

Present Situation and Prospective of the Brazilian Dam Engineering

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Flavio Miguez de Mello

Introduction

Brazil is a country with vast continuous and almost square territory, most of which lies in the south hemisphere. Since the country covers such an enormous area, 8.5 million square kilometers, there are different natural aspects such as rainfall pattern, water resources, climate, geology, relief and vegetation. The environment varies from the flood plains of the Amazon equatorial rain forest and the low and wetlands of the Pantanal to the highlands of the central part of the country, from the coastal mountain range in the southeast to the flat savannas in the south and midwest, ranging from a number of large wet regions to the vast arid northeast hinterland, with rivers like the Amazon with an average long term flow over 200 000 m³/s to intermittent rivers. In the arid steppes of the northeast the average specific surface flow can be as low as 3 l/s.km² while in the north the long term specific flow can be over 40 l/s.km².

The oldest dam in operation in the country, Apipucos Dam, is a small earthfill embankment structure that dates back to the XVI Century. Presently there are over 1500 large dams (according to ICOLD definition) in operation and an enormous number of small dams all over the country.

Quantitative description of existing infrastructure and of present activity

Hydropower

Since 1883 when the first hydroelectric power plant started its operation in Brazil, hydropower has been the main agent to promote the development of the country. Until the early fifties, all power producers were private utilities. Due to the Code of Waters adopted in 1934 with the deletion of the clause that protected the utilities from inflation, there was a disastrous restrictive tariff policy that discouraged the investors. By the year of 1960, the overall nationwide installed capacity was barely over 5,000 MW, of which 3,700 MW were from hydroelectric power stations. In 1964 the law changed and several large hydro power plants were put under construction from that time on. At that time huge reservoirs were created providing full guarantee of supply of electricity during a period of 90 successive months even under the worst historic hydrologic conditions.

Presently the total generating capacity is over 120,000 MW of which close to 90,000 MW are installed in hydro plants. There has been a concentration on large generating plants as can be seen in the following table.

Table 1 – Hydroelectric power plants with capacity over 3,000 MW

Itaipu	14,000 MW	(in operation - 50% Paraguayan)
Belo Monte	11,233 MW	(under construction)
Tucuruí	8,535 MW	(in operation)

São Luiz	8,040 MW	(soon under construction)
Ilha Solteira	3,444 MW	(in operation)
Jirau	3,300 MW	(under construction and starting the operation)
Santo Antônio	3,150 MW	(under construction and starting the operation)
Xingó	3,750 MW	(first phase in operation)

Large reservoirs guaranteed in past years large firm power to the generating system.

Table 2 – Largest hydroelectric reservoirs

	Volume (km ³)	Active Volume(km ³)	Area (km ²)	Length (km)
Serra da Mesa	54.4	43,25	1,784	116
Tucuruí	50.5	38.97	3,007	170
Sobradinho	34	28.67	4,214	350
Itaipu	29	19.0	1,350	170
Porto Primavera	20	4.3	2,25	250
Balbina	17.5	7.79	2,30	225

Very large hydroelectric plants presently under construction are being built with reservoirs not very large and with no active volume at all. They are to be operated as run of river power plants.

Table 3 – Large hydroelectric power plants under construction as run of river projects

	Capacity (MW)	Reservoir Volume (km ³)	Active Volume (km ³)
Santo Antônio	3,150	2.08	nil
Jirau	3750	2.75	nil
Belo Monte	11,233	2.51	nil

The large majority of the power plants are designed to have a capacity factor of 55%. The range of capacity factors goes from 39% in Belo Monte due to lack of reservoir in order not to flood large areas but not for peak power purpose, to 95% in some small plants in regulated river flows. The federal government does not consider peak power production as an economical benefit to the system yet. For this reason up to the present time there is no pumped storage projects in the country, although it is clearly necessary.

Due to the interconnected transmission system, the new planned hydropower plants, besides helping the development of the areas where they are to be built, they provide benefits to other distant regions. As a result, a major transmission network provides link among the various parts of the country joining the two major systems: the North/Northeast System to the South/Southeast/Midwest System. The high voltage transmission system has 100,000 km of well developed interconnected AC transmission lines of 230 kV to 750 kV and up to 500 kV DC transmission lines. The very wide Amazon river was recently crossed by an extra large high voltage transmission line connecting the two sides, north and south, of the Amazon region.

Presently the long term average power production of the hydroelectric plants is close to 380 TWh. Only a few years ago much more than 90% of the electricity was produced by hydroelectric plants. Nowadays, due to opposition of the so called environmentalists, this percentage has dropped to 75%. Nuclear, wind, bio and solar generation plays a modest part of the power production. The relative loss of the participation of the hydro generation has been occupied by conventional thermal plants which operation is much more expensive and detrimental to the environment. Power production in Brazil is not so clean and renewable as it used to be until the recent past.

The total Brazilian economical power capacity is estimated in 246,000 MW. Less than one third of this capacity is presently installed. The largest undeveloped power projects are located in the main tributaries and sub-tributaries of the Amazon river.

Domestic and industrial water supply systems

Dams have been built as part of water supply systems for both urban and industrial consumption for a number of large cities and industrial areas. The most outstanding of these is the Cantareira water supply system constructed in order to supply water to São Paulo and surrounding cities, implemented in the seventies and consisting of six large embankment dams, seven tunnels excavated in gneiss and granite rocks with total length of 29 km and one large underground pumping station to supply 40 m³/s of water.

The main water supply system to Rio de Janeiro and nearby cities is also worth mentioning. This system was progressively built since the first half of the last century, taking advantage of the diversion of the Paraíba do Sul and Pirai rivers to generate power at the foot of the almost 400m high mountain range situated 50 km from downtown Rio. It is a complex of ten dams and dikes, two pumping stations, one of which with reversible units, four hydroelectric power plants, several kilometers of canals both overland and underground, and the largest water treatment plant in the world with a treatment capacity over 53 m³/s.

Another impressive water supply system is the recently constructed one for Fortaleza city. The system includes the 85m high Castanhão dam built in 1999 and 256 km of canals to supply 22 m³/s to the city and to irrigation projects.

Flood control

For many years since 1944, a federal department under the Ministry of the Interior was active in flood control projects involving several dams, dikes and polders projects and dredging works in river beds. Several dams were built to prevent floods in populated areas. The two most outstanding projects were the flood control of Itajai Açu river basin in the South which includes three dams that are only used for liberate to the downstream areas, safe outflow values when large income flood flows get to the reservoir areas, and the protection of the Recife city comprising three embankment dams. The general design hydrologic aim of all the flood control projects was to control the 50 year return period flood flow. In the 1990s the activities of this department were discontinued and soon after, the department was extinguished. Nowadays state and local governments have to face the problems of flood control; In general they are unable to do it properly. The power authority operates the hydroelectric dams of some few river basin in order to try to avoid floods. But the country lacks new large and effective projects for flood control.

Irrigation and low water support

The year 1877 was the start of the country greatest national tragedy due to natural phenomena: the Great Drought in the Northeast region. The drought lasted for more than four years and left scars that are unforgettable. It was decided that dams and irrigation systems should be built all over the so called

Drought Polygon. Hundreds of dams were built since the beginning of the XX Century until the late sixties when the implementation of new reservoirs started to slow down. The large majority of the dams in Brazil are in the Northeast and most of them are not very high earthfill embankment dams, with the main purpose of minimizing the effects of droughts that frequently occurs whenever El Niño is intense in the South Pacific.

Proposed in the last years of the XVIII Century, a large project diverting the water of the São Francisco river that has a long term average flow of 2,000 m³/s, to the Drought Polygon is been built for the last eight years. In the final stage of the project, 2,3% of the river flow will be diverted to the dry areas. There will be several dams, dikes, canals, pumping stations and power plants. During large flows in the São Francisco river, up to 127 m³/s will be transported to the dry areas. Here again, the construction works are very much behind schedule.

Navigation

Inland navigation is the most popular transportation method in the North region, mainly in the Amazon river and in the lower stretches of its tributaries. In these long and large rivers navigation with large boats, barges and even large ships can be done all year around with no need of navigation locks. In other regions the few navigation projects are appendixes of hydroelectric plants. The main river basins with navigation locks installed in hydroelectric dams are the Tietê and Paraná river in São Paulo state and the São Francisco river in the Northeast.

Recreation and landscape

Since the construction of the Pampulha embankment dam in 1958, which formed a beautiful artificial lake in Belo Horizonte, the capital city of Minas Gerais state, small dams were built in other cities to create reservoir of constant water level. The largest and most famous is the Paranoá reservoir that separates the capital city of Brasília in two sections. Recently in several clean and clear water reservoirs, activities of recreation have been implemented. In some cases in reservoirs that are operated with intense drawdown during dry seasons, opposition to this operation criteria have been recorded.

Tailings disposal

Mining industry plays a very important role in the country economy. Mainly due to the environmental legislation, a large number of tailings dams have been and are presently under construction. There are more than 700 existing tailings dams in the country being built or already abandoned. The Germano dam is worth mentioning because its final height is 170m. The most applied construction method for coarse and fine/coarse tailings is the upstream method. For fine tailings, such as for gold mine operations, the downstream method is mostly used.

A major accident happened in November, 2015. The Fundão iron ore tailings dam collapsed and hit the reservoir of a water retention dam downstream. A large quantity of mud flooded the 650 km river bed of the Doce river all the way to the ocean. The mud impacted several water supply systems and four hydroelectric power plants. Due to the collapse of the dam seventeen people died and two others have not been found under the mud that travelled with a speed close to 60 km/h. This was by far the most tragic dam accident in the country.

The needs at the present and for the future

As mentioned above almost all hydroelectric plants that were built in the past two decades or are in the design phase or are under construction, are or will be operated as run of river because if not it would be extremely difficult and most improbable to get the environment permits. This is causing the necessity of the addition of many oil, diesel, coal and gas thermal plants that are much more expensive to generate power and much more aggressive to the environment. There is a need to add a generating capacity of 6,000 MW each year to the system. A little more than half of this new capacity is to come from the implementation of hydroelectric power plants although there have been strong oppositions to every new dam and reservoir. Till 2019, forty eight large hydro power plants are to be built, half of it in the Amazon Region. The installed capacity in 2021 must be 182.4 GW which is a growth of 65 GW in ten years. The total installed capacity of the hydro plant in Brazil was 86 MW in 2013. This capacity is to be increase to 117 MW by 2021.

The federal planning sector is not aware of the necessity of providing more storage to avoid the escalation of thermal generation. It is also not aware of the necessity to provide peak power capacity close to the largest load centers.

Only two nuclear power units are in operation adding 2,000 MW to the system, close to 2% of the total power consumption. These two units are situated at the sea shore between the two large load centers: Rio de Janeiro and São Paulo. A third 1,300 MW unit is presently under construction in the same place. All the cooling water that is needed is taken from the ocean.

Unhappily, at this time, dams for river flow regulation are out of the main goals of state and federal governments.

As long as intermittent power is concern, the amount of solar and wave energy production is too small. Several wind power plants have been installed in the last ten years but presently it represents a very small part of the power generation. It is expected that wind energy will become more important in the power generating matrix.

As long as floods are concerned, the main problems are in the most populated areas. Most of the dangerous areas are in small and somewhat steep watersheds. In the near past, floods have occurred causing severe hazards in some cities in the footsteps of the mountain regions not very far from the sea.

Present and future obstacles

As mentioned above, it demands a lot of work and time to obtain environmental authorization in this country. The legislation is a very good one but ONGs, politicians and even people from overseas always try to stop all large dams and reservoir projects, even those that have very small negative impacts to the environment. To see how strong is the opposition to hydroelectric projects, in 1970 almost all power came from hydroelectric plants: 99% hydro and 1% thermo. In 2009 hydroelectric plants produced 90% of the electricity, 7% came from thermo and 2,5% from nuclear plants. In 2013 the generated power came 73% from hydro, 23.2% from thermo, 3,2% from nuclear and 0.6% from wind power plants.

Only very seldom is project financing used in this country. Almost all investors go for loan from a large federal development agency that lends money on a not high interest basis.

Sedimentation of reservoirs occurs. There are some small reservoirs that are almost completely full of sediments. It is unknown the volume and the position of the silting in the large reservoir that are used to regulate flows of the large rivers. This is due to two reasons: It is quite expensive to properly prospect the evolution of the actual useful volume of large reservoirs and any loss of useful volume will mean loss of

firm power and, consequently, loss of revenue in the case of a hydroelectric plant. The federal authority that is in charge of the operation of the hydro power plants has not been strong enough to demand the utilities to update the useful volume of the reservoirs.

The recent dam safety act was the main trigger for a large program of dam safety inspection. There were some cases (not very many) of large works on dam rehabilitation but there have not been replacement or abandonment of dams in Brazil.

The trends

Small dams for hydro plants used to be a strong trend in the near past. With the start of the wind power, with taxes reductions and small tariffs, the small hydro projects are now in a stand by position. The concentration on very large hydropower plants is being kept in the planning of the expansion of the country's generating capacity. Since there is no regulatory procedure for pumped storage projects, this kind of hydro power plant has not been proposed yet. Almost every new hydro project is a run of river power station in order to minimize local environment impacts. The country has lost the capability of regulate river flows as it had in the past. The consequence is that thermal power has been widely used and the cost of power to industries and to the general public is growing fast and high. At this time (2013/2014) all thermoelectric power plant, even the older and more expensive ones are under full operation due to lack of heavy and constant rainfall during the wet season of the last year and this year, and, of course, lack of active volume in the recent built reservoirs.

Private initiative has been active in most of the large projects associated with federal and state utilities. In these cases private firms have more than 50% of the capital of the project. In small power plants private investors hold 100% of the capital of the SPCs.

The growth of power consumption in the country is expected to be 4.7% per year from 2014 until the year 2022, getting to 785,100,000 MWh/year.

All large and small tailings dams are owned by private firms. Dams for water supply can both be private or belonging to a state company. In the past there was activity in construction of a number of large or medium size flood control dams. Nowadays the few dams that are being designed for flood control are small and are implemented to protect localized populated areas in small watersheds.

Climate change has been addressed in technical meetings but up to the present time there has not been any consideration in the planning of water resources related to this important topic.

Dam safety, the need to implement large active volumes in the future reservoirs as it was done in the past and environment impacts to non Indian populations and to Indian tribes in the Amazon region are the main topics that have been debated.

There were very few cases of heightening of dams in Brazil other than tailings dams.