PERFORMANCE OF UNDER EXCITATION LIMITER OF SYNCHRONOUS MACHINES FOR SYSTEM CRITICAL DISTURBANCES

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ABSTRACT - **This paper presents actual cases of machine undamped oscillations caused by unstable Under Excitation Limiter-UEL, when the machine is forced to absorb an excessive amount of reactive power during system disturbances. A different and simpler UEL structure has shown not to be susceptible to this problem.**

An actual system situation is also shown, where the use of PSS based on electric power in machines electrically close to others making use of accelerating power PSS will result in inadequate interchange of reactive power between machines. This may lead to unnecessary machine tripping by the loss of excitation protection. The employment of the same type of PSS in electrically close machines may be required in cases where reactive power absorption is critical.

Keywords - Excitation Control System-ECS, Power System Stabilizer-PSS, Under Excitation Limiter-UEL.

1. INTRODUCTION

The control of the machine terminal voltage was the unique function of the early excitation control systems. Their response was slow and their effect on power system dynamics was practically negligible.

The modern static ECS systems provided with high control loop gains, on the contrary, have been employed as a means of enhancing system dynamic performance and increasing system stability limits. Additional control loops implemented into the ECS, the so-called Power System Stabilizer-PSS, have proven to be an efficient and economic alternative to produce system damping for critical stability conditions. The PSS is, nowadays, part of almost all modern ECS.

Other control loops have also been introduced into the modern ECS by the manufacturers with different purposes, such as: a) the Under Excitation Limiter-UEL, b) The Volt/Hertz Unit; c) Maximum Armature Current Limiter; d) Maximum Field Current Limiter. These control loops are supplementary controls which are slow enough to be considered as a "steady-state control". It means that these controls are not designed to influence the system electromechanical transients, as the case of the PSS.

PE-603-PWRS-0-01-1997 A paper recommended and approved by the IEEE Power System Engineering Committee of the IEEE Power Engineering Society for publication in the IEEE Transactions on Power Systems. Manuscript submitted August 5, 1996; made available for printing January 8, 1997.

Taking the UEL controls into consideration is not usual in the system stability studies certainly due to the fact that they are not active in most situations. Only a few and recent papers [1], [2], [3], [4], [5] have been found in the literature dealing with the effect of these controls on system dynamics.

This paper shows that in some critical dynamic conditions, that might occur in the Brazilian Northern-Northeastern interconnected power system, these control loops are active and may influence significantly the machine dynamic performance. A careful analysis of UEL transient response is hence required for some system disturbances.

The coordination between PSS of generation plants with different types of PSS is also required to prevent inadequate interchange of reactive power that, in turn, will contribute to undesirable UEL actuation.

2. DESCRIPTION OF STUDIED POWER SYSTEM.

2.1 General Characteristics

The Brazilian Northern-Northeastern interconnected power system is comprised of two main generation centers connected by 2000km long, 500kV transmission lines. One generation center named Tucuruí (3900MW) is located in the Amazonas region. The other generation center in the Northeast region is composed by the hydroplants Sobradinho (1000MW), Paulo Afonso (4200MW), Luiz Gonzaga (1500MW) and Xingó (3000MW) along the São Francisco river (Figure 1). Approximately 500 MW flow most of the time from the Northern to Northeastern system. The major load centers, are located around the large cities, and are connected to the generation plants through 500kV and 230kV transmission lines. The transmission system derived from Xingó to subsystem South is under construction but not yet operational. Xingó operates in a base point equal to 3x500MW since it is the last plant in the river cascade.

2.2 Characteristics of Machine Controls

Paulo Afonso, Luiz Gonzaga and Xingó (Figure 1) are the generating plants concerned with the problem described here. The units of Paulo Afonso and Luiz Gonzaga have similar ECS, whose block diagram is shown in Figure 3. The PSS Switching Logic indicated in Figure 3 is not used in Luiz Gonzaga. This is a detailed model obtained from a careful analysis of the actual electronic circuits and makes use of real physical quantities in Volt. The interface of the model with the generator and with the network "per-unit" system is accomplished with appropriate gains. The steady-state characteristic of the UEL is shown in Figure 2. Two important features of the Paulo Afonso ECS (Figure 3) should be noted:

a) PSS based on machine electric power
b) The control structure of UEL includes a PI regulator. When the UEL is active, it takes over the excitation control. The voltage regulator output is disconnected so that the PSS contribution will also be removed.

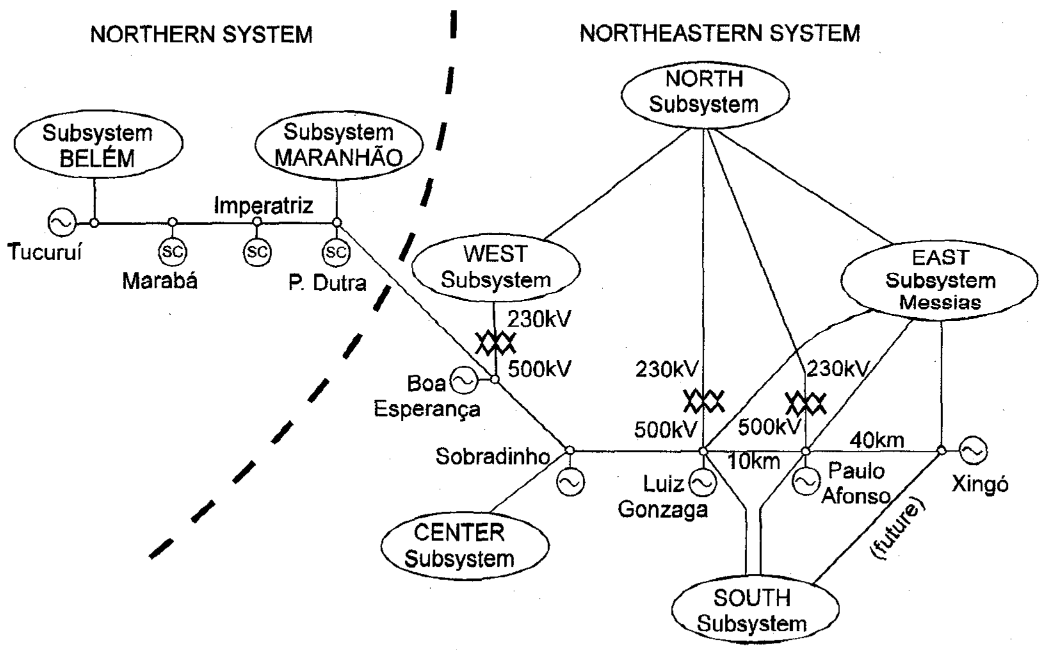

Figure 1 - Simplified one-line diagram of Brazilian Northern-Northeastern system

Two noteworthy features of Xingó ECS (Figure 4) are:

a) The PSS is based on accelerating power integral.

b) The UEL is not provided with PI regulator. Also, the UEL output is introduced before of the voltage regulator, that is, the UEL control action doesn't remove the voltage regulator and, in consequence the effect of the PSS.

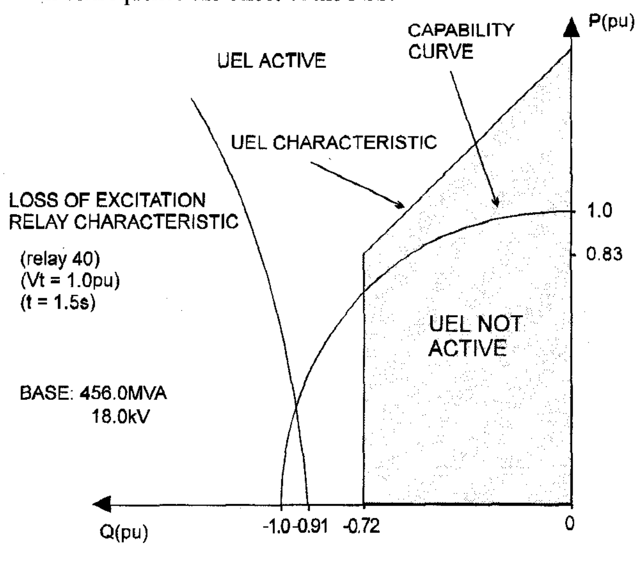

Figure 2 - Machine capability, UEL characteristic and under excitation curves.

3. UEL PERFORMANCE UNDER CRITICAL CONDITION

3.1 Identification of the Problem

UEL parameters are defined to coordinate with the under excitation relay curve as shown in Figure 2. It should be fast enough to keep the machine operating point inside the region delimited by the UEL curve and both P and Q axis.

Under normal conditions, the output of the UEL PI regulator is limited to $V_{LIM} = A_7 = -5.0V$ (Figure 3). Thus, $U_{ST} > V_{LIM}$ and the machine excitation is controlled by the voltage regulator ($U_{STF} = U_{ST}$). When the machine is absorbing a large amount of reactive power, so that the machine operating point tends to the region not enclosed by the UEL curve, the signal V_{LIM} can reach a positive and increasing value. The UEL will take over the machine excitation control whenever V_{LIM} becomes greater than the voltage regulator output (U_{ST}). Under certain circumstances, the UEL action forces the machine operating point into the internal region of the UEL curve, when the voltage regulator takes control over again. Depending on the system dynamics, this switching control action between UEL and voltage regulator may give rise to oscillations. Figure 5 shows the UEL and the voltage regulator outputs in case of loss of the Sobradinho to Luiz Gonzaga transmission line. This contingency results in a sequence of events as follows:

a) Loss of interconnection of the Northeastern system with the Northern system due the loss of synchronism.

b) Due to the high generation deficit, approximately 1000MW (20%), the frequency starts to decay at a very large rate.

c) The speed regulators of Paulo Afonso and Luiz Gonzaga start a fast increase of mechanical power. These generators are provided with PSS based on electric power that promotes a de-excitation in the machines of these two plants.

d) The Load Shedding Program - LSP starts to reject selected loads in the proper buses. This results in a decompensation of reactive power of the transmission system forcing the generating units to absorb a large amount of reactive power.

The conjunction of these events contributes to aggravate the problem of excessive reactive power absorption, establishing conditions for the actuation of machine UEL.

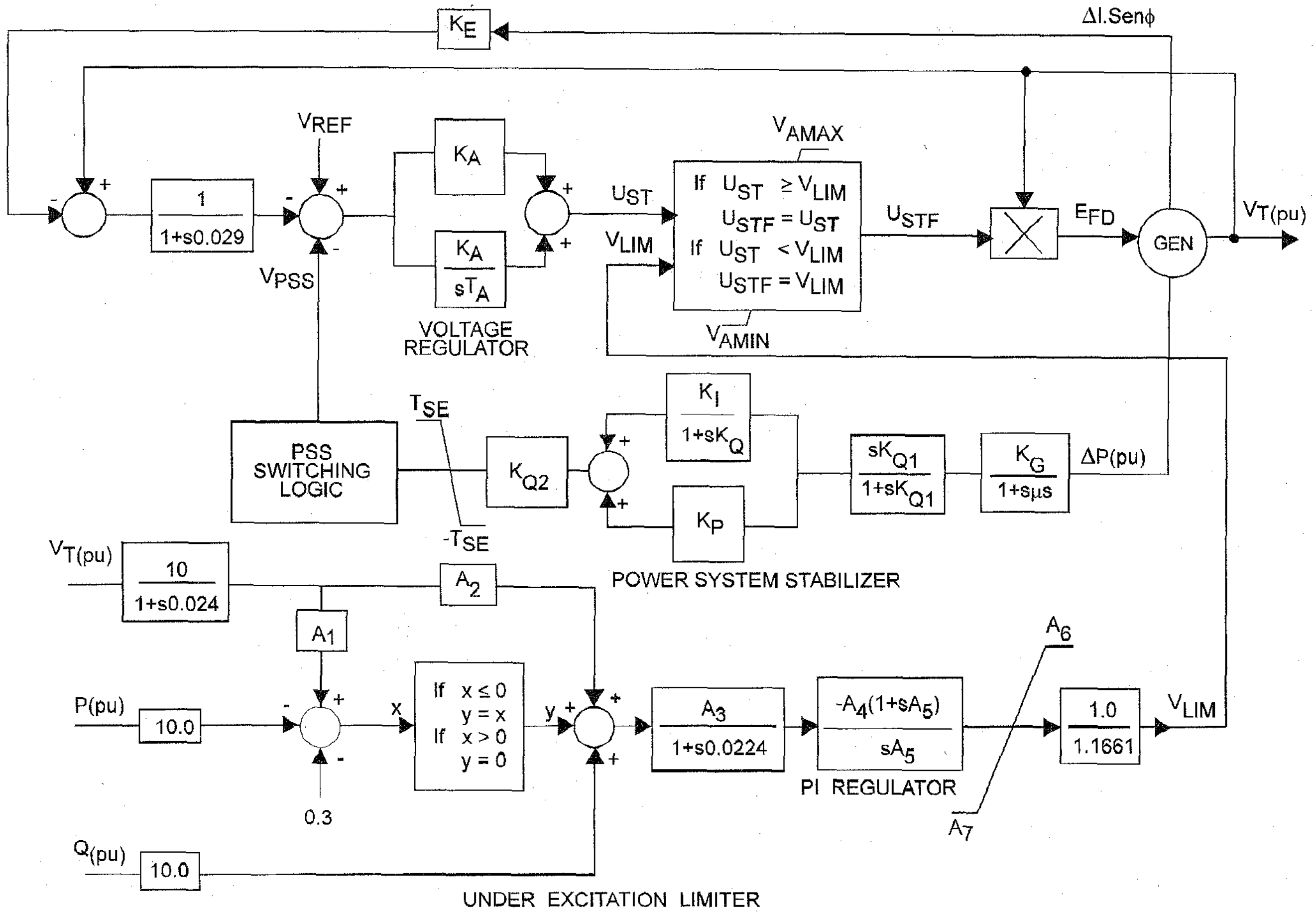

Figure 3 - Block diagram of Paulo Afonso and Luiz Gonzaga ECS.

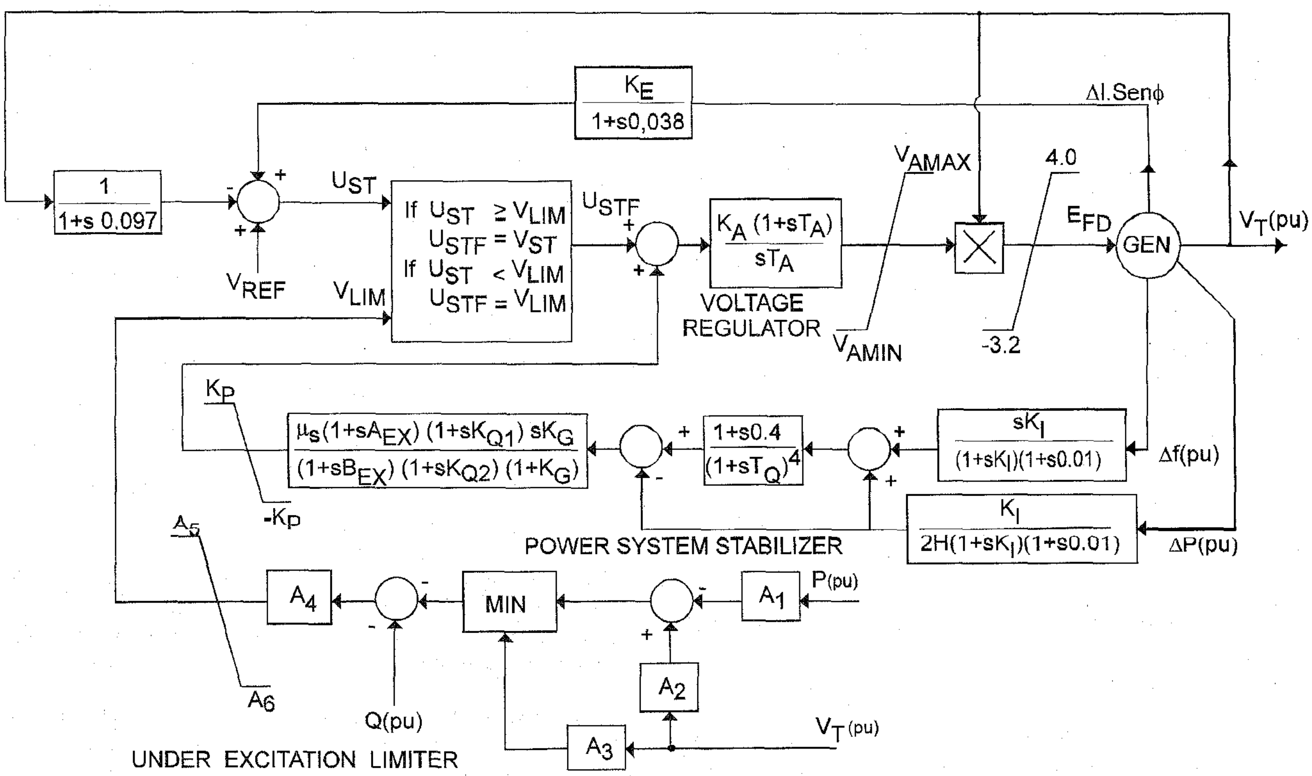

Figure 4 - Block diagram of Xingó ECS.

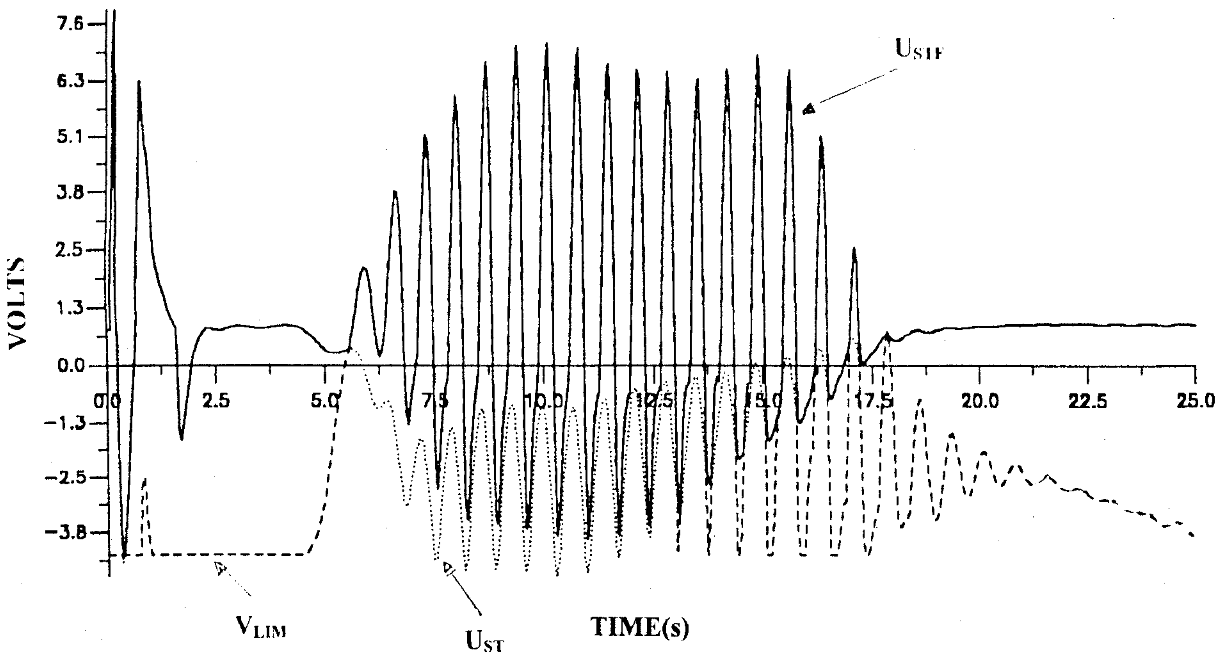

Figure 5 - Variables of Paulo Afonso ECS

Figure 5 shows the oscillations whenever the UEL takes over the excitation control, that is, $V_{LIM} > U_{ST}$ and $U_{STF} = V_{LIM}$. This simulation indicates that the UEL constitutes an unstable control loop.

It should be noted that system stabilization was reached because the voltage regulator was capable, in this case, of taking over the excitation control again. Figure 6 shows machine active power while the UEL keeps excitation under control.

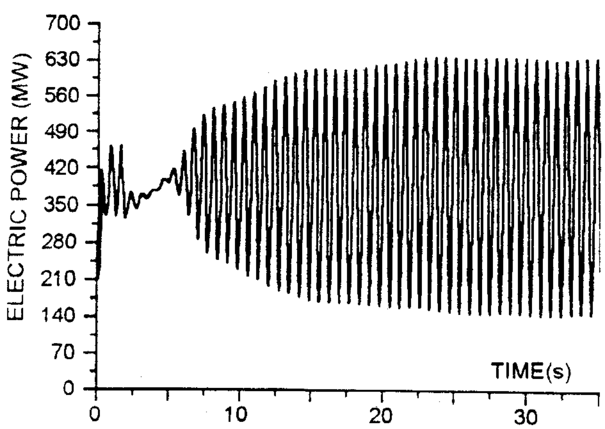

Figure 6 - Paulo Afonso active power - Old parameters

3.2 Adopted Solution

A detailed analysis of several cases has indicated two alternatives to avoid this problem:

a) Reduction of UEL control loop gain. The UEL transient response must be, however, sufficient fast to coordinate with the under excitation relay (Figure 7).

b) Modification of ECS control structure. The employment of a UEL in Paulo Afonso, similar to the UEL of Xingó (Figure 8).

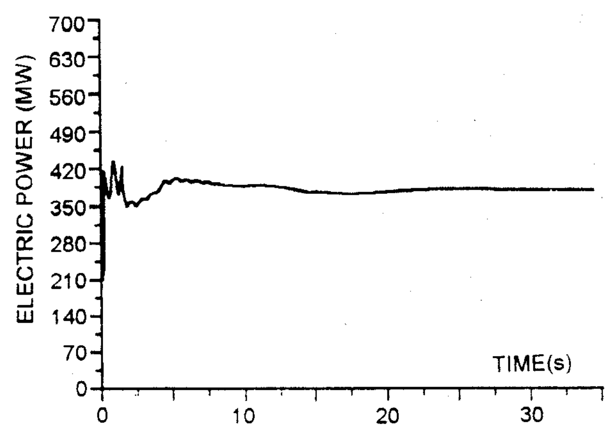

Figure 7 - Paulo Afonso active power - New parameters

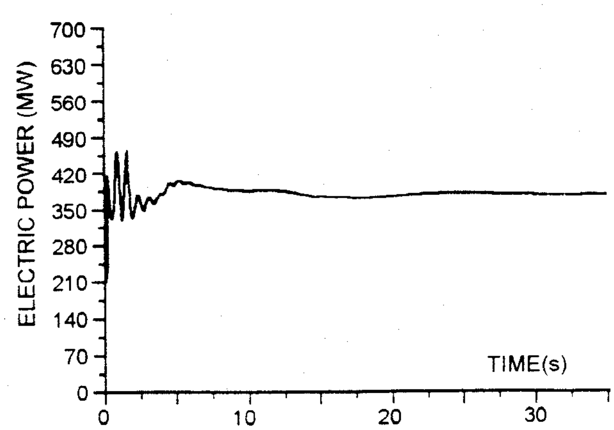

Figure 8 - Paulo Afonso active power - UEL without PI regulator of its own

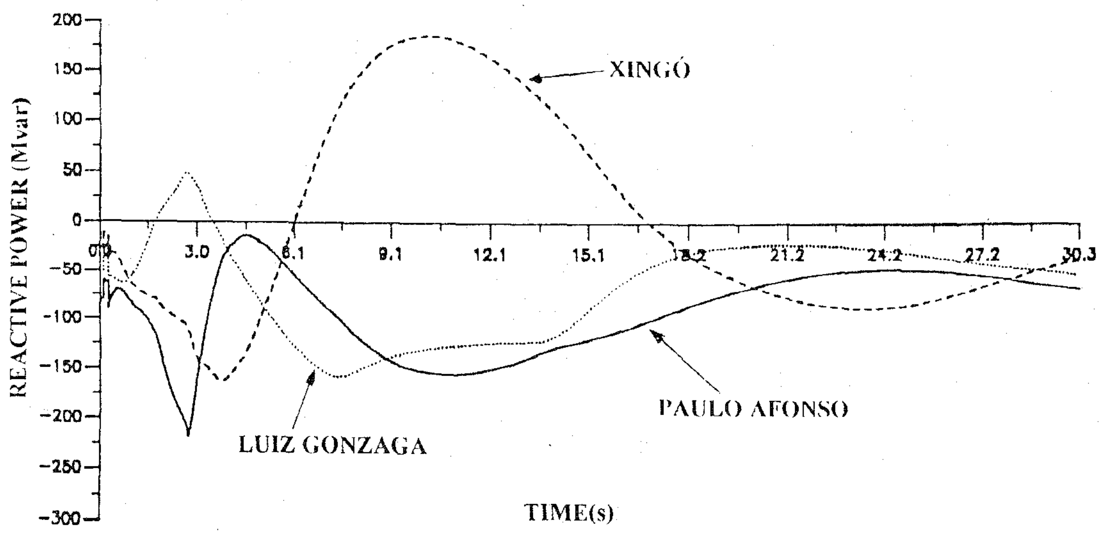

Figure 9 - Transient response of generator with different type of PSS

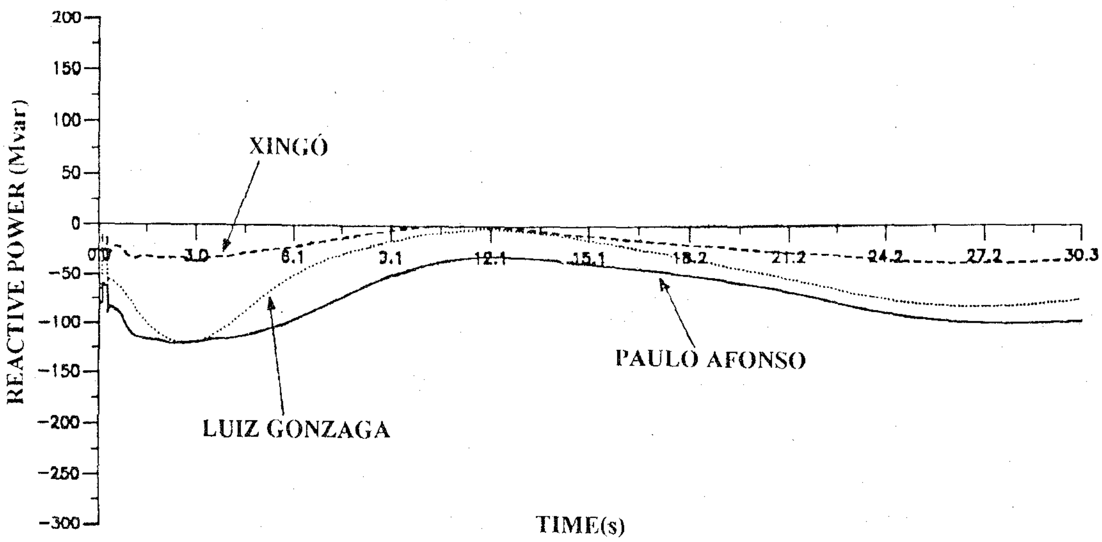

Figure 10 - Transient response of generator with same type of PSS

A reduction in the UEL control loop gain was accomplished by using a new set of parameters. This solution was chosen due to its simplicity and considering that it meets the coordination requirements with under excitation relay.

Figure 7 shows the system response with the new set of parameter of Paulo Afonso's UEL, for the case shown in Figure 6. Figure 8 shows the same case as before, but using in Paulo Afonso a UEL which is equal to that of Xingó.

Numerous simulations carried out with this system have indicated that the UEL structure of Xingó is not susceptible to instability. Furthermore, this structure enables the continuity of the PSS action.

It should be emphasized that modern ECS, with multiple control loops operating in power systems, and susceptible to the aforementioned problems, require a judicious analysis to determine the appropriate ECS control strategy. These are unusual non-linear problems not detected in simulations when they are not expected and hence the ECS is not properly modeled.

4. INADEQUATE REACTIVE POWER INTERCHANGE BETWEEN GENERATION PLANTS

The first machine of Xingó generation plant started to operate in 1993. Hence, Xingó is the most modern plant in the Northern-Northeastern system nowadays. The ECS is provided with a digital PSS based on accelerating power integral [2], performance of which is less sensitive to ramp increasing of electric power.

On the other hand, there are machines of the 1970's and 1980's in Luiz Gonzaga and Paulo Afonso plants. They are provided with analog PSS based on electric power, that are sensitive to a rise in machine power as a result of the speed regulator action, for instance.

Figure 9 shows the reactive power transient of the above mentioned generation plants for system disturbances, where a lack of coordination between Xingó and Paulo Afonso/Luiz Gonzaga is evident, due the employment of a different type of PSS. This is a case of generation deficit and frequency decayment with fast speed regulator response. The electric power PSS of Paulo Afonso and Luiz Gonzaga start a de-excitation action that results in a drop in the machine terminal voltage. Xingó ECS, in turn, injects reactive power into the system, attempting to control the terminal voltage. This is an unacceptable situation due to the high and unnecessary risk of machine tripping by the loss of the excitation relay.

Figure 10 shows the same case as above, when the PSS of Paulo Afonso and Luiz Gonzaga were substituted by an accelerating power PSS.

Taking into account that an additional loss of generation in this case may lead the system to a collapse, the decision was made to replace the electric power PSS of Paulo Afonso and Luiz Gonzaga by accelerating power PSS in all generator units. This has already been done in the former generation plant.

5. CONCLUSIONS

1. It has found that the Under Excitation Limiter - UEL of synchronous machine may be susceptible to instability. Thus, a proper modeling of UEL has to be considered in carrying out detailed studies when the generators absorb large amount of reactive power and the UEL is active.

2. Large absorption of reactive power by generators, are likely to occurs with long lines, heavily shunt compensated transmission system with concentrated loads, when a high rate of frequency decayment, caused by abrupt generation deficit, requires load tripping by a Load Shedding Program. This condition is aggravated if electric power PSS are utilized.

3. Our operational experience to date suggests the employment of a UEL structure similar to that used in Xingó (Figure 4). In this structure, the UEL transfer function doesn't contain a PI regulator and its output is introduced before the voltage regulator. The PSS remains active regardless of the UEL being active. No instability condition was detected with this structure.

4. The use of different types of PSS in electrically close generation plants may lead to an inadequate interchange of reactive power. In some critical cases, the unnecessary high absorption of reactive power by machines with electric power PSS may cause the machine tripping by the loss of excitation protection.

5. PSS based on accelerating power integral has shown to be more suitable then the electric power PSS for the above mentioned situations.

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BIOGRAPHIES

ÁLVARO JOSÉ PESSOA RAMOS was born in Recife, Brazil, in 1951. He received the B. S degree in Electrical Engineering from the Federal University of Pernambuco, Brazil in 1973 and the M. Sc from the Federal Engineering School of Itajubá, Brazil in 1975. From March/1986 to March/1987 he was at the University Erlangen Germany and at the High Voltage Transmission Engineering Department of Siemens AG for a research program. In 1974 he joined CHESF, Recife, Brazil, where he is engaged on system stability and power quality problems. He is senior member of the IEEE and a member of the CIGRÉ.

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APPENDIX

Description of variables and symbols.

P(pu)	per unit machine active power
Q(pu)	per unit machine reactive power
V_T(pu)	per unit machine terminal voltage
Δf(pu)	per unit machine frequency deviation measured from machine terminal voltage.
ΔI.Senϕ	reactive component of generator armature current.
GEN	generator
SC	Synchronous Condenser