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ASSURING SYSTEM RELIABILITY IN A COMPETITIVE ENVIRONMENT

by

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ABSTRACT:

Electrical power systems are changing from a cooperative model to a competitive one. What will happen to stability aspects in this new scenario? This paper discusses some aspects related to this issue, comparing the traditional approaches with the new IPP approaches.

Keywords: Restructuring, Competitive Environment, Stability, Independent Power Producers.

1. INTRODUCTION

Brazil is rapidly facing the restructuring of its power sector. The changes are from a highly centralized hierarchical and state-owned system to a new model characterized by competition in generation with guaranteed access to open transmission.

Unlike the case of other industries such as communications and transportation, where overloads result merely in telephone "busy signals", or grid lock at toll plazas, the nature of power consumption is essentially instantaneous. Power must be supplied the moment a switch is turned on. Inadequacies in the generation/transmission plant can result in system collapse with unacceptable consequences.

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The dynamic performance of power systems, that is, the ability of maintaining reliable and stable supply within tolerable limits of
voltage and frequency is a function of the joint characteristics of generation, transmission, control, protection and loads.

In the traditional approach of integrated planning of bulk electric systems by a centralized agency, the decision process on generation, transmission, distribution and control additions was a well structured one aimed at an optimum allocation of investment in the various segments so as to achieve a desired level of reliability at minimum cost.

For decades under the traditional approach, due to the high relative cost of generation, the plans of generation additions were established almost independently, with mere estimates on transmission feasibility.

Transmission planning then proceeded to accommodate an already established generation masterplan.

Within the last decade, the abundance of natural gas and the rapid progress of combustion turbine and combined cycle technology, along with other environmental factors, has drastically changed the economics of generation. Concurrently, the worldwide trend to deregulation has opened the power generation industry to independent producers. The consequent restructuring of the power industry has given rise to new problems, some of the most difficult ones being the twin issues of establishing requirements on new generation equipments and controls and administering the required ancillary services (9) in the operating environment of the restructured industry.

So while competition will force the evolution of the most economic generation additions, there will still be some aspects on dynamic characteristics requiring cooperation dictated by effects on overall system performance.

Stability controls are one of such issues including the equitable allocation of associated costs.

The predominantly hydro Brazilian system, spans large geographical distances and has most of its generation remote from load centers. Unfavorable hydrological conditions frequently call for high power transfers between regions, even during light load conditions. Stability problems are therefore naturally aggravated during these conditions.

This paper deals with aspects related to stability controls as an ancillary service, considering the large diversity of operating conditions. Up to now, the allocation of costs of stability controls has been decided jointly by the GCPS and GCOI, the national coordinating pools for planning and operation of the Brazilian power system, whose decisions are mandatory. The stability controls considered involve: control of system oscillations (PSS), generation dropping, underfrequency load shedding, dynamic voltage controls, HVDC controls, controlled islanding, automatic switching of shunt compensation and others.

In the old system structure stability problems were detected and resolved by GCOI/GCPS. The introduction of IPP's, cogeneration and a possibility of an ISO - Independent System Operator, changes this picture. Attributing responsibility for a given stability problem and distributing the costs of candidate solutions are very complex issues, which can lead to opposing opinions from the different parties. There is therefore a strong need to investigate all these aspects, in order to establish the guidelines, responsibilities and associated costs for the stability controls in a competitive environment.

This paper does not propose a methodology for solving this problem, but rather discusses important issues related to control actions in a competitive environment, and how important it is to develop a methodology for allocation of these costs. CEPEL is presently engaged in developing methods and related computer tools to address these issues.

2. THE BRAZILIAN ELECTRIC SYSTEM

The Brazilian electric system has an installed capacity of 56,000 MW, which is predominantly hydro (95%) and involves an extension of 150,000 km of transmission lines of voltage levels from 138 kV to 765 kV. The energy production is of the order of 309 TWh, with 97% being produced by hydro powered stations. There are about 40 million consumers, with 32.5 million being residential consumers. The energy consumption per capita is 1,954 kWh/year for residential consumers.

Other system characteristics are given below:

- Large capacity hydro power plants, remote from the load centers.
- Large hydroelectric dams, having plurianual (up to 5 years) storage capacity for good regulation of variable inflows.
- Hydro units of large capacity: Itaipu (700 MW), G. Munhoz (418 MW), Itumbiara (380 MW), etc.
- Long transmission lines, sometimes presenting bottlenecks at some transmission corridors
- Frequent operating conditions which involve heavy energy transfers, even during light load, due to hydroelectric generation coordination for optimal water usage.
- High load growth (6% per year, during 1996/1997)
- Delays in construction of high capital investment power plants, with consequent need for urgent generation expansion.

During unfavorable hydrological conditions, the transfer of large blocks of energy between generating subsystems having hydrological diversity is carried out, mainly during light load conditions. In some parts of the system, it is common to have reversals in the power flow of some transmission lines and transformers. In a few cases involving highly unfavorable hydrological conditions, the system has operated with violations of the existing criteria of transient stability. Note that in these cases the system must still meet the criteria for small signal stability, so as to not face spontaneous oscillations.

As stated before, there are two coordinating bodies for the expansion planning and operation of the interconnected systems, which are composed of managers from Eletrobras and all the other Brazilian utilities, the GCPS (Coordinating Group of System Planning) and GCOI (Coordinating Group for Interconnected Operation). These two Groups perform regular dynamic stability studies, and establish recommendations concerning the required control actions for system stabilization.

3. NEW SCENARIOS FOR THE BRAZILIAN ELECTRIC SYSTEM

The last Ten-Year Plan, released every year by GCPS, estimates that the rise in electrical energy demand in the period 1997-2006, will call for the installation of an additional 3200 MW of generation every year. Two immediate questions appear: a) How will the transmission system evolve? and b) What will be the expansion process for this additionally needed generation.

Taking into account the ongoing restructuring process of the Brazilian electrical industry, the Government stimulus to private investors and the highly developed technology for combustion turbines, it is possible to envision the following scenario:

- Significant increase in thermal generation, mainly gas turbines. It is expected that in the next ten years the gas turbines will represent 10% of the total installed capacity in Brazil.
- Implementation of several international interconnections, initially with Argentina, Uruguay and Bolivia, which will be carried out through HVDC links or back to back schemes.
- Utilization of alternative energy sources: Wind power and solar generation, biomass (sugarcane leftovers), mainly in the Northeastern part of the country.
- Significant rise in distributed generation.
- Operation of the existing system closer to its maximum limits.

The above scenario is very likely, due to the following reasons:

- The country needs to increase its generation capacity in the immediate and near future, so as to prevent the possibility of severe power shortages.
- The newly implemented legislation, regarding IPPs and the assured open access, created favorable conditions for the arrival of these new agents. The reduced construction period for these power stations, driven by gas turbines, is ideal to face the challenge of rapidly commissioning this needed additional generation. Another advantage is that these gas turbines are meant to be located close to the load centers, therefore minimizing high investments in long distance transmission.
- The high level of technology development of combustion turbine driven power plants makes the combined cycle power plant one of the most efficient forms of electrical power generation, offering very-competitive energy prices. These power plants cause low environmental impact, with negligible levels of audible noise, atmospheric pollution and emission of liquid or solid waste. The turbine has acoustic insulation, the natural gas has very low levels of sulfur and the burners can meet the most severe environmental legislation. The gas supply to these power plants is guaranteed by Petrobras (newly discovered gas fields as well as imported gas), together with the gas pipelines Bolivia-Brazil and Argentina-Brazil. There will also be gas pipelines within the Brazilian territory to distribute gas.
- Another important factor is the co-generator with Petrobras as the biggest. Considering the various oil fields and refineries owned by Petrobras where the gas is currently being burned, it can be estimated that as much as 10,000 MW can be generated if this gas is used to produce electricity.
- The North-South interconnection will be commissioned by December 1998, interconnecting the North-Northeast system to the larger South-Southeast-Centerwest system. It is a 500 kV circuit, 1,000 km long, which will bring a gain of 600 MW of guaranteed energy by making optimal use of the hydrological diversity between the river basins involved. This interconnection together with those with Argentina will cause some areas of the system to operate close to their maximum transmission capacity. This interconnection will have a TCSC as a means of enhancing stability [8].

This scenario calls for the solution of an important structural problem: How to stimulate private agents to build hydro plants? There is still a considerable hydro potential to be explored in Brazil, that is economically feasible. This requires, however, an intensive capital investment, and private agents prefer investments that can be recovered in shorter periods. Undoubtedly, the solution for this problem is to form partnerships between private investors and ELETROBRAS, so as to ensure that investments that are sound for the whole system will actually be made. In this case, we will be faced again with long distance transmission and with the need for stabilization actions that are always needed for such type of system.

In addition to the above factors and uncertainties which have a major impact on the overall system dynamic performance, there are the effects of major changes in the generation scenarios over the next two to three years when a significant amount of gas fueled generation will be operating close to the major load centers.

All of the above factors point to continued importance of the phenomena of network stability and increasing dependence on control actions. The problem in the new competitive generation framework is how to establish costs, both first costs and operating costs for controls and how to allocate them among the various parties.

4. COORDINATION PLANNING AND OPERATION IN A COMPETITIVE ENVIRONMENT.

Organizational and administrative issues under the new competitive environment can only be resolved successfully following recognition of highly technical factors which make interconnected operation possible. This paper is primarily concerned with bringing such issues for discussion, rather than advocating any particular approach in the administrative and financial spheres.

4.1. ASSURING COMPATIBILITY OF EQUIPMENT DYNAMIC CHARACTERISTICS.

In the traditional vertically integrated power system model, the overall system reliability is the responsibility of one entity, whether state or investor owned. In this environment the acceptable characteristics of generation transmission, controls and protection evolved naturally to fairly uniform patterns among various utilities as dictated by techno-economic considerations. There would be no tendency to under invest in one segment (generation, transmission or controls) causing a disproportionate impact on reliability in the case of a single owner of all segments, responsible for overall system reliability. In this scenario the cooperative approach to accepting one's share of investments in the various sectors, dictated by dynamic considerations, was natural for a mutually beneficial interconnected operation.

Where necessary, organizations such as NPCC, WSCC, ERCOT etc. in the U.S.A., UNIPED in Europe and GCOI/GCPS in Brazil issued recommendations on practices to be followed by all members of such power pools. Examples are patent in the area of primary frequency control (droop settings and spinning reserve) and automatic generation control (area control error reversals per hour etc.).

In the case of interconnected systems using long distance transmission, the problem of poor damping of inter-machine and inter-area electro mechanical oscillations becomes a serious reliability problem and, just as in the case of system stiffness (area regulating characteristic), the techno-economic solution is to distribute control effort (PSS in this context) over the major portion of generators. Members of interconnected systems owning both transmission and generation have no problems obeying voluntarily the guidelines set by coordinating councils (every unit over 75 MVA in the WSCC is to be equipped with a PSS).

Since this problem of damping can also be abated by the much more expensive expedient of stiffening transmission, one can appreciate the problem of enforcement of the most techno-economic solution, usually to be borne by the generation segment, where independent producers, with no stake in transmission are concerned.

This same dilemma extends to other system reliability aspects such as transient stability, load shedding, generator dropping etc. Distributed generation in systems linked by EHV and UHV transmission can present major challenges in system and protection design, since the possibility of load rejection and system separation with overspeeding generators connected to excessive line charging could easily lead to very high overvoltages and widespread damage to system and consumer equipments.

It is not merely stability that must be addressed. The entire system design must be done by a highly trained team considering all relevant parts of the system regardless of ownership.

Reference 6 describes how the evolution of system structures can affect the necessity for stabilization and its location. Loading, with its effect on angle separation and relative inertia between sending and receiving areas play an important role.

In systems with widespread transmission and significant interchange over long distance, the problem of oscillatory instability can dictate the need for stabilizing action under normal operating conditions. In others the problem can only arise during and following contingencies. Since the nature of the system structure following multiple contingencies can be almost unpredictable, units which normally are not participating in oscillation damping action can become critical contributors under contingency conditions.

The effectiveness of PSS's in providing damping is not only a function of their application in a major portion of generating units but also a function of the adequacy of their control tuning adjustments along with those of the associated excitation systems. System wide dependence on PSS's for adequate damping performance will no doubt require more formal enforcement of inspections and testing by the ISO in the restructured power industry.

5. THE IMPACT OF NEW THERMAL GENERATION ON SYSTEM DYNAMIC PERFORMANCE

5.1. BENEFICIAL ASPECTS OF IPP'S

New thermal-based IPP's will bring many benefits to the interconnected system:

- Being close to the load centers they will bring better voltage control and smaller loadings in transmission lines, with consequent reduction in transmission system losses.
- Improvements to voltage stability, due to a larger reactive support near the load centers.
- Improvements to electromechanical stability, due to smaller line loadings and added dynamic voltage support. The damping of inter-area oscillations will also tend to improve as a function of the smaller phase angle differences.
- Extra flexibility in planning equipment and transmission line outages.
- The availability of more thermal generation in Brazil will allow an effective hydro-thermal coordination.
- Alleviates the problem of reliance on ever increasing transmission distances to bring power to the load centers.
- The better dynamic voltage control yields a more reliable operation of transmission line distance protection, with a significant reduction in undesired trippings. This decreases the risk of system separation, frequency decay and load-shedding.

5.2. DETRIMENTAL ASPECTS

IPP's, when compared with state owned generating companies, are oriented towards a higher return on investments and, preferably, in a short time period. Their motto is to maximize power production and reduce their costs. What could be the consequences of this fact? Some of the functions carried out for free in today's environment (voltage support, frequency regulation, dynamic response, transient overload capability, etc.) are classified in the new environment as "ancillary services", whose provision will have a cost associated. Some of these aspects are further elaborated in tables in section 5.4.
Offsetting some of the positive aspects of IPP's listed in 5.1 is the need for assuring redundancy in the case of unplanned outages of such facilities. Such outages result in loss of both power production and voltage support wich must be provided by alternate facilities.

5.3. PENDING QUESTIONS

Environmental Aspects: Does generation in an amount like 10,000 MW obtained through several, geographically distributed, "Clean" gas fired power plants have a greater environmental impact than a low head, high inundation area, hydroelectric power plant in the Amazon region? In answering this question, one must also consider the environmental impact caused by the associated long distance transmission system.

Several issues concerning System Design and Operation which

5.4. PROBLEM ISSUES WITH NEW IPP'S

need attention in the restructured industry are raised below in tables 1 and 2. These issues generally involve the need for considering dynamic aspects of the plant interacting with the external system. In the vertically integrated traditional utility or Power Pool made up of such utilities, the planning and design process is usually undertaken by owner representatives participating in joint Interconnected System studies with access to the entire data base. Reliability criteria are followed and the design process considers all logical most cost effective alternatives, whether they involve generation, transmission, protection or control.

In the new restructured environment the technical approach should be the same since the mere fact of separate ownership of generation versus transmission does not change the underlying laws of physics which govern the adequacy of overall system performance. The challenge is to develop an organizational structure which can execute the necessary system studies and enforce the indicated design requirements among the separate parties. These, as competitors, have a natural tendency to hold back on free exchange of information. IPP's are concerned with the generation process and normally would not have the expertise to determine complex control and protection requirements dictated by the overall system with all the interactions of the various components.
The foregoing considerations point to the logic of a strong independent and competent organization to not only be in charge of system operation, but also of licensing future system additions be they in generation, transmission, control or protection.

All issues listed in the tables point to the need of establishing methods and procedures for requiring certain design features in new IPP installations which fall in the category of providing ancillary services, like for instance reactive power support, primary speed control, supplementary damping control (PSS) etc. Little has been done so far to develop such methodology which should include allocation of costs to those agents which do not contribute their share of ancillary services.

If this is not done in the planning process, these IPP additions may impact the adequacy of transmission systems. The resulting additional reinforcements needed in transmission would be reflected in transmission costs which would have to be borne by all consumers.

Table 1. Protection, System Voltage/Frequency Control, and Stability Aspects

ISSUE	Traditional Approaches	Problem issues with new IPP's
Protection Settings	Settings take into account the plant equipment's and power system requirements	-Concerned only with plant equipment security. -Larger possibility of plant tripping during disturbances. -For disturbances that cause generation deficits, plant tripping will increase the magnitude of frequency dips. In this case it will be necessary to increase the total load shedding. In extreme cases it could lead to a system collapse. -For disturbances that cause overvoltages, plant tripping can aggravate the voltage profile, increasing the chances of reaching transmission lines protection settings. The tripping of transmission lines could lead to a system collapse -For disturbances that cause large absorption of reactive power by the generators controlling voltage profile, settings of minimum excitation limits can cause plant tripping. With increasing numbers of IPP plants, this can lead to larger system overvoltages, and equipment tripping (or damage).
Generator Power Factor	-Generators with low rated power factor (0.9) can be used. This can avoid network reinforcements.	Without consideration of system requirements during contingencies, the tendency would be to order less costly higher rated power factor machines. The deficiency of reactive reserve could require move expensive alternative equipment in transmission.
Short-Time Overload Capability of Generator Excitation System	-Exciters are able to produce up to 200% of rated reactive power for approximately 20 seconds. This improves system dynamic performance.	-Lower capacity excitation systems and conservative setting of limiters. This reduces IPP costs. The limiters actuation might be increased to protect excitation and generator windings against failure due to high voltage stress. This can lead to voltage control problems and even collapse. -System requirements could be enhanced with greater MVAr reserves in generators.
Operation of Generators as Synchronous Condensers	-This characteristic is used during light load conditions in order to provide better voltage profile control, to maintain short-circuit level and to avoid transmission line opening to mitigate sustained over voltage during light load.	-This expedient would require installation of clutches representing additional costs.
Excitation Systems, Power System Stabilizers and Governors	-Are fully utilized to improve the power system dynamic performance, being considered the most appropriate and economic means.	-Application of higher cost machines with improved excitation systems (high initial response yielding move effective action from PSS) would not be normally adopted without some hard rules to define compensation of costs by the System.
Participation in Special Protection Schemes (SPS)	The design and implementation of Special Protection Schemes (Emergency Control Schemes) are analyzed by all parties involved. The SPS is installed considering the best location for it, i.e., it can be installed in any plant.	The IPP may not accept to participate in any SPS. This non-acceptance may jeopardize system reliability, determining the need of reinforcements.

Table 2. Operating Aspects

ISSUE	Traditional Approaches	Problem issues with new IPP's
Minimum number of units in operation	The number of units in each plant is determined to guarantee a minimum value of system inertia and reserve.	-IPP could consider that they have no obligation to do that, and maintain the number of machines in operation in order to obtain the maximum productivity of the plant. -This could affect voltage control, system stability and increased frequency dips.
Generating unit operation with minor failures	When minor failures occur, the utilities may agree to keep the generating units in operation until system conditions evolve to level at which unit disconnection will not jeopardize the overall system reliability.	-The IPP could consider that they have no obligation with system reliability requirements, the main objective being to protect their own equipment.
Information Exchanges and data availability	-To provide a more reliable and secure operation, abundant information is made available on current limitations / unavailability of equipment's and power flow constraints. -Traditionally all the data are available including data from disturbances (oscillograms, plant operators report, etc.,) for post operation analysis.	-The IPP could consider having no obligation to inform the others on what is occurring to his plant. -This intentional withholding of information is detrimental to overall system reliability. -The IPP could even have inadequate data acquisition and recording equipment.
Black-start capability	The operational planning of the interconnected system determines the restoration planning with its various parallel subsystems. -Every subsystem has at least one power station with black-start capability.	-IPP's, for cost reduction, may rely on remote power station cranking rather than install black-start capability. -As a consequence, the system restoration time may be increased.

CONCLUSIONS

- Without careful planning and design studies to establish the proper integration of IPP's into the interconnected system, including special requirements in equipments, control and protection, the proliferation of IPP's, with their rapid installation cycle, can have detrimental impacts to system dynamic performance which may not be fully compensated by the transmission system at reasonable costs.
- Although transmission system investments (and expenditures) will rise, the overall system reliability could be somewhat degraded in the future.
- The eventual lack of control actions and the consequent rise in transmission prices can result in loss of economic efficiency in power production.
- Many efforts have been noted to develop methods and tools for some of the ancillary services. So far, however, very little has been done concerning control actions cost allocation. This should be considered a priority issue, in order to ensure economic efficiency.
- The transition period from the cooperative model to the competitive one, will cause some additional risks, which are not fully assessed.
- One way to minimize the detrimental impacts and additional risks, is to show to the IPP's that selling ancillary services can be good business. Something must be done in this way, so as to make generation fulfill all its natural or traditional ancillary functions, since finding other control alternatives in the transmission network (like FACTS) is always more expensive.
- The Independent System Operator concept is good but that organization should have added functions in long term operational planning and particularly, licensing and inspection of new facilities to ensure that they meet system requirements.

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