Available online at www.sciencedirect.com
ScienceDirect
Electrical Power and Energy Systems 29 (2007) 208–216
ELECTRICAL POWER & ENERGY SYSTEMS
www.elsevier.com/locate/ijepes

Power system stability reinforcement based on network expansion: A practical case

José E.O. Pessanha [a,*], O.R. Saavedra [a], Julio C.R. Buzar [b], Alex A. Paz [a], Carlos P. Poma [a]

[a] UFMA, Department of Electrical Engineering, São Luís, MA 65040-080, Brazil
[b] Brazilian North Utility, ELETRONORTE S/A, Av. dos Jequitibás, s/n Cohebe do Sacavém, São Luís, MA 65040-460, Brazil

Received 28 August 2004; accepted 15 June 2006

Abstract

On October 2002 the Interconnected North–Northeast Brazilian Power System experienced severe power and voltage oscillations in response to a sequence of line and load outages, triggered by a line-to-ground short-circuit in one 500 kV Northeast transmission line. Protective devices tripped out the links between these two systems, and as a result more lines and loads were tripped out. In the following days, the North power system operator detected abnormal operation conditions, such as voltage oscillations, apparently with no specific causes, indicating a high degree of vulnerability. In the years of 2003 and 2004, the adding of new transmission lines and generation units reinforced these interconnected systems. This paper investigates the 2002, 2003 and 2004 dynamic security of these power systems through large (time domain analysis) and small-signal (modal analysis) stability analysis using the October 2002 major disturbance as benchmark. It is also investigated the performance of the available FACTs devices as damping controllers. The dynamic oscillations for the 2003 and 2004 configurations are less severe in terms of amplitude and time duration as well, being damped out faster, resulting in the keeping of the system interconnectivity integrity. The results confirmed that the dynamic security state has been improved.

Keywords: Large signal stability; Small-signal stability; Angular stability; Voltage stability; Time domain; Computer simulation

1. Introduction

Large signal synchronous machine stability problems are usually analyzed through time domain computer programs. In general, these programs include dynamic models of synchronous machines, automatic voltage regulators, speed governors, static VAr compensators, induction machines, reactive power shunt devices, HVDC control systems, constant impedance loads and other fast acting devices. These conventional time domain methods are suitable for analysis of the phenomena from tens of milliseconds up to several seconds. Transient voltage stability scenarios can be investigated using conventional transient stability programs since the speeds of the phenomena are comparable and certifying that suitable models are available.

Analysis of power system dynamic phenomena, such as transient angular and voltage stability is useful to determine the time coordination of the equipment, to clarify the phenomenon and prevention of overdesign, improvement of simulation fidelity, time domain simulation forces a more careful analysis and the use (development) of more perfect models, to simulate fast dynamics associated with the final phases of the collapse; and to obtain the dynamic acting of the system through graphs where the evolution is visualized in the time of the phenomenon [1]. In the specialized literature, several papers deal with time domain analysis of voltage phenomena [2–8], including the analysis of real cases [9–11].

On the other hand small-signal analysis is useful to identify the causes of weakly damped or unstable power system oscillations and helps determining efficient means for

* Corresponding author.
E-mail address: pessanha@dee.ufma.br (J.E.O. Pessanha).

0142-0615/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ijepes.2006.06.010

oscillation damping control. Small-signal stability analysis is carried out based on the system nonlinear equations, describing the dynamic behavior of the system, linearized around a chosen operating point. This analysis is based on the computation of eigenvectors, eigenvalues and their sensitivities [12].

The present work investigates the actual North–Northeast Brazilian interconnected power system dynamic security through conventional large and small-signal stability computer programs. In order to achieve this objective, it is reproduced a real sequence of events, which took place in this interconnected system on October 2002. The initial events resulted in the loss of the transmission links between these areas, isolating the Northeast power system from the rest of the national power grid. Several undesirable consequences were observed in both power systems, such as partial/total voltage collapse, severe and time extended angular/power oscillations. The present investigation is concentrated only in the North power system, operated by the ELN utility.

Three sets of simulations are presented where the main difference is at the power system configuration. The first set reproduces in details the events taking into account the October 2002 configuration, including a voltage stability control analysis using VQ curve. The second and third sets reproduce the same events considering the 2003 and 2004 power system configurations, respectively, with new 500 kV transmission lines and generation units added in both North and Northeast power systems. The main changes started to be implemented in the year of 2003 and the objective is to make a comparison in terms of transient angular and power/voltage oscillations in order to verify the improvements and the resulting power system dynamic security state. In few words, this work tries to show the answer for the following question: "Is the North–Northeast power system actually dynamically safe for severe impacts, such as that occurred on October 2002?". The answer to this question is given based on time domain and modal analysis computer simulations.

The results reported in this work show that the measures implemented in 2003 and 2004 reinforced the interconnected systems in terms of dynamic security. The resulting angular, power and voltage oscillations are damped out much faster for the most recent configurations, avoiding undesirable lines and loads outages.

2. The Brazilian North Bulk Power System

The Interconnected Brazilian Power System is composed majority by three subsystems; North, Northeast and South/Southeast, forming the National Interconnected System (NIS). There are also isolated communities supplied by small and medium-port thermal plants, mainly in poor and difficult access areas, such as those found in the Amazon region, located at the north of Brazil.

The main electric energy of the North Power System Utility (ELN) comes from Tucuruí Hydroelectric Power Plant, located in the Tocantins River, 350 km away from the south of Belém, capital of the state of Pará. This power plant is located in the geographical and electrical Brazilian North region, and its construction was planned to take two stages. The first one operates since November 1984, and presently, this power plant has a total installed capacity of 8070 MW.

The states of Pará and Maranhão are crucial to ELN utility since the first one contains the major hydroelectric plant and the second one contains the main 500 and 230 kV ELN transmission lines. In the state of Maranhão, there is a huge industrial load (Alumar) composed by special thermal loads (electrolytic cells) with constant power/current characteristics, solid-state devices (rectifiers) for ac–dc supply, and induction motors. The actual industry demand is approximately 814 MW. This plant is supplied by São Luís II substation through two 230 kV transmission lines and it is considered one of the world's biggest alumina and aluminum industrial plant. Besides the special load characteristics described above, this plant is also heavily Mvar compensated. This load scenario is then very susceptible to voltage stability problems.

Just to illustrate how important this industry is not only to the local, regional and national economy, but also to the local, regional and national power grid, Fig. 1 offers

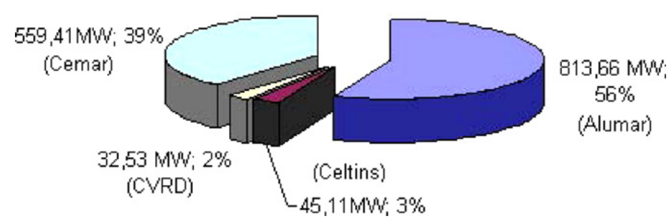

Fig. 1. Actual load composition.

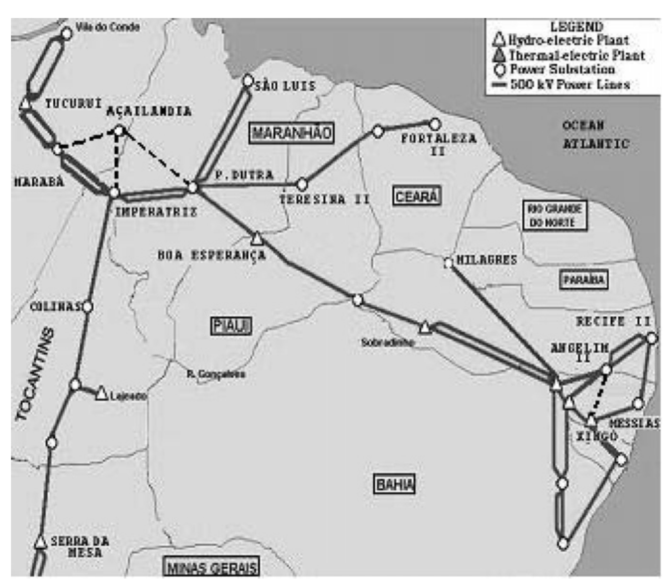

Fig. 2. Electrical/geographical Brazilian North–Northeast chart 500 kV transmission system.