POWER RESTORATION PRACTICES: THE BRAZILIAN EXPERIENCE

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SUMMARY

Restoration is a process of key importance to some utilities that experience regular disturbances and blackouts, or is considered a low priority topic at power utilities where serious disturbances rarely occur. However, we know that no power system is 100% reliable, and experiencing an interruption is an event that could happen to system.

The level of meshing between interconnected areas of power systems has become increasingly tighter in the recent years, due to the general trend of utilities and system operators to exploit the network as closely as possible to their maximum transmission capacity and to the liberalization of the electrical industry.

In this growing interconnection scenario and in the presence of high levels of power exchanges, some network operation problems may occur: increased active and reactive power losses, higher risks of voltage instability or collapse, stronger requirements for the load following and, most critical and important, higher criticism associated with possible grid contingencies.

Furthermore, the practice of optimizing the transmission assets is putting pressure on design reliability of transmission systems. In some cases, the investment criteria deliberately assume the equivalent of a certain number of interruptions per year. In this kind of scenario, efficient restoration becomes imperative.

For all of the above mentioned facts and considerations, it appears quite evident that the importance of a security assessment strategy, based on a well defined defense plan has become a priority.

This paper presents the part of the Brazilian Defense Plan related to the restoration process. Following a brief description of the decentralized approach to restoration, some other important aspects adopted to optimize this process will be described.

KEYWORDS


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1. INTRODUCTION

Electric systems are inherently susceptible to the risk of disturbances presenting various degrees of severity. An increase in the level of risk results from the sparseness and geographic extension of an electric system as well as from an excessive concentration of components in use at a single substation. An increase in severity is commonly the result of the location of the fault that gives origin to the disturbance and the amplitude of the event. These conditions, combined with a strong dose of unpredictability, determine the chances of a disturbance being contained by control and protection procedures or transformed into a general collapse of the energy supply – a blackout.

Further to the question of unpredictability, mention must be made again that there is no such thing as an electric system that is entirely immune to major disturbances, mainly when the system is predominantly based on hydro resources concentrated in far regions where such exploitation is viable, interconnected by long extension transmission lines linking the generation centers to the distant load centers in concentrated industrial and urban hubs. This happens to be the case in Brazil and the National Interconnected Electric System – the NIS. A large substation, even with the best construction, protection and control characteristics is always a potential source of a dangerous disturbance affecting the integrity of the whole system be it for “Acts of God” or “Human Errors” that nowadays includes acts of vandalism and national/international terrorist activity or even due to more prosaic reasons like the lack of auxiliary DC current.

Any and every systemic topological alteration, like the entry into operation of a new generation or transmission element, demands a thorough review of the restoration process in order to create alternative restoration corridors or, at least, updating the existing routes.

Although the threat of major blackouts has indeed been diminishing, they still occur as recently verified in the United States, Canada and Italy, among others.

This paper primarily focuses on the actions and procedures adopted by the National Operator of the Electric System – ONS (Brazilian ISO) in order to speed up and otherwise improve the restoration process in the NIS. In regard to recent disturbances, actions and procedures as well as the systemic and contingency conditions that are presently being investigated will also be reported, presenting the considerations and studies underway conducted by the Work Groups created at ONS. The purpose of this work is to conceptualize measures that may contribute to the improvement of the operational security of the electric supply to the Rio de Janeiro /Espírito Santo region.

2. OPERATIVE SECURITY ACTIONS IN THE NIS

The load restoration process is a very important task within the Defense Plan against extreme contingencies conceived by ONS (Brazilian ISO). This Defense Plan is founded on a threefold basis:

- Preventive actions: to minimize the probability of occurrence of large disturbances. These measures are intended to reduce the severity of the disturbances.
- Corrective actions: to minimize the spreading of unavoidable disturbances through the system. These measures are intended to limit the extension of the disturbances.
- Optimized restoration actions: to reduce the restoration time to acceptable values.

2.1 Examples of actions to minimize the probability of large disturbance events

- Definition of the minimum requirements for the connection of new generators to the NIS (characteristics of excitation systems, power system stabilizers, generator capability characteristic etc.) as stated in the Grid Procedures.
- Improvement of intrinsic characteristics of the existing substations through the refurbishing of busbar configurations, circuit bay relocation and other measures aimed at reducing the impact of a large disturbance.
Improvement of the NIS protection systems for each voltage class by means of the identification of line protections that must be replaced by new ones and the rearrangement of busbar configurations in the EHV network, where applicable, beginning with the substation at which the March 1999 disturbance started and in all similar substations.

![Figure 1: The Pillars of NIS Defense Plan.](image)

2.2 Types of actions to minimize the propagation of unavoidable disturbances

- Implementation and permanent updating of Special Protection Schemes
- Implementation and permanent updating of out-of-step tripping protections in order to isolate the sound portions of the system
- Optimization of PSS settings of the main power plants

2.3 Examples of actions to reduce restoration time

- Revision of the NIS planning from the system’s restoration point of view (identification of additional shunt reactors to facilitate the restoration process).
- Extensive use of underfrequency islandings of small and medium sized hydro power plants with local loads.
- Identification of new power plants for the installation of black-start devices.
- Identification of substations that must be necessarily manned to assist the restoration process, avoiding the susceptibility of tele-command and automatism failures that may occur at unmanned substations.
- Identification of the NIS vital substations, which will be subjected to a differentiated maintenance plan.
- Implementation of a schedule for periodic check-up tests of the black-start devices in the power plants capable of self re-energizing.
- Developing of qualification and training programs for operators and dispatchers.

3. PRESENT STATUS OF THE BRAZILIAN NIS CONCERNING ACTIONS TO MINIMIZE RESTORATION DURATION

- The periods of time spent in the restoration processes of the main transmission trunks during all the blackouts from 1984 to 2002 are being evaluated.
Reviews of the adopted concepts, philosophies and criteria are underway aiming specific recommendations of actions ranging from expansion planning to the real time operation.

As result of this work, shorter restoration cycles are not only envisaged but are already possible thanks to the installation of manoeuvrable shunt reactors and/or the substitution of existing reactors for larger ones.

The criteria for unassisted substations is being reviewed;

Criteria for the installation of black-start devices at new power plants are being defined.

One of the main purposes of reviewing the restoration processes is the need to reduce the duration of the restoration cycle. In regard to actions to be adopted to optimize the restoration cycles, it is important to take into account the prolonged restoring period as one of the immediate and major negative effects of a blackout. The adverse consequences that are detrimental to the image of electricity industry formed by public opinion interests are exponentially proportional to the restoration time, as shown in Figure 2.

4. PROPOSALS FOR RESTORATION IMPROVEMENTS IN THE NATIONAL INTERCONNECTED ELECTRIC SYSTEM OPERATIONAL GRID

In Brazil, restoration is based on a two-stage process: (i) fluent restoration; and (ii) coordinated restoration.

The first stage is begun at the plants with black-start capacity with the identification of the minimum configuration of the preferential transmission. In this phase, prioritary large load blocks of the system are restored utilizing only a minimum telephone communication between the operators of the hydro plants and substations involved, according to pre-established procedures. The process is managed without any interference from the Operation Control Centers, except in rare cases when this stage is not successfully executed by the plants themselves.

In the second stage, the operation centers coordinate the closing of parallels or rings existing between the subsystems that have been formed in the first phase, as well as the supply to load that is still disconnected.

The geo-electrical map of Brazil shown in Figure 3 defines the division of the country into electric regions that will be cited in this paper. The Brazilian Bulk Power System is presented in the same figure. The present restoration process implemented in the Brazilian Grid includes 34 fluent restoration areas, defined by region (North: 3 areas; Northeast: 6; Southeast: 16; South: 9).
ONS, along with the utilities, defined improvement proposals for restoration procedures in the South, Southeast, North and Northeast regions of the NIS which were published under the title - ONS REPORT RE-04/021/2004 [11]. A work plan and chronogram were also elaborated to conduct studies that first contemplated the priorities of analyses of areas related to restoration of the five electric regions cited above.

Based on such studies, coordinated by the National Operator, new areas were defined for fluent restoration or alternatives for already existing areas were established. The technical report related to the above mentioned studies was approved by both ONS and the sectorial Agents, which constituted the basis for the elaboration of a new priority procedure for fluent restoration alternative, whose implantation was executed giving rise to ONS Operative Instructions. As such, all key stages of this process are coordinated by the National Operator.

![Figure 3: Left: Map of Brazil (geo-political regions); Right: the Brazilian Bulk Power System](image)

5. INCREASE OF OPERATIONAL SECURITY OF POWER SUPPLY TO RIO DE JANEIRO AND ESPÍRITO SANTO (RJ/ES) STATES

5.1 Integral black-start plants in the NIS [9]

- ONS, through its Operational Routine - “Restoration Tests in the Operational Grid”, established the routines for restoration tests to evaluate the partial and integral black-start capacity of plants in the operational grid as well as the plants associated with the distribution network.
- For plants belonging to the existing fluent restoration corridors in the NIS, these tests must be maintained and conducted at least once every year in order to speed up the eventual restoration of loads in the NIS;
- For partial self-start plants belonging to the fluent restoration corridors in the NIS, a study must be made of Costs vs. Benefits in order to point out the viability (or not) of implementation of integral black-start process;
- For integral black-start plants not belonging to the existing fluent restoration corridors, new fluent restoration areas must be created or they must be incorporated to the existing corridors;
- For new plants to be integrated to the NIS, a procedure must be elaborated to evaluate whether the new player should be required to have black-start capacity, either integral or partial.
5.2 Viability analysis of islandings – an example: RJ/ES

- The formation of islands in a blackout situation permits the speeding up of load restoration, once they act as black-start areas from which the restoration process begins. With this objective, several islanding schemes were implemented in the National Interconnected System based on the underfrequency isolation of small and medium sized hydro power plants with local loads.

- Figure 4 presents a geo-electric map of the Rio de Janeiro – Espirito Santo area. The islanding of this entire area was discarded once, to have a possibility of success, it would be necessary to simultaneously open a large number of 345 and 500kV circuits as well as maintaining all thermal generation plants in a “flat” production condition in order to keep the difference between load and generation in the interior of the island not greater than 500MW. Studies showed that there are more chances of success in utilizing partial islandings and defined four islands, as shown in Figure 5:

![Figure 4: Geo-electric map of Rio de Janeiro / Espírito Santo area.](image)

![Figure 5: Partial islandings in Rio de Janeiro](image)
5.3 Substations and strategic equipment in the NIS [10]

- The substations and equipment considered strategic to the NIS were listed, not only from the systemic point of view but also in terms of guaranteeing the reestablishment of fluent restoration corridors and their interconnections, so as to assure both speed and safety of the partial or total post-disturbance restoration procedures.

5.4 Proposals for improvements in the restoration of the NIS operation network [11]

- There isn’t any known way to identify the best alternative for the restoration of a determined geographic area. There are, however, directives and criteria for defining a fluent restoration area that includes at least one black-start hydro plant with a minimum number of synchronized generation units and an associated transmission corridor with a minimal group of reactors in order to prevent over-voltages and assure the restoration of an amount of priority load in a safe and fast manner.
- A proposal was formulated to update existing procedures used to restore the post-disturbance Operation Grid in view of the expansion of the electric system. The participation of Transmission, Generation and Distribution agents in this process is of utmost importance since they are the players that implant and train the operative procedures needed for the success of a restoration program. The constant participation of ONS Control Centers and the sector agents in the studies for the interactions and adjustments that will be needed when considering the options offered in restoration proposals is also a key factor in these actions.
- A total of 10 new proposals for fluent restoration black-start areas were created, besides including new alternatives for restoration in existing areas.
- The expansion of the number of black-start areas and discussions among Agents in conjunction with the National Operator regarding restoration procedures were important factors that have improved the post-disturbance restoration procedures in Brazil.
- The new reactors defined in restoration studies held after the 2002 Black-out, which started to go into service in mid-2005, will make possible efficiency gains and reduction in system’s restoration times, mainly when dealing with priority loads in Rio de Janeiro / Espírito Santo and São Paulo areas. Figure 6 presents a diagram demonstrating the procedure used for fluent restoration in the Marimbondo Power Plant area and the associated 500 kV trunk line and alternatives made possible with the entry of new reactors to deal with the unavailability of system equipment.

Figure 6: Fluent Restoration in Rio de Janeiro Area from Marimbondo Power Plant
- Up to January of 2005, the restoration of the Espírito Santo area was only initiated after the completion of the fluent restoration phases of at least three restoration areas (L.C.Barreto, Marimbondo and Emborcação). Figure 7 presents a diagram of this procedure in the 500/345 kV systems of Rio de Janeiro and Espírito Santo.

With the entry into operation of the 345 kV Vitória / Ouro Preto transmission line, an alternative procedure was created to restore priority loads in the RJ/ES area. The new procedure is shown in Figure 8 and will be implemented only after conclusion of the fluent phases conducted at the L.C.Barreto and Emborcação areas. Once these conditions have been attended, the parallel will then be closed between these areas and the Southeast Nova Ponte 345kV system. This process goes on through energizing the 500 and 345kV circuits with a minimal group of reactors and intermediate load plugs, so as to assure that voltage levels in the entire corridor remains within the permissible limits up to the SE Ouro Preto 345kV system. With the energizing of the 345kV Vitória – Ouro Preto transmission line, up to 175MW can now be supplied to the Greater Vitória Metropolitan area. Expectations are that, with this new procedure conducted in an independent manner by the 345kV Adrianópolis – Vitória trunk, it will accelerate the full restoration of loads in the Espírito Santo area.

Figure 7: Restoration of the Rio de Janeiro / Espírito Santo Área

Figure 8: The Alternative Restoration of the Espírito Santo Area
6. CONCLUSIONS

Regarding the Brazilian Defense Plan, as far as the restoration process is concerned, some other important aspects adopted to optimize this process are included as follows:

- Implementation of new black-start power plants to increase operative resources during restoration.
- Development of studies to improve system restoration by the determination of new corridors.
- Interaction between studies and real time operation.
- Analysis of system planning of the interconnected system from the restoration point of view (identification of additional reactors to be installed in order to improve the system and make the restoration process more flexible).
- Massive use of small and medium-sized hydroelectric power plants islanding with local loads based on under-frequency relays (56Hz on 60Hz basis).
- Identification of substations to be necessarily assisted in order not to compromise the restoration process in case of command or automatism failures likely to occur in unmanned substations.
- Identification of the strategic system substations for the definition of a differentiated maintenance plan.
- Implementation of a periodical inspection plan for black-start devices at black-start power plants
- Creation of training and qualification programs for station operators and dispatchers.

BIBLIOGRAPHY