METHODS TO IDENTIFY GENERATORS TO BE EQUIPPED WITH STABILIZERS: APPLICATION TO LONGITUDINAL POWER SYSTEMS

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Abstract. This paper presents a comparative analysis and the application of several methods to identify the best generators to be equipped with stabilizers in multimachine power systems. Systems which exhibit electromechanical oscillatory instability with oscillation modes that have negative or insufficient damping are considered. The eigenvalue-eigenvector analysis is used as a basis in the identification methods presented. A novel method of identification using frequency domain analysis is proposed. These methods are applied in planning studies of a typical longitudinal power system, the Central Interconnected System of Chile (CIC) and results of those studies are reported.
Keywords. Power system stability; Power system control; Power system stabilizers.

1. INTRODUCTION

The phenomena of small disturbance instability is generally the result of extended use of static excitation systems, particularly in longitudinal power systems [9]. In planning stages of multimachine power systems, it is often necessary to perform studies of the small disturbance stability, to prevent future electromechanical oscillations and eliminate them if they are present. When a generator or power station is going to be commissioned in an existent power system, extensive studies to detect electromechanical oscillations with negative or inadequate damping must be carried out. The steady state electromechanical oscillatory instability (also termed steady state instability and small disturbance instability) can be solved inserting properly tuned power system stabilizers (PSS) into the automatic voltage regulators (AVR) of some generators of the power system.

The small disturbance instability problem has been extensively analyzed [3,2,1]. It is well understood in those cases where the instability is clearly identified with one machine or machine group. In such cases the application of the stabilizers will be easy. In other cases the identification of the best sites for stabilizers applications can be difficult [7,2]. The identification of the optimum location for stabilizer application in multimachine power systems has been studied using different techniques [1]. The usefulness of the eigenvalue and eigenvector analysis for the identification of effective PSSs sites has been demonstrated. In the case of new networks, modern excitation controls can incorporate stabilizers without extra specific requirements. In case of existent networks, there are many factors that affect the placing of stabilizers. For example, the incorporation of a stabilizer in an specific old machine could be very expensive, and that machine has to be discarded. Mathematical techniques can help to determine a suitable group of generators to be equipped with PSSs, but the system knowledge will be fundamental in the last selection.

The state space analysis and consequently the eigenanalysis are used in this paper to describe the most important methods to identify the best locations for stabilizer applications. Three known methods are mentioned and a new one proposed, the analysis of frequency response plots. These methods were tested in studies of the Central Interconnected Power System of Chile. It corresponds to a longitudinal power system which operates at the edge of stability without PSSs. However, the concern exists about its performance after three new hydraulic generation plants are commissioned to cope with future demand growth. Longitudinal power systems are prone to experience low frequency oscillations that may cause oscillatory instability; this would also be the case for the example system.

The studies of the Chilean system are complemented using procedures to detect the AVRs that need changes in their parameters settings. Conventional power system stabilizers which are composed of a series of lead-lag blocks with standard time constants and parameters values are proposed. The objective is to eliminate inadequate or negative damping, shifting the dominant eigenvalues to convenient left places in the complex plane, and thus show the efficiency of the identification methods.

2. IDENTIFICATION OF GENERATORS TO BE EQUIPPED WITH STABILIZERS

The linearized equations of a nonlinear power system, around an operating point, are expressed in state form as [6]:

$$d\underline{x}/dt = \mathbf{A}\,\underline{x} + \mathbf{B}\,\underline{u} \qquad (1)$$

$$\underline{y} = \mathbf{C}\,\underline{x} + \mathbf{D}\,\underline{u} \qquad (2)$$

$\underline{x}$ is the vector of the system state variables (state variables could be: generator variables Ed", Eq", Eq', ω, δ; excitation system variables; variables related to turbines and governors, and those related to stabilizers). If the initial state is zero, the Laplace transformation of the above equations results in matrix form as:

$$\begin{bmatrix} s\mathbf{I}-\mathbf{A} & -\mathbf{B} \\ \mathbf{C} & \mathbf{D} \end{bmatrix} \begin{bmatrix} \mathbf{X}(s) \\ \mathbf{U}(s) \end{bmatrix} = \begin{bmatrix} 0 \\ \mathbf{Y}(s) \end{bmatrix} \qquad (3)$$

Relating the output vector $\mathbf{Y}(s)$ and the input vector $\mathbf{U}(s)$:

$$\mathbf{Y}(s) = \mathbf{G}(s)\,\mathbf{U}(s) \qquad (4)$$

where: $\mathbf{G}(s) = \mathbf{C}\,(s\mathbf{I} - \mathbf{A})^{-1}\,\mathbf{B} + \mathbf{D}$ (5)

$$\det(s\mathbf{I} - \mathbf{A}) = 0 \qquad (6)$$

the roots of such polynomial are the eigenvalues λ of state matrix $\mathbf{A}$.

Basically, the idea of using stabilizers is to close a feedback like that of Figure 1, in which H(s) represents the power system stabilizer block diagram. The input signal to the stabilizer may be the rotor speed, accelerating power, terminal busbar frequency, transmission line apparent resistance, etc.[10,4,1]. The stabilizer structure depends on the stabilizer design criteria. The selection of the generators which need the installation of stabilizers in their AVRs, will involve finding the most critical eigenvalues because they supply complete information on the stability of the system for small variations. Four methods of identification will be described based in the above state space formulation.

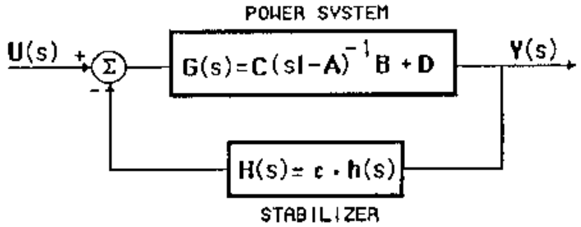

Figure 1. Power system and stabilizer

2.1 Mode Shapes Analysis [2]

The mode shapes analysis or right eigenvector method, is the most usual method of identification. The right eigenvector gives the mode shape, describing the evolution of the variables when this particular mode is excited. For example, the right eigenvector elements corresponding to rotor angle states in each one of the oscillating natural modes, are the rotor speed mode shapes. When the mode shapes of other variables, such as electrical power, are required, the relation of the interest variable to the state variables can be used. The relation is easily determined in the output variables matrix, using **Cj** (j represents the j-nth generator), multiplied by the eigenvector that corresponds to the eigenvalue of interest. Then all elements of the eigenvector can be normalized, the largest element will be 1+j0. The mode shapes analysis should be complemented with phasor diagrams.

The damping effects supply damping to high frequency oscillations. The oscillatory instability generally is related with oscillation modes at low frequencies. Therefore, the stabilizers are needed in machines that have the largest effect over low frequencies oscillation modes damping, frequently in the range of 0.1 to 3.0 Hz. The best positions for PSS applications are those machines that present the largest oscillation amplitudes. Then for multimachine power systems a group of generators can be selected as the best location for stabilizer applications in function of power (electrical or accelerating) and rotor speed mode shapes. The inertias of the machines influence in a decisive way the stability of the power system. Consequently, they are involved in the power mode shapes but not in the rotor speed mode shapes. For this reason, the generators to be equipped with PSS should be selected using the power mode shapes rather than rotor speed mode shapes.

An efficient way to compute the eigenvectors associated with the relevant or necessary eigenvalues is to use inverse iteration. The critical eigenvalues should be computed using particular techniques such as Lanczos method [12], the modified Arnoldi's method [11], etc.

2.2 Participation Factors [5,8]

The right eigenvector gives the mode shape that describes the activity of the variables when that particular mode is excited. The left eigenvector gives the mode composition that describes which weighted combination of state variables is needed to form the mode. The entries of these eigenvectors is arbitrary because the state vector considers different physical variables. The magnitudes of the entries of $\underline{v}_i$ and $\underline{w}_i$ (i-th component of right and left eigenvector respectively) change when the units in the state variables are changed. The generalized participations are defined by:

$$p_{ihj} = \underline{v}_{ih}\, \underline{w}_{hj} \qquad (7)$$

In the above equation, $\underline{v}_{ih}$ represents the i-th component of h-th right eigenvector and $\underline{w}_{hj}$ is the j-nth component of the corresponding left eigenvector. In case that i=j, the generalized participation is called participation factor:

$$p_{ih} = \underline{v}_{ih}\, \underline{w}_{hi} \qquad (8)$$

The participation factor is adimensional, and almost real and positive. For oscillating modes there is a relationship between the participation factors related to angle variables and those to velocities, expressed as:

$$p_{angle} = p_{velocity}\, [\, 1 + (D + m(\lambda))/M\lambda\,] \qquad (9)$$

since mod($M\lambda$) >> mod($D+m(\lambda)$), then $p_{angle} \approx p_{velocity}$

2.3 Computing of Residues [1,4,5]

This method was used in [1] with satisfactory results; a real case of instability was solved. It combines concepts of mode observability and mode controllability. It is powerful and could be termed the method of controllability factors. An expression can be derived from a property of the first derivative of the root locus. Suppose that all the zeros and poles of G(s) and **H**(s) (Figure 1) are distinct. When the feedback is inserted, there will be a shift $\Delta\lambda_i$ in the pole λ_i of G(s) given by:

$$\Delta\lambda_i = -\, R_i\, H(\lambda_i) \qquad (10)$$

R_i is the associated residue with **G**(s).

Let the transfer function $G^k(s) = y^k(s)/V^k_{ref}(s)$, where V^k_{ref} is the reference voltage of the AVR and y^k is a measurable output variable from which the stabilizer will be derived. Then, the state space equations associated to $G^k(s)$ are given by:

$$d\,\underline{x}/dt = \mathbf{A}\,\underline{x} + \underline{b}^k\, V^k_{ref} \qquad (11)$$

$$y^k = \mathbf{c}^k \underline{x} \qquad (12)$$

The poles of $G^k(s)$ are the eigenvalues of the state matrix **A**. Suppose that matrix **A** has n distinct eigenvalues $\lambda_1 ... \lambda_n$, the related right eigenvectors are $\underline{v}_1 ... \underline{v}_n$. Then, matrix **A** can be diagonalized through the following similarity transformation:

$$\tilde{\underline{x}} = V^{-1}\, \underline{x} \qquad (13)$$

Using (13), the transfer function $G^k(s)$ from equations (11) and (12) will be:

$$G^k(s) = \tilde{\mathbf{c}}^k\, (\, sI - \tilde{\mathbf{A}}\,)^{-1}\, \tilde{\underline{b}}^k \qquad (14)$$

$$G^k(s) = \sum_{i=1}^{n} \frac{R^k_i}{s - \lambda_i} \qquad (15)$$

the residue is given by:

$$R^k_i = \lim_{s\to\lambda_i} \frac{G^k(s)}{s - \lambda_i} \qquad (16)$$

an alternative expression for the residue is:

$$R^k_i = \tilde{\underline{b}}^k_i\, \tilde{\mathbf{c}}^k_i \qquad (17)$$

When the residue is zero:

- The state $\tilde{x}_i$ is not controllable and $\tilde{\underline{b}}^k_i = 0,\ \tilde{\mathbf{c}}^k_i \neq 0$
- The state $\tilde{x}_i$ is not observable and $\tilde{\underline{b}}^k_i \neq 0,\ \tilde{\mathbf{c}}^k_i = 0$

The values of R_i^k (k indicates the k-th generator) are proportional to the oscillation amplitudes. Then, the most effective generators for damping purposes are those where the greatest speed or power oscillation amplitudes are registered. In other words, the greatest residue (in moduli) indicates that the best possibility for stabilizer application is the k-th generator. There is a relation between the residues of power and rotor speed:

$$R_{accelerating\ power} = R_{speed} * [D + M\lambda] \qquad (18)$$

$$R_{electrical\ power} = R_{speed} * [D + M\lambda - m(\lambda)\,] \qquad (19)$$

m is the prime mover and $m(\lambda)$ corresponds to the variations of $\Delta P_m(\lambda)$ and resistive losses in the stator of the generator. In the above equations, the dominant term is $M\lambda$ for oscillation modes of interest. In Figure 1, **G**(s) is the transfer function that relates the variables $\underline{u}(s)$ and $\underline{y}(s)$; $H(s) = \varepsilon\, \mathbf{h}(s)$ is the feedback to close.

2.4 Analysis of the Frequency Response Plots

The frequency response methods allow the better understanding of small signal stability in multimachine power systems [3]. These methods are used in the design and synthesis of power system controllers. The transfer function matrix **G**(s) allows the frequency response analysis by substituting the Laplace variable "s" by "jω" in equation (5) and calculating G(jω) for discrete values of jω within the frequency range of interest (for example from 0 to 25 rad/s). It is necessary to observe the Nyquist stability criterion for evaluation of the closed loop stability of a feedback system (Figure 1). The basic idea is to plot the frequency responses for $\Delta\omega^k(s)/\Delta Vref^k(s)$ (ΔPt could be considered instead of $\Delta\omega$ if the stabilizer uses the power as input signal), taking into account that k=1...ng (ng=number of generators). Then it must be analyzed which plots in the complex plane allow to shift to the left half plane enroling the point (-1,0). Those plots which allow shifting the majority of their points to the left complex half plane (with the smallest action), indicate the best generators to be equipped with PSSs. The polar diagram for $\Delta Pt^k(s)/\Delta Vref^k(s)$ shows the effect of a standard delta omega stabilizer (PSS with rotor speed as input signal) when added to the k-th generator. The variables "ω" and "Pt" indicate the input signal to the stabilizer. Stabilizers with a frequency input signal need the frequency responses for $\Delta frequency^k(s)/\Delta Vref^k(s)$. If PSSs delta-omega, delta-P, delta-f, delta-omega-P, etc., are all available in an specific system, it is required to analyze their corresponding frequency responses. Obviously, that plot with the smallest action to encircle the point (-1,0) counterclock wise indicates the best generator for PSS application.

3. EXAMPLE

The Central Interconnected System of Chile (Figure 2) will be studied for two operating states in 1990 and 1992 (CIC901 and

CIC922). The CIC is a longitudinal system with hydraulic predominance. For the reported studies, it is modelled with 94 busbars, 165 lines, 14 synchronous machines, and two 500 kV circuits. CIC922 has a maximum demand of 2500 MW. At present the CIC operates without stabilizers devices [13]. However, it is assessed as marginally unstable (see dominant eigenvalues in Table 1). Probably, the use of incorrect data of AVR's could be causing the wrong assessment.

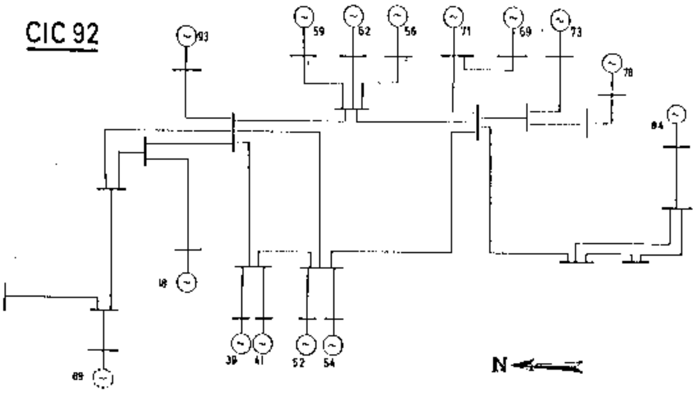

Figure 2. Simplified diagram of the Chilean system in 1992

The minimum damping requirement considered along this paper will be $\zeta = 0.03$ (logarithmic decrement); it corresponds to very poorly damped oscillating modes. This value is arbitrary but it can be increased up to $\zeta = 0.05$, a more restrictive option [9,1]. The expression for ζ (being the eigenvalue $\lambda = -\sigma \pm j\omega$) is:

$$\zeta = \frac{-\sigma}{(\sigma^2 + \omega^2)^{1/2}} \qquad (20)$$

Table 1. Dominant eigenvalues (CIC901)

#	real	imag.		damp.coef.ζ	SPR	f(Hz)
λ_{49} =	0.0354	6.2905	***	-0.0056	1.040	1.00
λ_{47} =	-0.5191	6.8598	<	0.0755	0.622	1.09
λ_{42} =	-0.6124	8.0037	<	0.0763	0.618	1.27
λ_{45} =	-0.5649	7.1627	<	0.0768	0.609	1.14

The following nomenclature is used in the tables:

SPR= successive peak ratios.

***= eigenvalue with positive or zero real part.

<<<< = eigenvalue with negative real part, $0 \leq \zeta \leq 0.03$ (critical).

<<< = id., $0.03 < \zeta \leq 0.05$ (very poorly damped).

<< = id., $0.05 < \zeta \leq 0.075$ (poorly damped).

< = id., $0.075 < \zeta \leq 0.1$ (lightly damped).

Table 2. Dominant eigenvalues (CIC922)

#	real	imag.		damp.coef.ζ	SPR	f(Hz)
λ_{55} =	-0.2464	6.3388	<<<	0.0389	0.783	1.01
λ_{53} =	-0.3724	6.8902	<<	0.0540	0.712	1.10
λ_{51} =	-0.5294	7.1764	<<	0.0736	0.629	1.14
λ_{48} =	-0.6456	8.0941	<	0.0795	0.606	1.29

The critical eigenvalues for CIC901 show that this system configuration is marginally unstable at the frequency of 1.0 Hz. There are three pairs of conjugated complex eigenvalues at frequencies close to 1 Hz which have damping coefficients less than 10 %. Nevertheless, they are greater than 5 %, the minimum ζ in all of these studies. The CIC for 1992 will have one more 500 kV circuit and three new hydraulic power plants to face up growing demand. For this reason, that configuration is stable, showing only one pair of eigenvalues with damping coefficients less than 5%.

3.1 Mode Shapes

The accelerating power mode shapes are selected, since they involve the machine inertias. Figures 3 and 4 show the phasor diagrams. From Figure 3, generators 18, 89 and 54 oscillate coherently against generators 69, 59 and 71. Generators located in busbars 54, 59, 71 and 69 can be selected as the best group (busbars 18 and 89 are not considered, as explained later). Figure 4 is an example of an interarea oscillation. The area is formed by generators 18, 56, 59, 93 and 54, which oscillate against the area formed by 71 and 69. That phasor diagram is the most important. The selected group includes generators 71, 56, 59 and 93. The selected generators are those placed in busbars 71 and 59. For 1992 generators located in busbars 56 and 93 are selected.

λ_{49}= 0. 0354+j6.2905 ***

# bus	ACCEL. POWER magnitude	phase	symbol
18	1.0000	0.0	A
89	0.5436	1.1	B
54	0.2459	0.4	C
59	0.2200	130.7	D
71	0.2171	-171.8	E
69	0.1777	115.9	F
52	0.0940	12.0	G
39	0.0538	15.6	H
62	0.0351	153.4	I

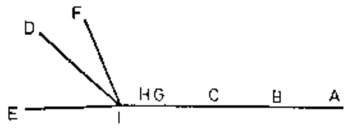

Figure 3. Accelerating power mode shapes of λ_{49} (CIC901)

λ_{55}= -0.2464 +j6.3388 <<<

# bus	ACCEL. POWER magnitude	phase	symbol
18	1.0000	0.0	A
71	0.8289	154.9	B
56	0.5743	-29.9	C
69	0.5127	133.6	D
59	0.3222	-13.6	E
93	0.2722	-7.4	F
54	0.2597	26.7	G
84	0.1591	145.3	H
52	0.0922	37.5	I

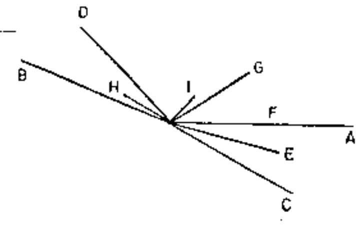

Figure 4. Accelerating power mode shapes of λ_{55} (CIC922)

3.2 Participation Factors

The velocity participation factors are used to select a group of generators to be equipped with PSSs in the CIC test system.

Table 3. Velocity participation factors for λ_{49} and λ_{47} (CIC901).

λ_{49}= 0. 0354+j6.2905 ***			λ_{47}= -0.5191+j6.8598 <		
# bus	PARTICIPATION FACTORS moduli	phase	# bus	PARTICIPATION FACTORS moduli	phase
18	0.2103	-2.2	54	0.3561	25.6
89	0.0950	-157.5	59	0.0881	20.1
71	0.0546	-109.5	52	0.0587	-61.7
54	0.0354	-62.2	18	0.0251	0.5

Table 4. Velocity participation factors for λ_{55} and λ_{53} (CIC922).

λ_{55}= 0. 0354+j6.2905 <<<			λ_{53}= -0.3724+j6.8902 <<		
# bus	PARTICIPATION FACTORS moduli	phase	# bus	PARTICIPATION FACTORS moduli	phase
71	0.1765	-38.3	54	0.3679	44.7
18	0.1049	2.0	18	0.1210	-29.8
69	0.0816	25.9	59	0.1069	110.3
56	0.0541	-6.0	52	0.0624	-1.9

Discarding the generators of busbars 18 and 89, using participation factors for CIC901, the set of selected generators is **(71,54,69,59)**. For CIC922 the best generators to equip with stabilizers are **(71,69,56,59)**. The generator in bus number 54 was not included since it has only one relevant residue for λ_{53}. Finally the selected generators for both system configurations are **(71,69,59,56)**. Generators in busbar 56 will only be in service in 1992.

3.3 Residues

According to the residues for $\Delta Pe^k/\Delta V_{ref}{}^k$ the following tables are obtained.

Table 5. Residues of electrical power of λ_{49} and λ_{47} (CIC901).

λ_{49}= 0. 0354+j6.2905 ***			λ_{47}= -0.5191+j6.8598 <		
# bus	RESIDUES moduli	phase	# bus	RESIDUES moduli	phase
71	1.0000	-170.2	59	1.0000	113.8
18	0.6323	112.5	71	0.1045	-172.5
89	0.3699	161.6	18	0.0800	60.9
59	0.2494	-174.9	62	0.0324	126.1

Table 6. Residues of electrical power of λ_{55} and λ_{53} (CIC922).

λ_{55}= 0. 0354+j6.2905 <<<			λ_{53}= -0.3724+j6.8902 <<		
# bus	RESIDUES moduli	phase	# bus	RESIDUES moduli	phase
71	1.0000	179.7	59	1.0000	144.9
56	0.3358	-167.9	56	0.7092	-140.7
59	0.1428	152.9	18	0.1222	-138.0
18	0.1045	134.7	71	0.0363	93.4

To damp the most critical eigenvalue (λ_{49}) for CIC901 the residues ranking reveals that the suitable group of generators to be equipped with PSSs is (**71,18, 89,59**). The generator of busbar 18 must not be included as a suitable generator because it is an old power plant; replacing its excitation system could be very expensive. The power plant 89 will be out of service for 1992. To damp the other dominant eigenvalue (λ_{47}) the best generators are (**59,71,18**). Generator busbar 59 is located at a strategic place in the system and is the better option in this case. Consequently for CIC901, the generators of busbars 71 and 59 are the best sites to locale stabilizers. From Table 6, the groups of selected generators are (**71,56,59,18**) and (**59,56,18**) for each dominant eigenvalue of CIC922. The hydraulic plant at busbar 56 is a new power station for 1992. It would have to be equipped with stabilizers. The generators of busbars 71 and 59 were again selected like the best to add stabilizers. Then, from residues information given in Tables 5 and 6, it is recommended that generators of busbars (**71,59,56**) are equipped with stabilizers to damp and/or prevent future low frequency electromechanical oscillations in the CIC. The residues phase information can be used to specify the stabilizers parameters in terms of the magnitudes and phases requirements.

3.4 Frequency Response Plots

It will be not necessary to obtain the frequency response plots for all generators. Generators in busbars 18 and 89 are not considered. From the previous methods, the best generators are (71,59,56,69). To finally decide which is the ranking of generators to equip with stabilizers, the polar plots of $\Delta\omega(s)/\Delta Vref(s)$ which correspond to these generators are compared (Figures 5-6). In terms of stabilizers gain and phase compensation, the ranking of suitable generators to equip with PSS is (**71,59,56**). Generators of busbars 84 and 93 which probably will be equipped with stabilizers were not considered, giving a conservative assessment. To demonstrate the adequacy of the stabilizer selection, simulations with standard delta omega PSSs included in generators 71, 59 and 56 were made for CIC922. CIC901 only considers PSSs in generators 71 and 59. The new dominant eigenvalues are listed in Tables 7 and 8. With these stabilizers the CIC is well damped. All damping coefficients are greater than the minimum requirement of 5%. The transfer functions of the proposed PSSs are included in the Appendix.

Table 7. Dominant eigenvalues (CIC901 with 2 PSSs)

#	real	imag.		damp.coef.ζ	SPR	f(Hz)
λ_{51} =	-0.3491	6.1243	<<	0.0569	0.699	0.97
λ_{47} =	-0.5276	6.8964	<	0.0763	0.618	1.10
λ_{45} =	-0.6231	7.9926	<	0.0777	0.613	1.27

Table 8. Dominant eigenvalues (CIC922 with 3 PSSs)

#	real	imag.		damp.coef.ζ	SPR	f(Hz)
λ_{58} =	-0.5414	6.7362	<	0.0801	0.603	1.07
λ_{56} =	-0.6286	7.1362	<	0.0877	0.575	1.14

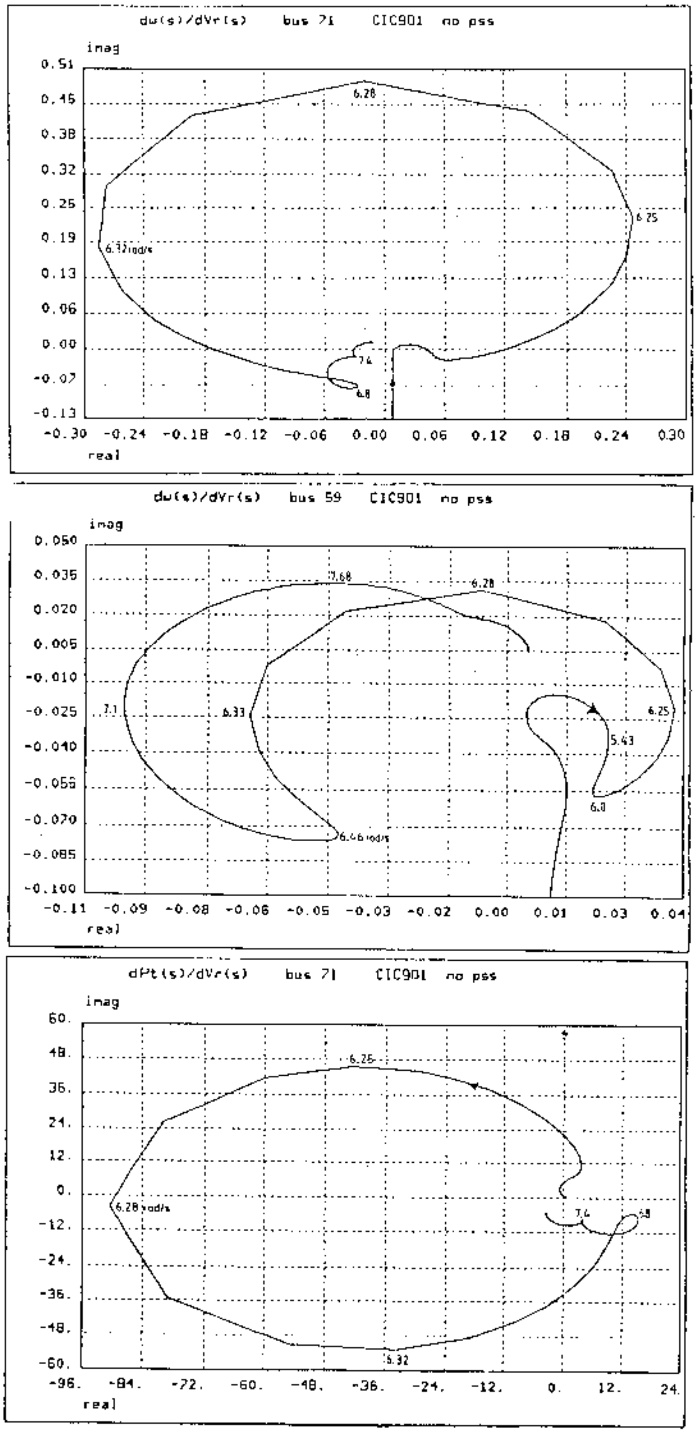

Figure 5. Frequency responses $\Delta\omega(s)/\Delta Vref(s)$ and $\Delta P_1^{71}(s)/\Delta V_{ref}^{71}(s)$ for the CIC901.

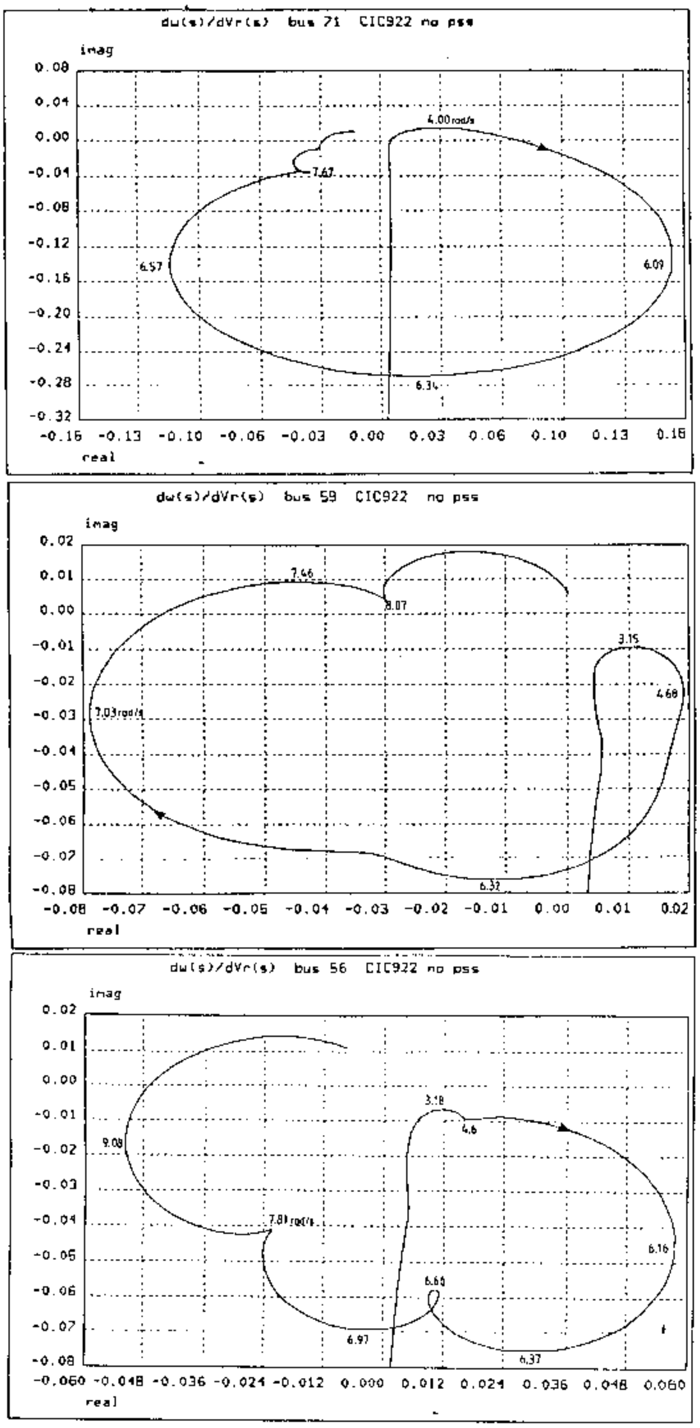

Figure 6. Frequency responses Δω(s)/ΔVref(s) for the CIC922.

4. CONCLUSIONS

4.1 Four methods to identify the best generators to be equipped with stabilizers in multimachine power systems are presented. They were tested with actual data corresponding to the Central Interconnected Power System of Chile, a typical longitudinal power system in South America.
4.2 A novel method of identification using frequency response analysis is proposed. The method can also be used for the designing and tuning of stabilizers.
4.3 The methods of identification of best sites for PSSs are useful in planning stages of power systems. The methods also identify generators whose stabilizers need to be retuned.
4.4 The comparison of these methods shows that the computing residues method is better because it supplies information about phase compensation required in the stabilizer. It also demonstrates which stabilizers are implementable. The frequency response plots analysis method is CPU time consuming but permits to define more exactly the stabilization requirements, such as the conventional stabilizers parameters.
4.5 It may be recommended to use more than one method in identification stages since several selected generator groups can be pinpointed, and the intersection can be determined.

5. ACKNOWLEDGEMENTS

Thanks to the United Nations Development Programme for support to Project CHI/87/030 "Efficiency in the Production, Transmission, Distribution and Consumption of Electric Energy". Thanks to Dr. Nelson Martins for his valuable suggestions during this project.

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APPENDIX

The generator busbars considered in this paper are listed below [13].

Bus Nº	Name	Bus Nº	Name	Bus Nº	Name
18	Rapel	39	Sauzal	41	Sauzalito
52	Cipreses	54	Isla	56	Pehuenche
59	Colbún	62	Machicura	69	El Toro
71	Antuco	73	Abanico	78	Concepción
84	Canutillar	89	Ventanas	93	Alfalfal

The transfer functions of standard stabilizers type delta-omega designed for generators 71, 59 and 56 are the following:

$$PSS_{71\omega}(s) = 3.5(s3)(1 + s0.5)^2/[(1 + s3)(1 + s0.05)^2]$$

$$PSS_{59\omega}(s) = 2.0 (s3)(1+s0.4)^2/[(1 + s3)(1 + s0.05)^2]$$

$$PSS_{56\omega}(s) = 1.0 (s3)(1+s0.5)^2/[(1 + s3)(1 + s0.05)^2]$$

Stabilizer gains of buses 71 and 59 are interchanged for CIC922.