Study Committee C2

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Brazilian Power System Operation under extreme operating conditions: recent examples and proposals to face future challenges

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Motivation

In Brazil, power system security is considered very relevant. In 2003, a 3 pillar-Defense Plan was implemented: the first one composed of preventive measures, aiming to minimize the probability of occurring severe multiple contingencies, the second composed of corrective measures aiming to minimize the propagation of unavoidable disturbances and the third one aiming to reduce the duration of the restoration process. Another relevant point is a deep pos-morten disturbance analysis, an important way to identify the lessons learned and to provide all processes, from expansion planning to real time operation, with feedback.

Power systems have changed faster than ever in the last two decades. Three major trends have been affecting power grids: electrification, decentralization, and digitalization.

Some drivers are associated with the changes:

- Fast changes in the generation mix.
- Climate change - increasing environmental impacts that are more severe and more frequent than before.
- cyber-attacks and man-made threats are now more impactful than before due to increased digitization and modern power systems' dependency on Information Technology and Operational Technology.

These drivers have created unprecedented vulnerability for power systems, HILF events.

Introduction

In the last years, the Brazilian Interconnected Power System -BIPS has faced 3 critical operational conditions due to extreme events, as follows:

- the first one, in 2015, was provoked by an extreme drought that seriously affected hydro plants' reservoirs and was followed by a severe hot wave that increased the load due to the rise in use of air conditioner devices. These facts made the power system to operate at an underfrequency regime for hours/day. In this condition a double contingency occurred, leading the Southeastern/Northern inter-regional interconnection to disconnect followed by large load blocks of load shedding.
- the second one occurred in the period June 1st – 6th, 2016. Adverse weather conditions provoked serious damage to 16 (sixteen) 440kV circuits located in Sao Paulo (towers collapsed).
- the third one occurred at the beginning of the period of Covid 19 Pandemic, which was characterized by very low load.
- In these 3 situations, despite the long operation under extreme conditions, the impact was minimum. Some multiple severe contingencies characterized before as HILF are more frequent now. So, these ones must be reclassified and considered in the analysis. Such contingencies are relevant to operational security and to the expansion of power system security concepts, being now included in the "Power System Resilience" analysis.

Brief description of the events

2.1. EVENT 1 - extreme drought that seriously affected hydro plants' reservoirs, and followed by a severe hot wave that increased the load

2.1.1. Description of the event:

The operation schedule for 01/19/2015 indicated the prospect of an around 500 average MW negative balance in the SE/MW and S regions in the period between 2:30 pm and 4:00 pm, for a total estimated demand of 51,463 MW in the SE/MW regions, and 16,952 MW in the Southern regions. This deficit of 500 MW, associated with the generation outages occurring before 2 pm, in addition to the load being above the schedule, led the BIPS to operate with a frequency around 59.4 Hz.

There was an estimated power loss due to the reduction in the height of fall of water and environmental conditions in the hydro plants located in the Southern, Southeastern and Midwestern regions of nearly 7,650 MW.

From 1:00 pm onwards, load increase, was verified in the BIPS, reaching values above those predicted for the day. To meet the demand in the South, Southeast and Midwest, the flow in the Northern/Southeastern interconnection had already been maximized since 10:00 am, up to the security limit.

There was also another systemic limitation in this transmission trunk by dynamic limit (n-2).

In view of the above, as the generation resources available at that time were concentrated in the Northern and Northeastern regions and could not be fully used, there was frequency drop, which was gradually accentuated by the increase in demand in the Southeastern and Mid-Western regions. At that time, ONS managed to carry out manual load cuts, in the South, Southeast and Midwest, if necessary, with a view to restoring the frequency.

The disturbance was characterized by a 2,915 MW generation loss at the time it was operating using all available generation resources in the SE/MW and MW regions, as well as the

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impossibility of transferring additional existing resources from the N and NE regions, resulting in frequency drop.

The impossibility of exploring additional resources by the North/Southeast Interconnection, in view of the defined security limits, as well as the reduction in the generation availability in the Southern, Southeastern and Midwestern regions, due to maintenance in generation units (7,522 MW) and power constraints due to power drop reduction and environmental conditions (7,650 MW) were seen as unbalancing factors for controlling the BIPS's frequency.

The high demands verified on 01/19/2015 and the constrains already described, led to a gradual drop in the BIPS's frequency, stabilizing at 59.4 Hz.

From 2:48 pm, with the frequency stabilized at 59.4 Hz, a double contingency occurred, leading the SE/N inter-regional interconnection to disconnect, causing an abrupt drop in frequency, which reached values below 59 Hz, imposing the need to carry out manual load cuts in the Southern, Southeastern and Midwestern regions.

At 2:55 pm, following the loss of another generation block, the frequency reached the value of 58.53 Hz, requiring additional load cuts in the S/SE/MW regions.

2.1.2. Measures adopted:

To restore the BIPS's frequency, manual load cuts were commanded by ONS and totaled 4,447 MW in the Southern, Southeastern and Midwestern regions.

The execution of the requested cuts, together with the operation of some generation units that had been turned off, were effective in restoring the BIPS's frequency, which returned to 60 Hz at about 3:25 pm. From then onwards, it was possible to gradually start load restoration, which was virtually completed at 3:55 pm.

Figure 1 shows the BIPS's frequency graph on the day of the disturbance, with emphasis on the interval 1-4:oopm

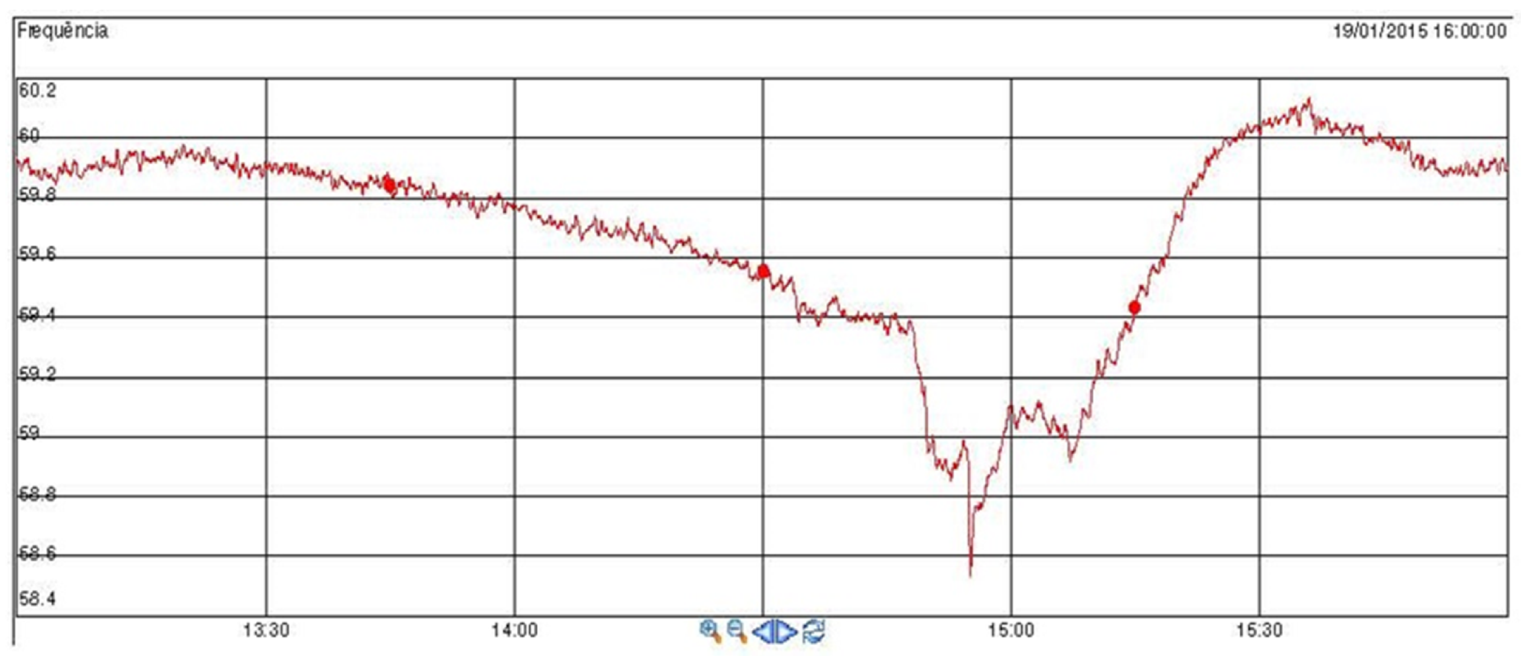

Figure1 - micro explosions verified in the city of Campinas

UFLS's partial actuation that occurred in some companies was due to the fact that the minimum frequency reached during the disturbance was at the threshold of the 1st stage actuation, at 58.5 Hz.

2.2. EVENT 2 - Adverse weather conditions provoked serious damage to several EHV circuits located in Sao Paulo State .

2.2.1. Description of the event:

In the period from June 1st to 6th, 2016 there were very adverse weather conditions in the state of Sao Paulo. In the early hours of Sunday (June 5th), there were almost seven hours of rain in the city of Campinas (SP), with 1,450 atmospheric discharges. Figure 2 shows a photo of the exact moment of one of the micro explosions that hit this city. According to UNICAMP's Meteorological and Climate Research Applied to Agriculture (Cepagri), the repetitive behavior of micro explosions in previous days, alerted to the possibility of the phenomenon becoming more frequent with the climate changes underway on the planet.

"A micro explosion is more violent than a tornado”. The curious thing is that they are no longer frequent in summer. The National Institute for Space Research (Inpe), disclosed that between 8:00pm on Saturday (4) and 2:40am on Sunday, 1,450 lightning strikes were recorded in the region of the city of Campinas.

The phenomenon happened again, from 6 pm on Sunday to 1:40 am on Monday, and, on Monday (June 6th, 2016). There were 553 electric discharges.

Figure 2 - micro explosions verified in the city of Campinas

On the 6th, because of the previous days' Weather conditions, sixteen 345/440/500 kV circuits were unavailable, due to fall of towers.

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The following figures depict the damage caused by storms on some 440 kV transmission lines (figures 3 and 4).

Figure 3 - Bauru-Cabreuva TL

Figure 4 - Bauru-S.Angelo TL

2.2.2. Measures adopted:
Immediately after the disconnection of the Lines, CTEEP transmission company concentrated efforts on identifying/restoring the affected lines.
It is noteworthy that the rains that hit the state of Sao Paulo remained steady for almost a week with few periods of drought. This situation lasted until at least 06/07/2016, making the initial restoration difficult. There were difficulties in transporting materials and moving equipment (crane, truck, tractors, etc.) due to the slippery terrain around the TL and access roads.
Even with the problems that occurred before, the actions taken by CTEEP made it possible to use the availability of strategic reserve structures, in previously selected locations, and the prompt action of specialized teams (figures 5 and 6).

Figures 9–and 10 - Strategic Reserve Structures

More than 50 towers were destroyed, leading to the outage of 16 (sixteen) 440 kV circuits. The average transmission lines repair took 11 days.

2.3. EVENT 3 – Load reduction provoked by COVID19 pandemic
2.3.1. Description of the event:
In 2020, due to the reduction of economic activities, there was a 20% decrease in electricity consumption.

The BIPS's maximum load, which had already reached nearly 90,500 MW, was reduced to nearly 68,000 MW. The minimum load, verified at the beginning of the day, reached values of around 40,000 MW, requiring the adoption of several operation measures to control the voltage profile.

2.3.2. Measures adopted:
To control the voltage profile, it was necessary to disconnect several EHV circuits in the Southeastern region (on April 19th, 2020, for example, 21 circuits: 1 - 765 kV, 14 - 500 kV, 5 - 440 kV and 1 - 345 KV). One converter was also disconnected for each HVDC bipole link associated with the 50 Hz Itaipu plant.
Several hydro generation units were turned off due to operational constraints, reducing system controllability . So, during the pandemic period, the increase in system operation complexity led to the requirement of special measures by ONS, in order to assure system security.
In relation to real time teams, an Action Plan including tests to protect teams was implemented, notably Real Time teams, to enable them to act during the temporary unavailability of some colleagues, as well as to mitigate the risks of spreading the Coronavirus in control rooms.

3. SOME LESSONS LEARNED FROM THE EVENTS:
3.1. Considering these 3 events and some others, it is possible to present some lessons learned, as followed:
- Reinforcing towers critically located in major transmission corridors.
- Training focused on further development of operators' knowledge, skills, and decision-making abilities.
- Effectively estimate transmission system capacity and system demand under extreme conditions.
- Use of faster modes of communication, such as social media, text, and email alerts.
- Resources to achieve greater observability and controllability (SCADA/EMS, Dynamic Security Assessment – DSA, Wide Area Monitoring System – WAMS, Wide Area Control System – WACS and Wide Area Protection System – WAPS).

4. CONCLUSION
- Resilience should be pursued by all players of the electric power sector. The plans and response capabilities should be developed collaboratively and exercised in a robust manner by all agents involved. Multi-agency planning and coordination during an incident (HILF event) is essential.