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Micro Reactors and Small Modular Reactors in the Brazilian Electricity Generation Market

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1. Introduction

The predominating nuclear power reactors operating in the world are usually large with capacity around 1000 MWe or more and despite their important advantages in terms of environmental sustainability, high cost for implementing new projects, construction delays and complex licensing procedures have inhibited its growth in the electricity market. Wind and solar photovoltaic sources have become competitive in the last decade, and generate electricity with capacity ranging from several kW (photovoltaic energy sources installed in roof tops and small businesses) to 100 MW (wind, biomass and centralized solar energy sources). These energy sources have established a lower capacity generation market ranging from less than 1% to about 10% of the typical large nuclear power plants. These sources, however, have great temporal variability, intermittence and low capacity factor.

The nuclear sector, seeking to participate in this emerging low capacity market, has undertaken the development of Small Modular Reactors (SMR) which are smaller nuclear power plants with modular solutions and system simplification aiming to overcome the difficulties of high capital cost and construction time delays[1-3]. The proposals with capacity between 50 and 300 MWe seek to compensate for economies of scale gains of large plants by adopting simplified systems possible only in smaller plants and emphasizing greater serial production of systems, components and structures in factories [1]. After 2015 there were proposals for micro reactors or nuclear batteries in order to meet the new market of micro electric generation, with units with capacity less than 1 MW up to 50 MW, normally offered by renewable sources in micro-grids of electricity. This new market for micro electricity generation opens an opportunity for nuclear micro generation in isolated, rural or urban areas, in microgrids. Both SMRs and micro reactors can provide ancillary services to the electric grids and microgrid with high share of renewables with great temporal variability, intermittence and low capacity factor. They can complement generation, stabilize the electric grids, increase the capacity factor of the system and improve the quality of the generated electricity [1,4].

This work analyzes the possibility of inserting lower capacity nuclear generation alternatives, SMRs and micro reactors, in the Brazilian electricity generation market. Initially we present information on the progress of the development of heat pipe micro reactors in the world, then some data on electricity consumption and small and micro generation in Brazil. Finally we discuss the insertion of SMRs and micro reactors in Brazil.

2. Development of heat pipe micro reactors

Among the micro reactors proposals, a very interesting group is the one based on heat pipe technology for transferring nuclear heat directly to the power generation system initially developed by NASA and LANL for space purposes, the Kilopower project [2]. This proposal aims at power generation between a few kW up to 20 MW and introduces nuclear energy into the micro-generation market [1]. As this new technology presents many new features, the Idaho National Laboratory prepared a document listing the main physical phenomena and important issues regarding manufacturing, operation, licensing and several technical solutions [3]. This document adopted as reference reactor the 5 MWt (2 MW electric) SPR reactor proposed by the Los Alamos Laboratory which is based on heat pipe technology. The core is a fast reactor formed by a solid block of stainless steel with holes to receive nuclear fuel rods and heat pipes for heat removal. The initial commercial targets would be local power sources for factories, military bases, electric vehicle charging stations, desalination plants, data centers, airports, seaports and, eventually, shopping malls, skyscrapers and communities [1,4].

Between January 2020 and August 2021, a plurality of articles appeared in the literature on micro reactors based on heat pipe technology with authors from China, South Korea, United States and Russia [1]. US presented 2 micro reactor projects, one of them being the eVinci developed by Westinghouse (thermal reactor) with support from the American laboratories Los Alamos and Idaho [5,6]. Westinghouse is working on the design, analysis and licensing of an eVinci nuclear demonstration unit to be under testing by 2023. Its capacity is around 0.5 MWe with estimated capital costs below US$10 million [5].

3. Micro and small electricity generation in Brazil

Figure 1a shows the evolution of electricity consumption in Brazil and in the State of São Paulo between 1994 and 2019. Electricity consumption grew until 2014 and was guaranteed by the contribution of the wind power and, in recent years, by the centralized and distributed photovoltaic (PV) generation. For instance, in 2020 the centralized PV installed capacity in the states of Piauí was 1.03 GW, of Bahia, 0.78 GW, and of Minas Gerais, 0.54 GW, and the PV distributed (roof top) installed capacity in the states of Minas Gerais was 0.98 GW, of São Paulo, 0.69 GW, of Rio Grande do Sul, 0.68 GW and of Mato Gross, 0.44 GW [9].

Figure 1b shows the distribution of installed capacity for electricity generation in Brazil in 2021, excluding the hydro source, and evidences the growth in the share of sources of smaller capacity. The first group presents the installed capacity of larger generation plants and the second group, the capacity of generation plants from small to micro renewables (tens of kW to ~150 MW). The greater share of renewable sources, similarly to what happens in the rest of the world, promotes a transition of the Brazilian electricity market from predominantly large-scale power plants (hydro sources in case of Brazil) to one with greater diversity of renewables and important share of small and micro generation. The State of São Paulo, through these small and micro generation technologies, begun again to invest in the electricity generation market. For example, only 50% of the electricity consumed in the State of São Paulo was generated in the state itself in 2019. The distributed PV micro generation in São Paulo in 2020 was smaller only to that of Minas Gerais.

To have a correct picture of the importance of micro generation in Brazil, in 2020/2021 the installed capacity of centralized solar photovoltaic generation was 3.4 GW based on 135,000 generating systems; of distributed photovoltaic (roof top), 6.3 GW based on 414,000 generating systems; and of wind power, 19 GW based on 726 generating systems. The capacity of distributed PV micro generation systems is less than 75 kW and the average capacity of wind power systems is 26.2 MW. This plurality of systems with hundreds of thousands of consumers/producers give the wind and PV power sectors intense dynamism. In 2021, both sectors seek economic sustainability by consolidating their productive chain involving specialized suppliers, technical support and maintenance firms, training qualified professionals and, in addition, creating thousands of quality jobs.

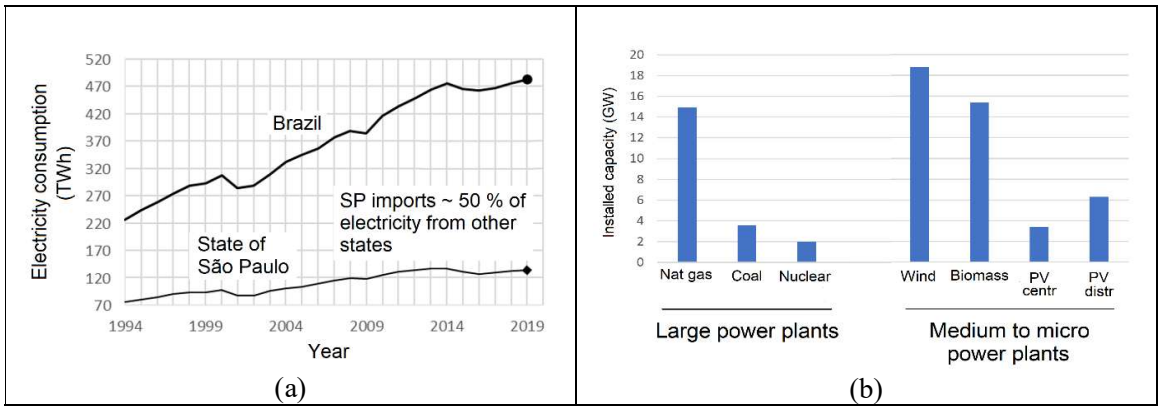

Figura 1 – a) Electricity consumption in Brazil and State of São Paulo from 1994 to 2019 [7]. b) Installed capacity in Brazil in 2021 divided into large power plants and medium to micro power plants. The share of the second group increases rapidly and the PV generation is already greater than those of coal and nuclear power [9].

4. SMR and micro reactors in the Brazilian electricity market

SMRs and Micro Reactors have considerable advantages over large nuclear power plants, such as lower risk for utilities, shorter construction times and lower capital cost compared to the cost of large 1 GW power plants. These projects, if implemented, add stable energy to the Brazilian electricity sector, which is currently supplied mainly by CNAAA's nuclear plants and natural gas-fired thermoelectric plants. The development of SMRs and micro reactors is carried out internationally through startups or innovative divisions of consolidated companies such as Westinghouse, and has the technical and financial support of national research centers and science and technology development agencies. The development programs aim to enable safe technological solutions, with low construction and operation costs, and to facilitate the licensing process.

Unlike the international scenario, in Brazil there is a state monopoly that limits the handling of nuclear materials, as well as the operation of nuclear power plants of any size to Brazilian state companies. Including the private sector in such an undertaking is a complex and long process, as it will require changes to the Brazilian Constitution. Therefore, any initiative for the development of SMRs and Micro Reactors in Brazil has to be led by a Brazilian state-owned company in associations with national and foreign consolidated companies and startups, and with technical collaboration of national universities and research institutes.

In case of a successful entry of micro reactors in the Brazilian electricity market, the operation of hundreds of nuclear batteries is probably unfeasible to be carried out by state-owned companies. In this case it appears obvious it will require the revision of the state nuclear monopoly allowing the participation of the private sector without excluding the participation of Eletronuclear. This alternative, with the participation of startups and international companies, could lead the Brazilian nuclear sector to experience the growth process that took place with photovoltaic and wind sources for the multiplication of initiatives and possibilities. Flexibility of the state monopoly in the nuclear sector already exists in the area of nuclear medicine, which allows the participation of numerous small private companies, with the majority of professionals trained in university courses of medical physics and nuclear engineering in the country.

As a final comment, it is important to highlight that the new technologies are very promising and would bring many benefits to the national industry, as small reactors can, to a large extent, be produced in Brazil. Brazil could become an important player in the nuclear industry with the development of a productive chain of specialized suppliers of components, systems, technical services and maintenance services in the nuclear

sector. Another important benefit would be the appearance in Brazil of a large number of trained and qualified professionals in the nuclear power sector, for there will be very many private companies looking for good professionals in addition to the state-owned companies.

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