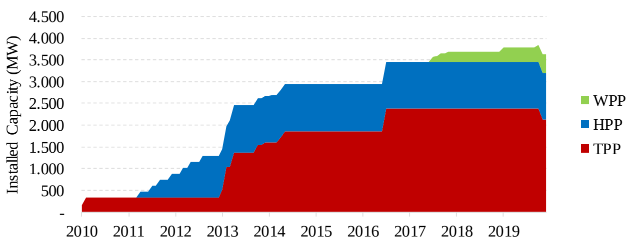

Fig. 2. Installed capacity in Maranhão State

The generation of electrical energy in the State of Maranhão plays an important role in the electric balance of the North and Northeast regions. Fig. 3 presents the daily electricity generation data in the North and Northeast subsystems and in the State of Maranhão, from Jan. 2017 to Dec. 2019.

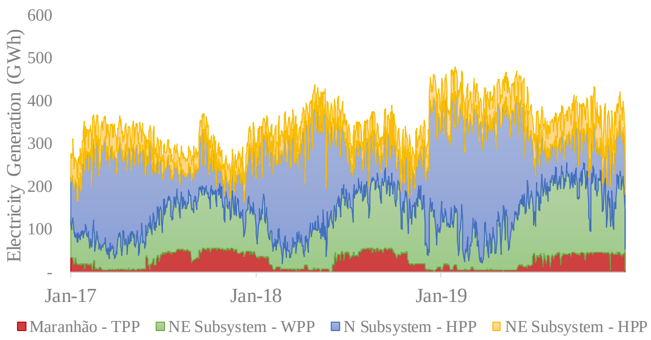

Fig. 3. Electrical energy generation in N, NE and Maranhão

From Fig. 3 (ONS, 2020), it is possible to observe that the electric power generation of Maranhão acts in a complementary way to the intermittent sources of both subsystems, evidencing that Maranhão plays an important role in the electric balance of the North and Northeast regions.

Fig. 4 (ONS, 2020) presents the comparison between the generation from Hydroelectric Power Plants (HPP) in the North subsystem, from WPP in the Northeast subsystem and from TPP in Maranhão State.

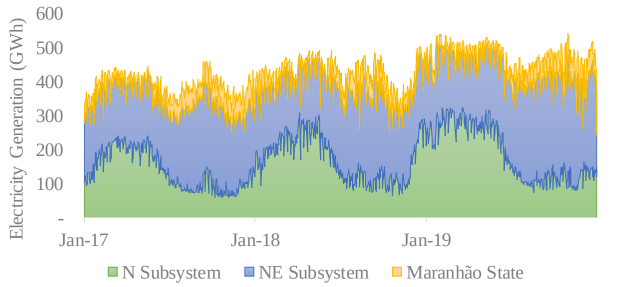

Fig. 4. Comparisson between generated energy from HPP in North Subsystem, WPP in Northeast Subsystem and TPP in Maranhão

From Fig. 4 three important conclusions can be achieved: 1) TPP acts in a complementary way with HPP. When HPP reservoir decrease, the Marginal Cost of Operations (MCO) increase, and National System Operator (ONS) dispatch TPP; 2) WPP are also complementary to HPP, due to complementarity of its primary sources. However, despite of complementarity between wind and rains cycle, WPP generation has a huge variability and its physical guarantee differs from HPP, since HPP has energy stored to mitigate variability in river affluence. 3) TPP supply the lack of energy left by WPP, since WPP are not still enough to supply all energy supplied by HPP in rain periods, and mitigate the variability of WPP generation, increasing system flexibility and availability.

The Natural Gas TPP installed in Maranhão are indeed very important to guarantee the energy balance in North and Northeast regions.

2.1. Electrical Energy Generation from Wind and Photovoltaic sources

In December 2019, the installed capacity of wind power plants was 9% of SIN capacity (Fig. 5 (ONS, 2020)).

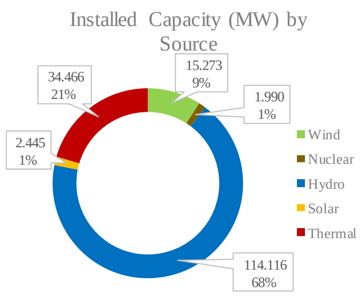

Fig. 5. Installed Capacity by Source (Dec-19)

After governmental incentives, among them PROINFA, but mainly the subsidy for the implementation of the plants with the discount of 50% of the Tariffs for the use of the distribution systems (TUDS) and transmission (TUTS), provided for in Law 9,427, of December 26 of 1996, there was a great increase in the installed capacity of wind power plants (Fig. 6 (ONS, 2020)). The Northeast subsystem was the focus of wind energy investments, due to the favorable wind conditions on the coast.

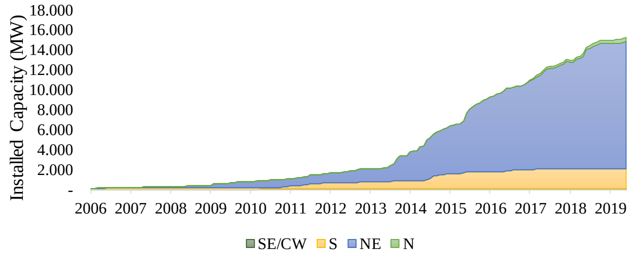

Fig. 6. Wind plants installed capacity evolution in each subsystem

Currently wind power plants represent 39% of the installed capacity of the Northeast subsystem (Fig. 7 (ONS, 2020)). It should be noted that, despite the advantages of generating electricity from WPP, this energy generation has many daily variations, due to the uncertainties associated with its primary source: wind.

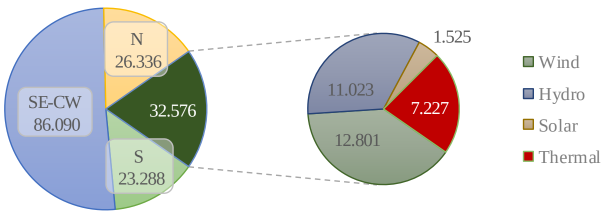

Fig. 7. Installed capacity by source in Northeast region (Dec-19)

However, despite the great evolution in the installed capacity of wind power plants, there is still a great difference between the physical guarantee of the source when compared to energy generation, as seen in Fig. 8 (ONS, 2020).

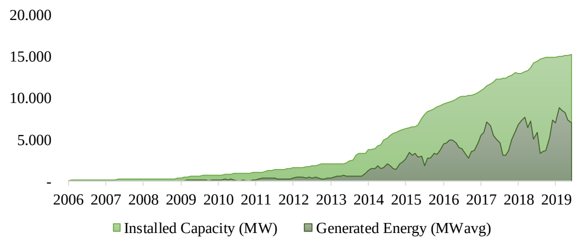

Fig. 8. WPP – Installed Capacity versus Average generation

In Fig. 9 (ONS, 2020) it is possible to observe large daily variations. It is possible to verify that the N-NE exchange reduces as the wind generation increases. However, despite the large amount of energy generated by wind energy sources, due to its variability, this source cannot guarantee energy in the short term. Therefore, it is necessary to make investments in generation from plants with low cost and rapid entry into operation, converging, in this case, to Natural Gas Power Plants.

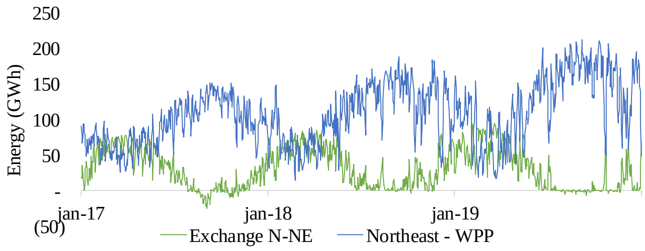

Fig. 9. Daily windy energy generation in NE subsystem x Exchange N-NE

2.2. *Flexibility in electrical systems*

The flexibility of electric power systems is its ability to handle variability and uncertainty in generation and/or demand. In other words, flexibility may indicate whether an energy system can accommodate a large share of renewable sources (Pinto, et al., 2017) (Ferreira, et al., 2011).

The flexibility of a system is directly related to the existence of generation resources that have quick responses, and can absorb variations in intermittent sources without losing the balance load-generation.

An important event involving wind farms is the generation ramps (Holttinen, et al., 2012) (Gallego-Castillo, et al., 2015). Similar phenomena observed in PVPP, however with much higher rates of variation.

The tendency for the increase of PVPP and WPP in the north-northeast regions is evident, due to the natural conditions of the region, allied to aspects related to relief, land prices, among others. This leads to a large concentration of high variability generation, which can lead to problems if mitigating actions are not foreseen in order to provide adequate levels of local flexibility for reliable operation.

3. Generation Expansion

Renewable sources correspond to 49% of the contracted capacity expansion until 2019 (EPE, 2019). Wind corresponds to 25% and PV to 10%. Fig. 10 shows the annual capacity increase based on the contracted expansion until 2019.

The large amount of wind and PV projects competing in the last electrical energy auctions, mainly in North and Northeast regions, indicates that the installed capacity of these sources may increase considerably (ANEEL, 2019).

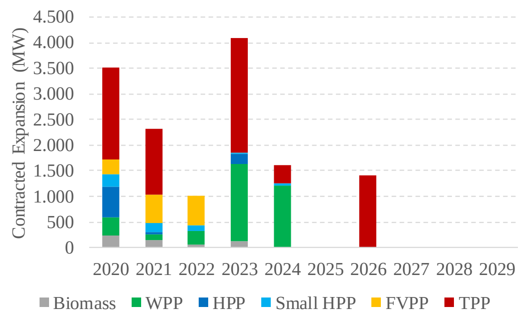

Fig. 10. Contracted expansion until 2019 – Annual capacity increase

The installed capacity of Natural Gas Power Plants installed in Maranhão will also increase. At New Energy Auction (A-6), held on 08/31/2018, 363 MW of installed capacity was contracted, with a Physical Warranty of 326 MW_{avg}. In addition, in the 01/2016 auction, 5.54 MW was contracted, with a Physical Warranty of 3.4 MW_{avg} (ANEEL, 2019).

Fig. 11 (ONS, 2020) shows WPP daily generation from 2017 to 2019. It is clear that it will be necessary to install new TPP that promote physical guarantees to the subsystems.

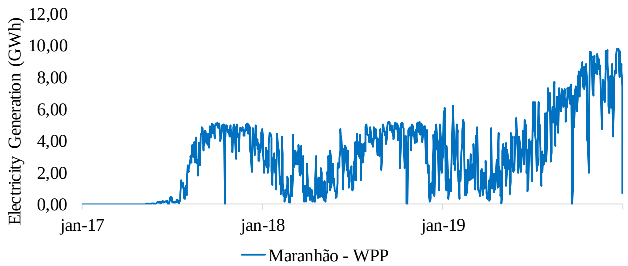

Fig. 11. Daily electrical energy generation from Wind Plants in Maranhão

In addition to operating advantages, the cost of generating electricity from natural gas power plants in Maranhão is quite competitive.

In Fig. 12, the Variable Costs per Unit (VCU) (ONS, 2019) of all the TPP of the North and Northeast subsystems are presented in a box plot graph. From the analysis of Fig. 12 it is possible to verify that the Natural Gas TPP from Maranhão are among the TPP with the lowest VCU. Therefore, the model adopted in the state is beneficial to the tariff moderateness (this is one of the pillars of the restructuring of the Brazilian electric sector).

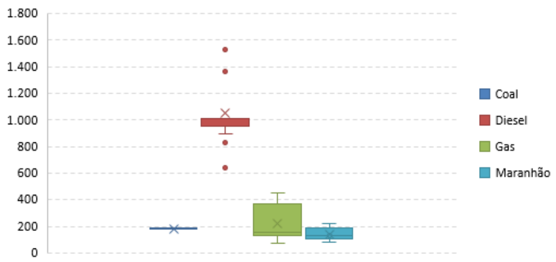

Fig. 12. Box Plot of Termoelectrical Power Plants VCU in N-NE, by fuel, and Maranhão (R$/MWh)

4. POWER TRANSMISSION SYSTEM

Maranhão has a robust electrical transmission network. This system will be further strengthened in the 2018-2023 horizon, with two new transmission lines: the 500 kV Bacabeira-Parnaíba TL and Miracema-Gilbués TL (ANEEL, 2019).

Fig. 13 (EPE, 2019) shows the SIN transmission Lines. The system is more interconnected in the SE and S regions. This fact is explained by the concentration of industrial production, high population density and high amount of power plants in these two regions. North region (green area) is poorly covered by TL, since it is mostly occupied by Amazonia Forest and its urban centers are very disperse.

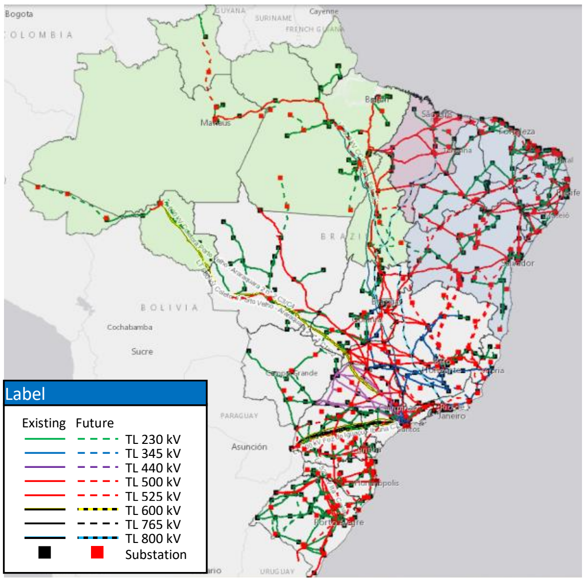

Fig. 13. Brazilian Interconnected Power System (Transmission Lines)

Fig. 14 (EPE, 2019) presents a closer look of Maranhão state. As mentioned before, Maranhão is in a transition region between N and NE regions. Its robust Power Transmission System, despite of its low industrial activity and low population density, can be explained by its important role in the exchange between N-NE and N-SE-CW.

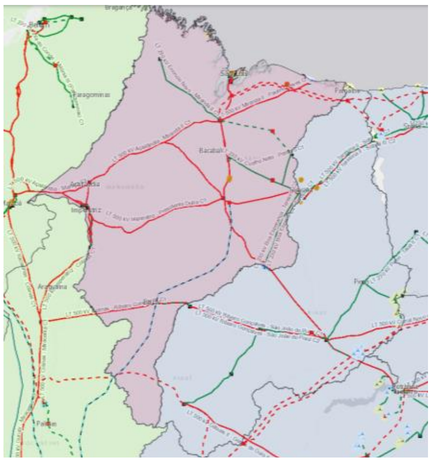

Fig. 14. Maranhão Transmission System – Existing and Projected

Fig. 15 (ONS, 2020) shows the comparison of MCO in each subsystem along 2018 and 2019. North subsystem, in many days, had MCO equal to zero R$/MW, while in other subsystems have positive prices. This indicates lack of power transmission capacity and excess of available hydropower during part of the year. In other words, in the first semester North had excess of power available with reasonable price, but was not able to generate due to transmission limitations.

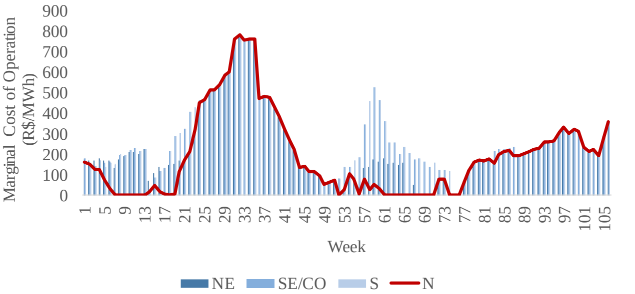

Fig. 15. Marginal Cost of Operation (MCO) of the four subsystems (2018 and 2019)

In the second semester, North's DLP becomes equal to the other subsystems and overcome the VCU of Natural Gas Power Plants (NGPP). This means that new NGPP installed in Maranhão will have a high probability of been dispatched.

As can be seen in Fig. 13 and Fig. 14, many reinforcements and improvements in capacity are planned. It means that North, and consequently Maranhão, will be able to export more Power to other subsystems, which means that more Power Plants can be installed.

Finally, the existent Power Transmission System and its expansion projected guarantee low investment in new Power Plants, since they can be installed close to the TL, following the *reservoir-to-wire* model, where Power Plants are built in a short distance from Transmission Lines.

Therefore, it is believed that the insertion of Maranhão in the capacity reserve auctions, under study by EPE and MME, to attenuate the issues associated with generation variability in the entire NE region, as these TPP would close the energy balance of intermittent renewables, and would bring benefits to the Natural Gas sector, for the reasons explained above.

5. NATURAL GAS SCENARIO IN MARANHÃO

The supply of Natural Gas in the State of Maranhão comes from internal production, onshore, in the Parnaíba Basin. In 2018, Maranhão had the second largest production of Natural Gas onshore (Fig. 16), with an average of 3.9 MMm³/day (ANP, 2019).

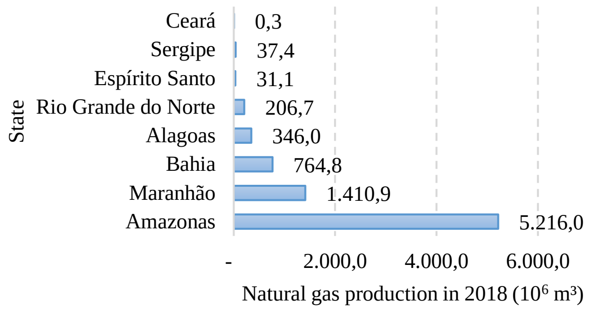

Fig. 16. Natural Gas production onshore by State (10^6 m³)

The Parnaíba Basin is one of the most promising in Brazil. The results of the last ANP auctions prove this, since several blocks offered in this basin were auctioned. The proven Natural Gas Reserves in Maranhão were 20,672 million m³ in 2018 (see Fig. 17), according to the Oil, Natural Gas and Biofuels Statistical Yearbook 2019, published by ANP (ANP, 2019).

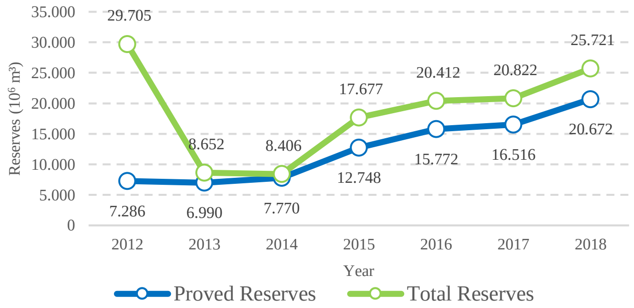

Fig. 17. Maranhão's Natural Gas Reserves (MMm³)

Unlike other older basins (e.g., Campos Basin) the Parnaíba Basin is still a little explored basin. There is insufficient seismic data to determine the total volume of the reserve and new discoveries can be made as exploration companies conduct exploration in the region. New discoveries can leverage the allocation of natural gas to new markets.

Maranhão still does not have transportation pipelines that interconnect it to the country's gas pipeline network. From the analysis of Fig. 18 (ANP, 2019) it is possible to verify that the Natural Gas transportation infrastructure is not present in all states of the country. In addition, it is mostly concentrated on the country's coast. Therefore, the implementation of LNG ventures in states not covered by the pipeline infrastructure could help to leverage the market in these regions, internalize the market and leverage the interconnection of the pipeline network. The possibility of insertion of natural gas from several suppliers would bring gains in reliability to the grid and competitiveness in the commercialization. A concept similar to that of the Brazilian Interconnected Power System (SIN) of the electricity sector.

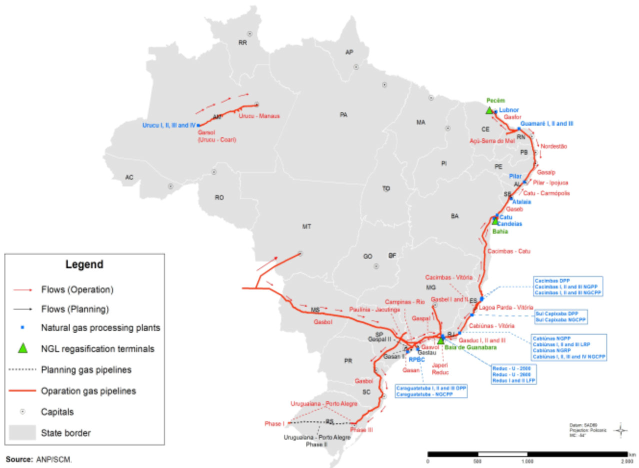

Fig. 18. Natural Gas transport and production infrastructure (2018)

6. CONCLUSION

The intense increase in the concentration of intermittent sources in the north - northeast region of Brazil is putting the experts and operators of the interconnected system on alert. The region will quickly be dominated by intermittent sources (solar and wind power plants) causing serious challenges for operators to ensure the instantaneous generation-load balancing. An interesting alternative that can be taken into account to mitigate this problem is the use of open cycle natural gas plants.

In this paper, we discussed the use of natural gas to provide greater flexibility and resilience to the electric system and thus mitigate the impact of the great variability of generation in the region where they preferentially occur. Gas turbines are characterized by rapid response ramps to generation-load changes, and can be used in the gas-to-grid success model.

The region has important natural gas reserves that can be exploited as well as good interconnection capacity of the transmission network favoring local projects and promoting the "local" balance of generation intermittency.

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