OPTIMIZATION OF EXCITATION ADJUSTMENT FOR AUTOMATIC CONTROL OF ALTERNATORS

التحديد الأمثل لتغذية التحكم الآلى لمولدات القوى الكبيرة

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ملخص

نظرا لأهمية عملية التحكم فى تغذية تيار التنبيه المولدات الكهربائية وأهميته لتعضيد وتقوية الإتزان الاستاتيكى وكذلك إخماد الذبذبات الكهروميكانيكية فى نظم القوى الكهربية، ونتيجة لزيادة فاعلية هذا التكنيك وظهور تأثيره جليا فى الشبكات متعددة الآلات "المولدات" فان هذا البحث يقدم طريقة مقترحة تقوم بحل كافة المشاكل الخاصة بعملية التحكم فى التغذية. وهذه الطريقة تعتمد على تعيين عناصر الذبذبة الكهروميكانيكية "الترددات الطبيعية، معاملات الإخماد ومعاملات التوزيع لنظام الذبذبات المطلق". وأيضا تعيين معاملات الحساسية لتغيير أجزاء الجزء الحقيقى لجذور المعادلة طبقا لتغير معاملات الإتزان. وتمتاز هذه الطريقة بانشاء مساحة مستقلة للإتزان الإستاتيكى تساوى درجة الإتزان.

و يقدم البحث تحليلا كاملا للطريقة المقترحة وتصنيفها عن طريق خوارزم وبرنامج فورتران على نظام كهربى كبير "ستة مولدات كهربية" بجهد عال 220KV. ولقد توصل البحث إلى نتائج جيدة. هذه النتائج توضح أن:-هذه الطريقة أعطت إخمادا عاليا لذبذبات النظام الكهروميكانيكى تحت أى شروط، كذلك صغر الزمن المستخدم فى الحساب على الحاسب الآلى لنظام متعدد الآلات، وقد أعطى أيضا تساويا للإتزان ودرجته لتغذية المولدات.

و يحتوى البحث على النتائج وتحليلها وتوقيعها على المنحنيات، والتطبيق المقترح حدد كذلك طريقة التحكم المثلى لتغذية تيار التنبيه إلى المولدات الكهربية.

ABSTRACT

To solve the problems associated with damping the electromechanical oscillation in electric power systems as well as to support the static stability there are many methods: one of them is the optimimum excitation for automatic control of alternators (EACA). Improvement of EACA requires up-dating methods to operate the electric power stations at high efficiency. This paper presents a technique to achieve this improvement aim. In this technique; the electromechanical formulation of EACA is determined and it consequently depends on the following points:-

(i) electromechanical oscillation parameters;

(ii) sensitivity coefficients for changing the real parts of the system equations roots corresponding to the variation of stability coefficients;

(iii) construction of an independent area for static stabilities which determines the EACA parameters.

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The suggested technique is applied to a system containing six power units feeding a ring power system. The ring system is composed of 220 kV transmission lines with different tapping loads.
The obtained results show that, (i) EACA gives high equal damping oscillation of electromechanical system at various conditions; (ii) minimum computation time even in case of multi power units. The suggested technique gives the equality between the control area of stabilities and the stability degree of EACA.

INTRODUCTION

The importance of excitation automatic control for alternators (EACA), with special stabilized channels, is essentially required for supporting the static stability, and damping the electromechanical oscillation in electrical power systems. The most important aim, in the effective EACA in multi-machine electrical systems, is the best choice of both the correction arrangements and the selection of parameters of the stabilizers[1].
For constructing EACA in a multi-machine electrical systems an advanced technique and complete formalized searching procedures must be used [2]. This technique depends on :-
1) determination an algorithm for electromechanical oscillation parameters form, which based on calculating the eigen values and eigen vectors of rotor motion equations, and realizing it in computer program [3,4];
2) determination of the sensitivity coefficients of changing the real part of system equation roots corresponding to the variation of stability coefficients EACA [5];
3) the construction of independent area for static stabilities determines the EACA parameters[6].
The complex solution of EACA optimal arrangement in multi-machine electrical systems requires computer program, including all variables; and all the various stability conditions of electrical systems [7].

THE PROPOSED TECHNIQUE AND FORMULATION ANALYSIS

The proposed technique is described in the following steps:-
1-Determination of the electromechnical oscillation parameters such as: (natural frequencies, damping coefficients, and distribution coefficients of absolute system oscillations). These parameters are based on calculating the eigen values and the eigen vectors of matrices H for the equivalent coefficients of rotor motion equation:-

$$\left(T_j \frac{d^2}{dt^2} + P_d \frac{d}{dt} + M_c \right) \Delta\delta = 0 \qquad (1)$$

This equation may be written in the following form:-

$$\frac{dX}{dt} = H X \qquad (2)$$

$$Where:- \quad P_d = \frac{1}{\omega_k} I_m M(P) \quad , \quad M_c = R_e M(P)$$

The damping and synchronisation system coefficient matrices are obtained according to minimum and real parts of electromagnetic moments of synchroneous machines M(p) at $p=\lambda_k=[-\beta_k \pm j\omega_k]$ for desierd k<u>th</u> oscillation form:-

$$H=\begin{bmatrix} T_j^{-1}P_d & -T_j^{-1} \\ E & 0 \end{bmatrix} \quad ; \quad X=\begin{bmatrix} \Delta S \\ \Delta\delta \end{bmatrix} \qquad (3)$$

where:- $\Delta\delta$, ΔS– are the vector column matrix of absolute angles and the rotor slip; E, 0 –are the unit and zero matrices .

The proposed allgorithm for determination of the electromechanical oscillation parameters form is based on the complex parameter λ_k, which is realized in the computer program. The eigen values λ_k and and eigen vectors K_{jk} of each matrix is characterized the multi-freequency of electromechanical oscillation of system parameter X at the N- alternators of the electrical system. These values, in the general case, represent the summation of components:-

$$X_j(t)=\sum_{1k} A_{1k}\, K_{jk}\, e^{-\beta_1 t}\cos(\omega_k t+\phi_{1k}+\theta_{jk}) \qquad (4)$$

Where:- k = 1, 2, 3, ... and , N – 1 , A_{ik}, φ_{ik}- are the intial values of parameters; ω_K ,β_K,K_{JK}-are nature frequency, damping coefficient and amplitude distribution of K_{th} oscillation form,which are complex values of :-

$$K_{jk}=\left|K_{jk}\right| e^{j\theta_{jk}}$$

Plotting the vector diagrams for Kjk will determine the groups of opposite phase oscillated generators for every natural frequency of the system[5]. These vector diagrams give electromechanical oscillations and the corresponding frequencies for them.

2- Determination of the sensitivity coefficients μ_I of changing the real part of system equation roots β_h =-Re [λ_n] corresponding to variation of stability coefficients EACA K_i ,i.e. $\mu_i = -[\partial \beta_h / \partial K_i]$. EACA of every generator shows that, the practical calculations have maximum effective value from the point of electromechanical damping at it[4].

3-The construction of independent area for static stabilities equal to the degree of stabilities in plane of EACA parameters. Every EACA damping insertion gives the sum oscillation damping for natural frequencies[6,7].

The summation components of both the damping coefficients of EACA $\beta_{EACAi(k)}$, and the damping coefficient at every natural system frequency β_{nat} will give the reflect nature system damping i.e. for K_{th} nature frequencies:-

$$\beta_{\sum(k)}=\beta_{nat(k)}+\sum_{i=1}^{N}\beta_{EACA(k)} \quad ; \quad k=1,2,........,N-1 \qquad (5)$$

The $\beta_{EACA(k)}$ components are determined by system damping coefficients of systems $\beta_{i(k)}$

These coefficients are calculated at independent work of EACA i_{th} system generator in the absence of regulators on the other generators (at $\beta_{EACAi(k)} = 0$ for $j\neq I$), as:-

$$\beta_{EACAi(k)}=\beta_{i(k)}-\beta_{nat(k)} \qquad (6)$$

Analysis of comopenent $\beta_{EACAi(k)}$ gives the evaluation of EACA effective operation of all generators in the case of damping oscillations. The negative damping of regulator is detected at every natural system frequency component.

Assuming that, the principle of covering damping EACA, Eq. (1) weaken the natural effect of regulators. At this stage the EACA construction of every machine can be chosen. At this case, the natural damping is computed, for all computers programs.

For multi-machine system [5], this condition may be recorded as:-

$$\alpha_{max(k)} \approx \sum_{i=1}^{N} \alpha_{maxi(k)} - (N-1)\,\beta_{nat(k)} \qquad (7)$$

Where $\alpha_{maxi(k)}$ is determined, from autonomous region and from zone at all generators EACA.

Generators EACA frequencies are changed by small value if they are compared with natural frequencies of unregulated system[8].

Choosing the best quality of $\alpha_{0(1)}$ and $\alpha_{0(2)}$ will determine high orders of damping, low orders of damping and the stability for working systems. The electromechanical formulation of EACA method for six machines of power systems is used.

SUGGESTION OF THE SYSTEM

The system under investigation is shown in Fig. (1), which shows a multi- machine power system. It contains six power units connected to a ring power system. G_4&G_5 are thermal power stations, G_2 &G_3 are low power stations;andG_1&G_6 are compensator synchroneous stations.The ring system is composed of 220kV transmission lines with tapping loads at points 7&8 and 13.

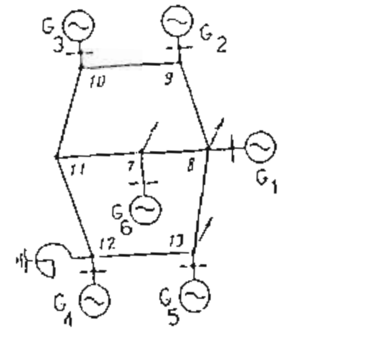

Fig.1 Researshing circuit of power system.

THE RESULTS AND DISCUSSION

The results of the application technique can be summerized as the following points:-

(1) The calculations of irregulariting of power systems by realization model program, in the case of the effective equations of rotor motion, give five forms of electromechanical oscillations:-

$\lambda_{1,2} = -0.22 \pm j\,5.0$; $\lambda_{3,4} = -0.44 \pm j\,8.5$; $\lambda_{5,6} = -0.73 \pm j\,11.1$; $\lambda_{7,8} = -0.99 \pm j11.9$; $\lambda_{9,10} = -5.22 \pm j\,11.3$

(2) Fig. (2 a, b) shows the electromechanical oscillation analysis of power irregularity by the distribution coefficients of angles. Fig. (2 a, b) shows also, the dominance of oscillation systems which have frequencies ω_1=5.0 rad/sec and ω_2=8. 5 rad /sec . Fig.(2-a) shows that,the oscillation of first frequency ω_1=5.0 rad/sec. has the maximum amplitude of power which is observed by the lines 8-13 and 11-12, and contacting with the generators G_1,G_5 and G_4, G_6 see fig. 3-a, but other lines 8-9 and 10-11 has the minimum amplitude of power and contacting with the generators G_1,G_2 and G_3,G_6. The oscillations analysis at first frequency ω_1 is represented by two sub-systems, which tie the inter-systems 8-13 and 11-12 (fig. 1). The oscillation analysis at second frequency ω_2 = 8. 5 rad/sec. is represented by three sub-systems, which tie the inter systems 8-9, 10-11 and 7-8 (fig.1). These three sub-systems give large amplitude of oscillation form (fig. 3b).

The sensitive coefficient roots analysis of EACA are damped at every dominance frequency of electromechanical oscillations. Table 1 illustrates that, the suitable installation of EACA alternator at oscillation damping with frequencies ω_1= 5. 0 rad/sec. are to be installed at generators G_1, G_4 , G_5 and with frequency ω_2=8.5rad/sec. at generators G_2 , G_3.

For optimization excitation adjustment of EACA, the parameters coordinates stabilizers of EACA for each generator have to constract in terms the control areas of static stability.

The stabilizer coefficients K_{0f} and K_{1f} are represented as a part of excitation at no load generator and are given in terms frequencies (fig. 4).

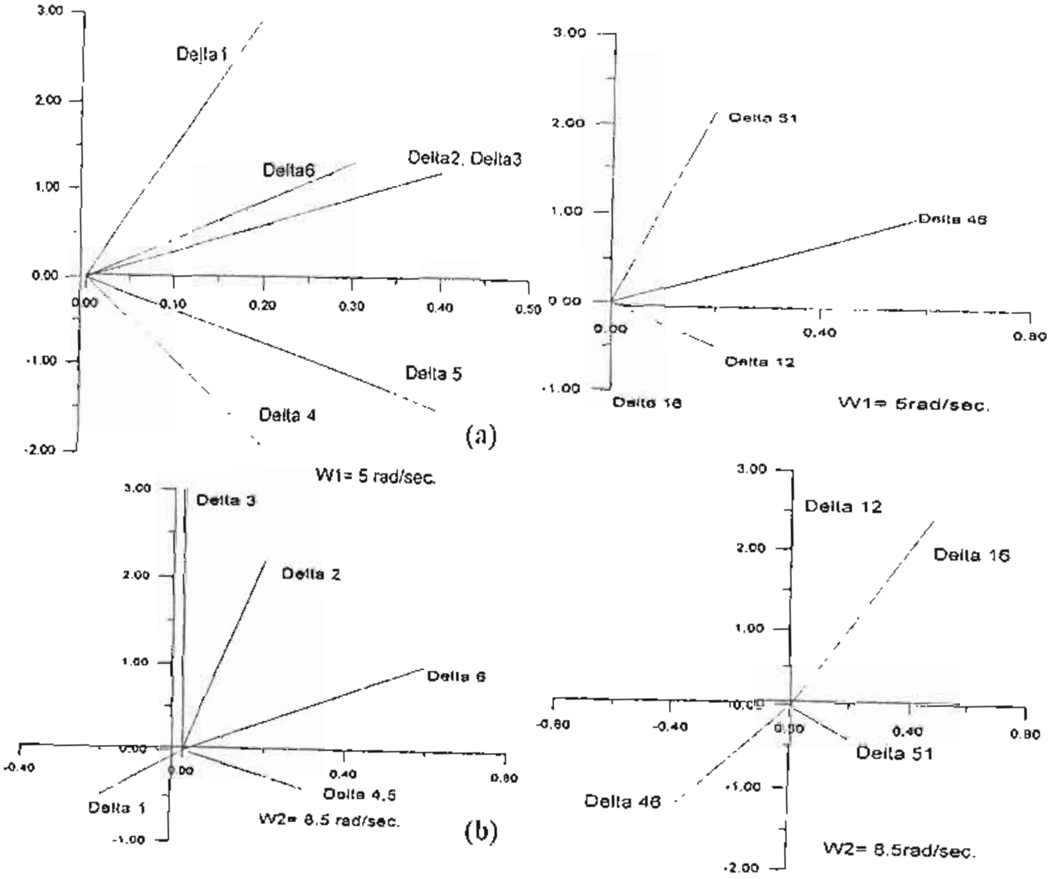

Fig.2 The vector diagram of distribution coefficients (the amplitude of damping and angles fig.a,b).

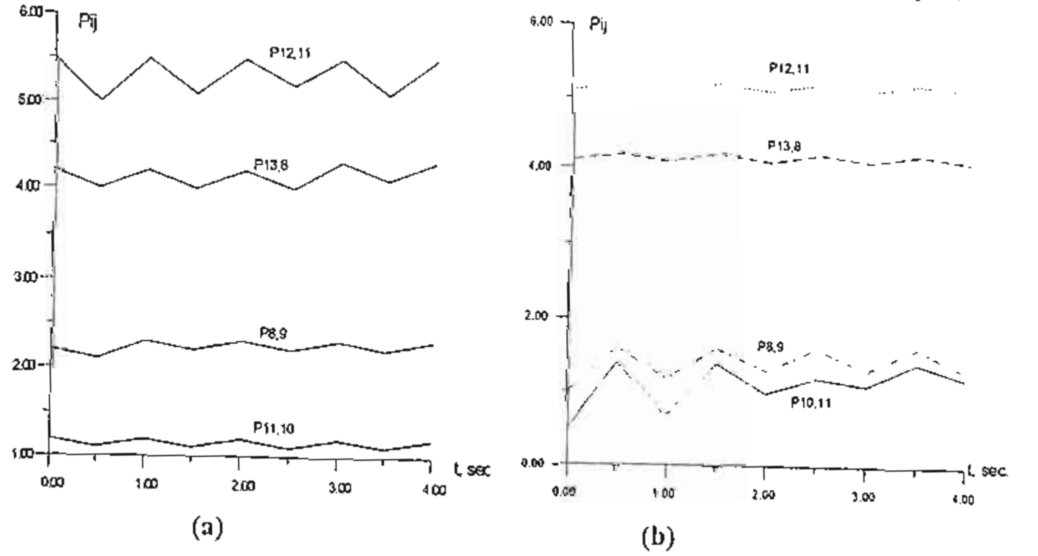

Fig.3 The vector diagram of the transient process after excitation at irregulation system
(a-shortcircuit at line 8-13,b-short circuit at line 8-9).

(3) The stability area and α-curves are constructed at simultaneous work for all EACA (fig.4, table.2, varient 1). The adjustment EACA of G_1, in general cases of areas α_{max}, is determined at frequency ω_1. The effective operation of EACA is tested for choosing the optimum adjustment and for estimating their dampings by the computer program.
This computer program calculates the values of matrix H, and determines the damping systems of EACA for every generator, $\beta_{i(k)}$ and $\beta_{min(k)}$, at all frequencies of electromechanical oscillation. In table 2 the reduction of $\beta_{EACAi(k)}$ depends on the type and adjustment of EACA for each generator at dominance frequencies.
(4) For generator G_1, the control adjustment of stability areas and δ-curves are equal to the stability degree. This is for the outcome (no.1) at two varients (no.2-disconnection line 8-9 and no.3-disconnection of one circuit of four circuits 8-13) conditions. The stability degree (α=1) is given for all conditions of switching (table.2, varient 2) and defines EACA of G_1 at the frequencie ω_1 (fig.5). The comparison of the values of matrix H is given in table 2. These values of matrix H correspond to the dominance inter-phases of electromechanical oscillations.

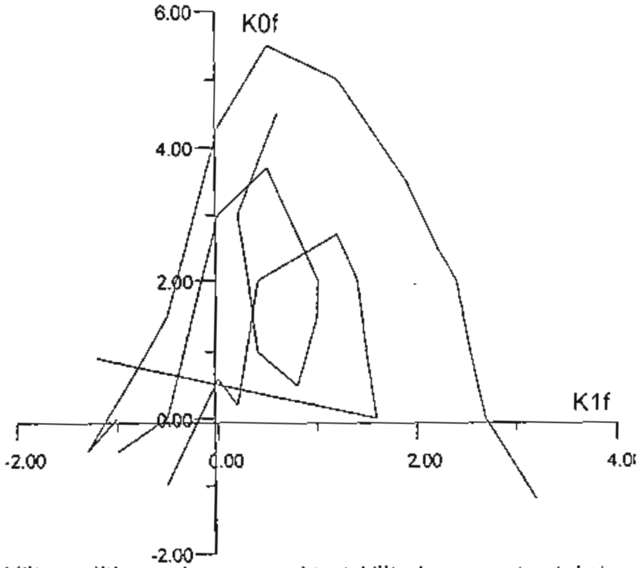

Fig.4 The static stability conditions and curves equal to stability degree,constructed at coordination of adjustment EACA for generator G1 at simultaneous work for all EACA systems (condition no.1,varient 1,table 2).

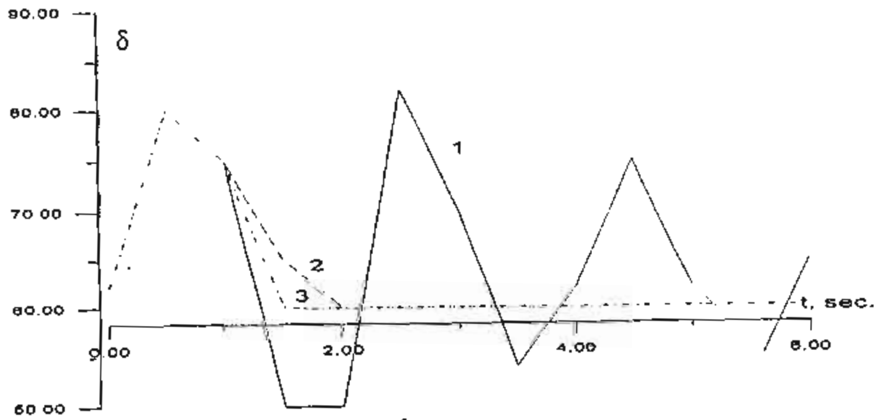

Fig.5 Transient stability after removal of the short circuit at line 8-13,where:- 1-without EACA; 2-with EACA, table 2,varient 1,with EACA,table 2,varient2.

The stability degrees in varient 1 choose the type of adjustment EACA (table3 and fig.4), and determine the damping at second dominance frequency ω_2 and formulate at $\alpha \approx 0.5$/sec. At varient 2 the damping of inter-stations at high frequencies of oscillation ($\omega \approx 12$rad/sec.) and in all conditions(no.1,no.3) is given at low $\alpha = 0.7$ /sec. (table 4).

Table 1

Frequencies.	Sensitivity coefficients , μ_i / $\mid \mu_{imax} \mid$					
.	G_1	G_2	G_3	G_4	G_5	G_6
ω_1	- 0. 82	- 0. 02	- 0. 11	- 1. 0 0	- 0. 46	- 0. 05
ω_2	0. 00	0. 00	- 0. 10	0. 00	0. 00	0. 00

Table 2

No.of arrangement varient of EACA	No. of generators	Adjustment of EACA				Damping of EACA	
		K_{0u}	K_{1u}	K_{0f}	K_{1f}	$\beta_{EACA(1)}$ [ω_1=5]	$\beta_{EACA(2)}$ [ω_2=8.5]
1	1	50	0	40	4	0. 652	0. 092
	2	20	---	---	---	- 0. 002	0. 004
	3	20	---	---	---	- 0. 001	0. 003
	4	50	7	30	8	0. 614	0. 048
	5	50	7	30	8	0. 617	0. 033
	6	50	0	0	0	- 0. 007	0. 024
	$\Sigma_{i=1 \to 6}$ [$\beta_{EACAi(k)}$]					1. 87	0. 006
2	1	50	0	40	4	0. 652	0. 092
	2	50	0	0	4	0 . 014	0 . 645
	3	50	0	0	4	0. 007	0. 988
	4	50	7	30	8	0. 614	0. 048
	5	50	7	30	8	0. 617	0. 033
	6	50	0	0	0	- 0. 007	0. 024
	$\Sigma_{i=1 \to 6}$ [$\beta_{EACAi(k)}$]					1. 88	1. 65

Table 3

No. of varients	Frequencies	β_Σ . /sec.	β , /sec.	β_s , /sec.
Irregularity	ω_1	0. 22	0. 22	0. 32
systems.	ω_2	0. 44	0. 44	0. 45
1	ω_1	2. 10	2. 21	no tobserve
	ω_2	0. 45	0. 54	0. 57
2	ω_1	2. 12	2. 46	not observe
	ω_2	2. 08	2. 15	2. 10

Table 4

K	$\lambda_{(x)} = -\beta_{(x)} \pm j\,\omega_{(x)}$		
	condition no.1	condition no.2	condition no.3
1	- 2. 46 ± j 5. 0	- 2. 31 ± j 4. 9	- 1. 57 ±j4.1
2	- 2. 15 ± j 8. 5	- 1. 72 ± j 7. 7	- 1. 81 ± j8.4

CONCLUSIONS

1-The suggested technique of EACA develops the optimal adjustment of excitation automatic control for large-power alternators, and has strong effect of collecting the elements of power system. The basis of minimizing the quality function, takes into account the dominance roots and the order of stability in all systems. Therefore, using simultaneous coefficients of EACA stability coefficients will give high effective and full formulation of mathematical procedure for the complex power systems.
2-The development of EACA depends on the calculation method area for adjustment EACA. So, it will give high equal damping oscillation of electromechanical system in the normal attenuation range and also after varient conditions.
3-The direct method of calculations suggests the arrangement of EACA for various types of large power systems at every station. The optimum adjustment is chosen for constructing the control area of static stabilities and equal to the EACA parameters.
The suggested method choose the optimal adjustment of EACA for six-alternators of the power system, which produce good coincidence data with the calculation results of the transient processes.

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