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ADAPTIVE CONTROL OF ELECTRICAL POWER GENERATING SYSTEMS USING THE PROPERTIES OF VARIABLE STRUCTURE SYSTEMS (VSS)

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1. ABSTRACT

In the present paper, a new algorithm for solving the control law in electrical power systems, is introduced. This new algorithm is based on the sliding mode property, existing in variable structure systems (VSS). The resulting control law is discontinuous by its nature. However, it does not require informations about the system parameters or its manner of variation.The only requirements are the maximum and minimum limits of variation for each parameter.

An adapitve controller is designed, for an electrical power system, on the basis of that new algorithm. The main function of the controller is the adaptive control of the electrical power system, Meanwhile, it can be used as an observer.

Theoretical and computetional results, using that controller insure the adaptive control property in the electrical power system model. The adaptive property verifies under rapid and wide range of parameters variation and also under the effect of a unit step external disturbance.

2. INTRODUCTION

Adaptive control of electrical power systems seems to be a complicated problem, if we tried to solve it using classical methods of control. This complication arises because of:

1- Lack of information about parameters variation.

2- Existance of external disturbances.

Discontinuous control methods such as self-oscillating adaptive control; high gain co-efficient control and those methods based on the theorems of liapounov and hyper-stability criterion, can not overcome the parameters variation in wide range as well as the effect of external disturbances.

Variable structure systems(1) are able to solve this problem. This type of discontinuous control has an important property known as sliding modes(2). Once in a control system a sliding mode is realized, the system becomes insensitive to parameters variation as well as to the external disturbances. For realizing sliding modes in control systems, a new general approach was developed(3). This approach does not need any information about the parameters variation as well as the level of external disturbances. Only, the upper and lower limits of these variations are to be known. On the basis of this approach, a new algorithm for adaptive control of electrical power systems, is developed.

The paper contains the development of a power system model. Then, the evolution of (VSS) technique is presented.

3. MATHEMATICAL MODEL

Consider an interconnected power system comprising N subsystems. The block diagram, representing the ith subsystem is shown in figure(1), where reheat turbines are considered. The transfer functions of the reheat turbines are given by:

$$G(s) = \frac{\Delta P_{gi}(s)}{\Delta X_{ei}(s)} = \frac{1+sK_{ri}T_{ri}}{(1+sT_{ri})(1+sT_{ti})}, \quad i = 1,2,\ldots,N \qquad (1)$$

If $K_{ri} = 1$; $G(s)$ reduces to $\frac{1}{1+sT_{ti}}$, representing the transfer function of nonreheat turbines. The shown controller, in conventional case, has the transfer function $-K_{ri}$. However, in the case of VSS control the controller is modified as shown in figure (2).

Suppose that the dynamics of the interconnected power system is described by the state equation

$$\dot{x} = A(x,t)x + B(x,t)u + D(x,t)\,F(t), \; ; \; x \quad R^{n} \; ; \; u \quad R^{m} \; , \; P \quad R^{1} \qquad (2)$$

where;

$A(x,t)$ - (nxn) functional matrix of the state vector;

$B(x,t)$ - (nxm) functional matrix of the controlling input;

$D(x,t)$ - (nxl) functional matrix of external disturbance;

x - state vector; u - controlling input; F - external disturbance.

Matrix $A(x,t)$ is in the form

$$A(x,t) = \begin{bmatrix} A_{11} & A_{12} & A_{1i} & A_{in} \\ A_{21} & A_{22} & & \\ A_{i1} & & A_{ii} & \\ A_{N1} & & A_{Ni} & A_{NN} \end{bmatrix} ;$$

matrix $B(x,t)$ has the form

$$B(x,t) = [B_1 \quad B_2 \quad \ldots\ldots\ldots \quad B_i \quad \ldots\ldots \quad B_N]^T \qquad \text{and}$$

matrix $D(x,t)$ is given by

$$D(x,t) = [D_1 \quad D_2 \quad \ldots\ldots \quad D_i \quad \ldots\ldots \quad D_N]^T$$

Considering the subsystem i we have

$$A_{ii} = \begin{bmatrix} 0 & 0 & 1 & \gamma_i & 0 & 0 \\ 0 & -\frac{1}{T_{gi}} & 0 & \frac{-1}{T_{gi} T_i} & 0 & 0 \\ 0 & 0 & 0 & 2\pi T_j \sum\limits_{i \neq j} T_{ij} & 0 & 0 \\ 0 & 0 & \frac{-K_{pi}}{T_{pi}} & \frac{-1}{T_{pi}} & \frac{K_{pi}}{T_{pi}} & 0 \\ 0 & 0 & 0 & 0 & \frac{-1}{T_{ti}} & \frac{1}{T_{ti}} \\ 0 & \frac{1}{T_{ri}} - \frac{K_{ri}}{T_{gi}} & 0 & \frac{-K_{ri}}{T_{gi} R_i} & 0 & \frac{-1}{T_{ri}} \end{bmatrix}$$

where:

K_{ri} = reheat co-efficient; T_{ri} - reheat time constant;

T_{ti} - turbine time constant; γ_i - frequency bais setting;

R_i - speed regulation due to govern action;

T_{gi} - governer time constant; T_{pi} - power system time constant;

K_{pi} - power system gain;

T_{ij} - synchronising co-efficient between subsystems i & j;

$$A_{ij} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 2\pi T\ T_{ij} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} ;i = j \;; \quad i=1,2,\ldots,N \;;$$

$$R_i = \left[\, 0 \quad \frac{1}{T_{gi}} \quad 0 \quad 0 \quad 0 \quad 0 \,\right]^T ;i=1,2,\ldots,N \;;$$

$$D_i = \left[\, 0 \quad 0 \quad 0 \quad \frac{-K_{pi}}{T_{pi}} \quad 0 \quad 0 \,\right]^T ;\; i=1,2,\ldots,N$$

4. STATEMENT OF THE PROBLEM

It is required to design a controller, which generates an actuating signal to control the frequency deviation Δf_i, as well as the tie - line power change Δp_{tie}, resulting from sudden changes in the load Δp_{di}.

The following set of minimum requirements are stated (4) by the North American Power Systems Interconnection Committe :

i) The static frequency error following a step laod change must be zero.

ii) The transient frequency swings should not exceed $\pm$ 0.02 Hz under normal conditions.

iii) The static change in the tie-line power flow following a step change in each must be zero,

iv) The time error should not exceed $\pm$ 3 second and,

v) The individual generators within each area should divide thier loads for optimum economy.

5. A NEW ALGORITHIM FOR REALIZING A SLIDING MODE IN POWER SYSTEMS

The vectorial control problem could be divided into m-scalar problems as follows:

from the state equation (2) we can write :

$$\dot{x} = A(x,t).\, x(t) + b^{1}(x,t)u_{1} + b^{2}(x,t)u_{2} + \dots +$$

$$+ b^{m}(x,t)u_{m} + D(x,t).\, F(t) \qquad (3)$$

where :

$b^{1}(x,t)$; $b^{2}(x,t)$; .... ; $b^{m}(x,t)$ are the columns of matrix b(x,t). Hence, a set of sliding modes could be organized simultaneouysly on the m-hyperplanes

$\delta_1, \delta_2, \dots\dots\dots, \delta_m$

where :

$\delta_1 = C^{1T} x$; C^{1} - (n) vector column ; $x \in R^{n}$

$\delta_2 = C^{2T} x^{1}$; C^{2} - (n-1) vector column ; $x^{1} \in R^{n-1}$

.... ; ....

$\delta_m = C^{mT} x^{m-1}$; C^{m} - (n-m+1) vector column ; $x^{m-1} \in R^{n-m+1}$

The elements of vector columns C^1, C^2, ..., C^m could be determined using the standard coefficient method (5).

The necessary and sufficient condition for realizing a sliding mode on the plane $\delta 1$ is $\delta 1 . \dot{\delta} 1 < 0$ (2).

To achieve this condition we shall require that the following conditions are realized :

$$C^{1T} b^1(X,T) \neq 0 \qquad (4-a)$$

$$C^{1T} b^1(X,T) . \phi 1(\delta 1) < 0 \text{ when } \delta 1 > 0 \qquad (4-b)$$

$$C^{1T} b^1(X,T) . \phi 1(\delta 1) < 0 \text{ WHEN } \delta 1 < 0 \qquad (4-C)$$

$$\left| C^{1T} b^1(x,t) . \phi 1(\delta 1) \right| > \left| C^{1T} A(X,T) . X(t) + C^{1T} b^2(x,t) u_2 \ldots + C^{1T} b^m(x,t) u_m + C^{1T} D(x,t) . F(t) \right| \qquad (4-d)$$

Condition (4 - a) could be realized if the following conditions were satisfied :

i) The element C_{n-m+1} in the vector row C^{1T} has a nonzero value,

i.e. if C^{1T} had the form

$$C^{1T} = (C_1 , C_2 , \ldots , C_{n-m+1} , 0 , 0 , \ldots , 0) \qquad (5-a)$$

ii) The vector column has the form :

$$b^1(x,t) = [0 \ 0 \ \ldots \ b_m \ b_{m-1} \ b_1]^T \qquad (5-b)$$

Condition (4 - b), (4 - c) and (4 - d) could be realized, if the function $\phi_1(\delta_1)$ was chosen as a nonlinear multi-valuable function having the following properties:

a- multi-valuable ; b- closed at $\delta_1 = 0$ as a set and limited.

c- semi-continuous at $\delta_1 = 0$

d- values of 1, 2, ... , m in the neibourhood of $\phi(\delta_0,t) \in \phi(\delta_0)$.

The above mentioned multi-valuable function is shown in figure (3).
After satistying conditions (4 - a), (4 - b), (4 - c) and (4 - d) we get

$$\delta_1 = C^{1T} x$$
$$\dot{\delta}_1 = C^{1T} \dot{x} \qquad (6 - a)$$

$$= C^{1T} [A(x,t).\ x(t) + b^1(x,t)\phi_1(\delta_1) + b^2(x,t)u_2$$
$$+ b^3(x,t)u_3 + \ldots\ldots + b^m(x,t)u_m + D(x,t).\ P(t)\ ] \qquad (6 - b)$$

from (6-a) and (6-b) we have

$$\delta_1.\dot{\delta}_1 = \delta_1.C^{1T} b^1(x,t)\phi_1(\delta_1) + \delta_1 C^{1T}.[\ A(x,t).x(t)$$
$$+ b^2(x,t)u_2 + \ldots\ldots + b^m(x,t)u_m + D(x,t)\ F(t) \qquad (7)$$

From (7) it is easy to show that the inequality

$$\delta_1.\dot{\delta}_1 < 0$$

will be always satisfied; i.e. there will be a permenant sliding motion on the hyperplane σ_1.

Existence of a sliding mode on the plane σ_1 means that the motion of system (3) can be described by the following equations:

$$\dot{x} = A(x,t).\ x(t) + b^2(x,t)u_2 + \ldots.. + b^m(x,t)u_m + D(x,t)\ F(t) + b^1(x,t).\ \xi_1 \quad (8-a)$$

$$C^{1T}\ x(t) = 0 \quad (8-b)$$

where:

ξ_1 – a single valued (scalar) function or the first component of the nonlinear predetermined vector function – (additional controlling input) and is given by

$$\xi_1 = [C^{1T}\ b^1(x,t)]^{-1} \left\{ -C^{1T}\ [A(x,t).\ x(t) + b^2(x,t)u_2 + \ldots.. + b^m(x,t)u_m + D(x,t)\ F(t)\ ] \right\} \quad (9)$$

Similarly, it is possible to establish another sliding modes on the hyperplanes σ_2, ... σ_m using the same technique. The multi-valueble function could be generated using a multiplier as shown in figure (4).

A suggested flow-chart for a computer program to carry-out algorithm is shown in figure (5).

In the flow chart we used the following symbols:

i) A_o and B_o are the steady state matrices for the controlled system.

ii) ω_o - a scalar which determines the response speed of the controlled system at steady state (6).

iii) NT - number of computation points.;

NST - additional variable cycle.;

NK1 - number of points from starting till applying the change external disturbance.;

NK - number of points from starting till applying the adaptive control vector.

iv) $e_i = x_i - x_{o_i}$ - error between the state vectors of the system under consideration and its steady state values.

6. EXAMPLE

Consider an interconnected power system consisting of 2 subsystems (identical steam plants). The case of nonreheat turbines will be considered.

For comparison purposes, the same values of the system parameters contained in (7) will be used: = 0.425 p.u. MW, $T_t = 0.39$,

$K_p = 120$ Hz/p.u. MW, R = 2.4 Hz/p.u. MW, $T_g = 0.8S$, $T_t = 20s$,

$T_r = 10s$, $2\pi T_{12} = 0.545$ p.u. MW and $K_r = 1$.

The aystem matrices are given by

$$A_{11}=A_{22}=\begin{bmatrix}0 & 0 & 1 & 0.425 & 0\\ 0 & -12.5 & 0 & -5.206 & 0\\ 0 & 0 & 0 & 0.545 & 0\\ 0 & 0 & -6 & -0.05 & 0\\ 0 & 3.33 & 0 & 0 & -3.33\end{bmatrix};A_{12}=A_{21}=\begin{bmatrix}0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & -0.545 & 0\\ 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0\end{bmatrix};$$

$$B_1=B_2=[0 \quad 12.5 \quad 0 \quad 0 \quad 0]^T ; D_1=D_2=[0 \quad 0 \quad 0 \quad 0 \quad 0]^T$$

We shall consider two different control schemes, where no physical constraints are imposed on the system variables.

i) For conventional control,the control laws are assumed to be(7)

$$u_i = -0.75x_{i1} , \quad i = 1,2 \tag{10}$$

ii) For VSS control, using the new algorithm we obtain:

The switching hyperplanes are given by

$$\sigma_i = C_i^T x_i \qquad i = 1,2 \qquad \text{where}$$

$$C_i = [\ 0.082 \quad -33.2 \quad 0 \quad 6.02 \quad 33.3\ ]$$

Figure (6) shows the simulation results of ΔF_1, ΔP_{gi}, ΔP_{tie}, ΔF_2, ΔP_{g2} when subsystem 1 is subjected to a step load change of 0.01 p.u. Results using conventional control are also included for comparison purpose.

7. CONCLUSION

A controller for an electrical power system is suggested, using the main property of VSS-(sliding modes). This controller insures the adaptive control of the system and its invariance to the external disturbance. Design of this controller does not need information about either the system parameter or external disturbance variation. It is required only to know their upper and lower limits of variation.

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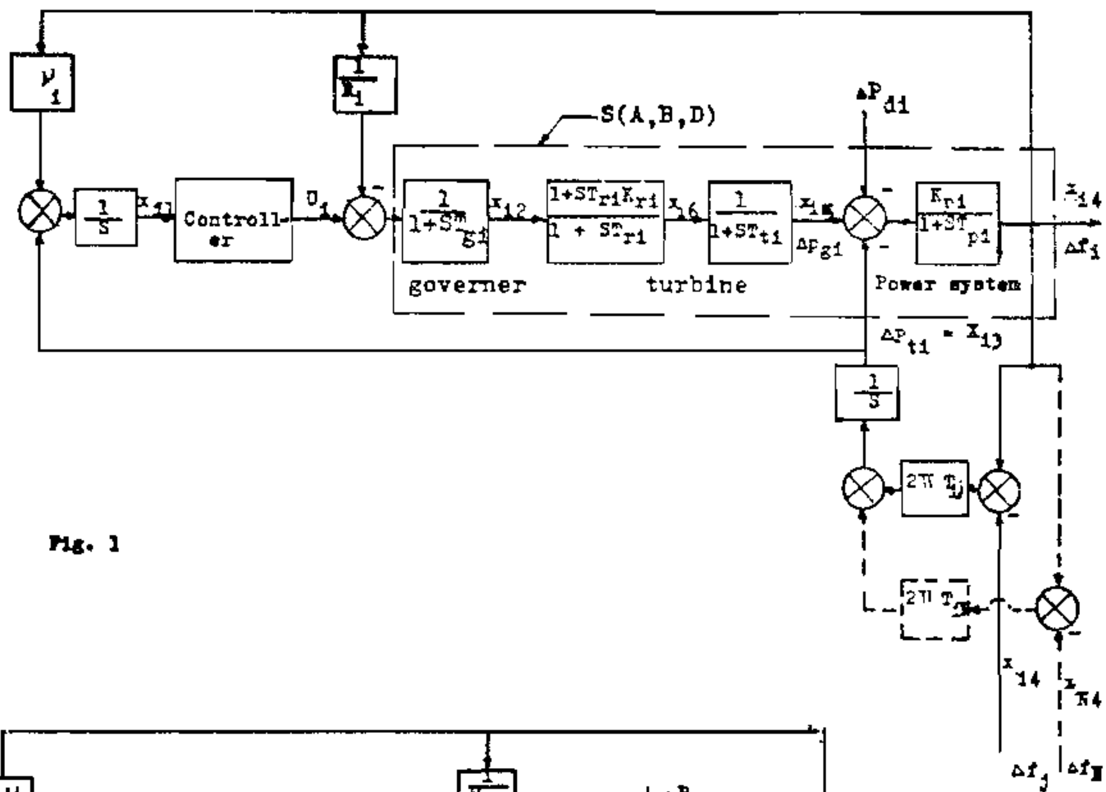

Fig. 1

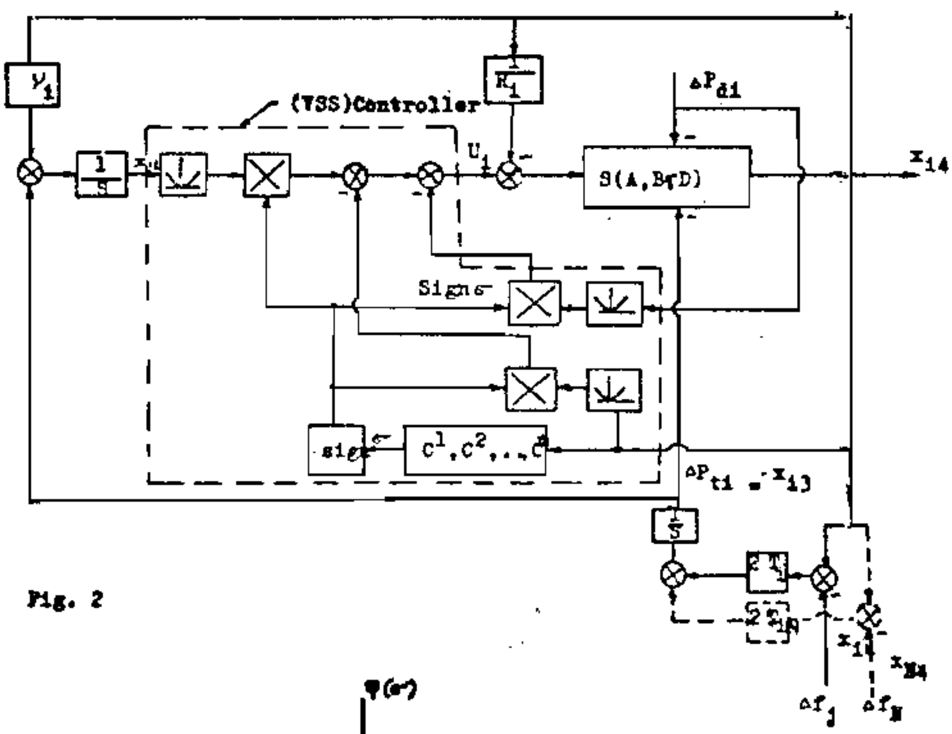

Fig. 2

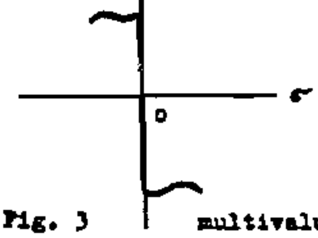

Fig. 3 multivaluable function

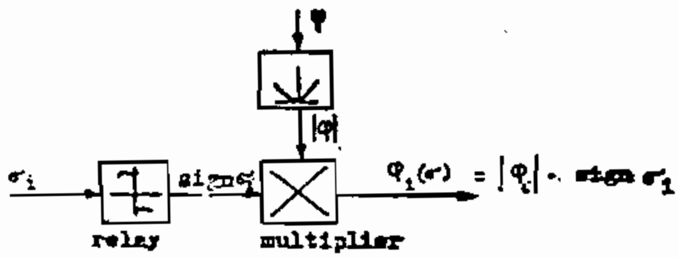

Fig.4 Generation of multivaluable function

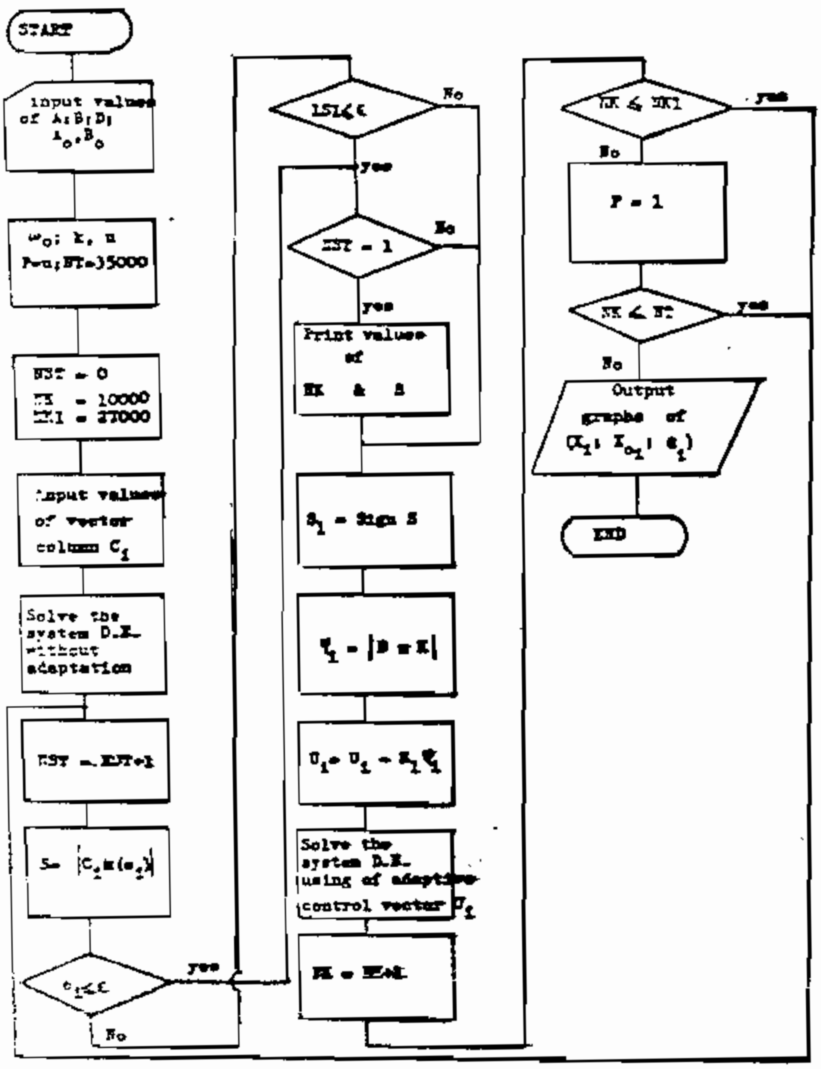

Fig. 5

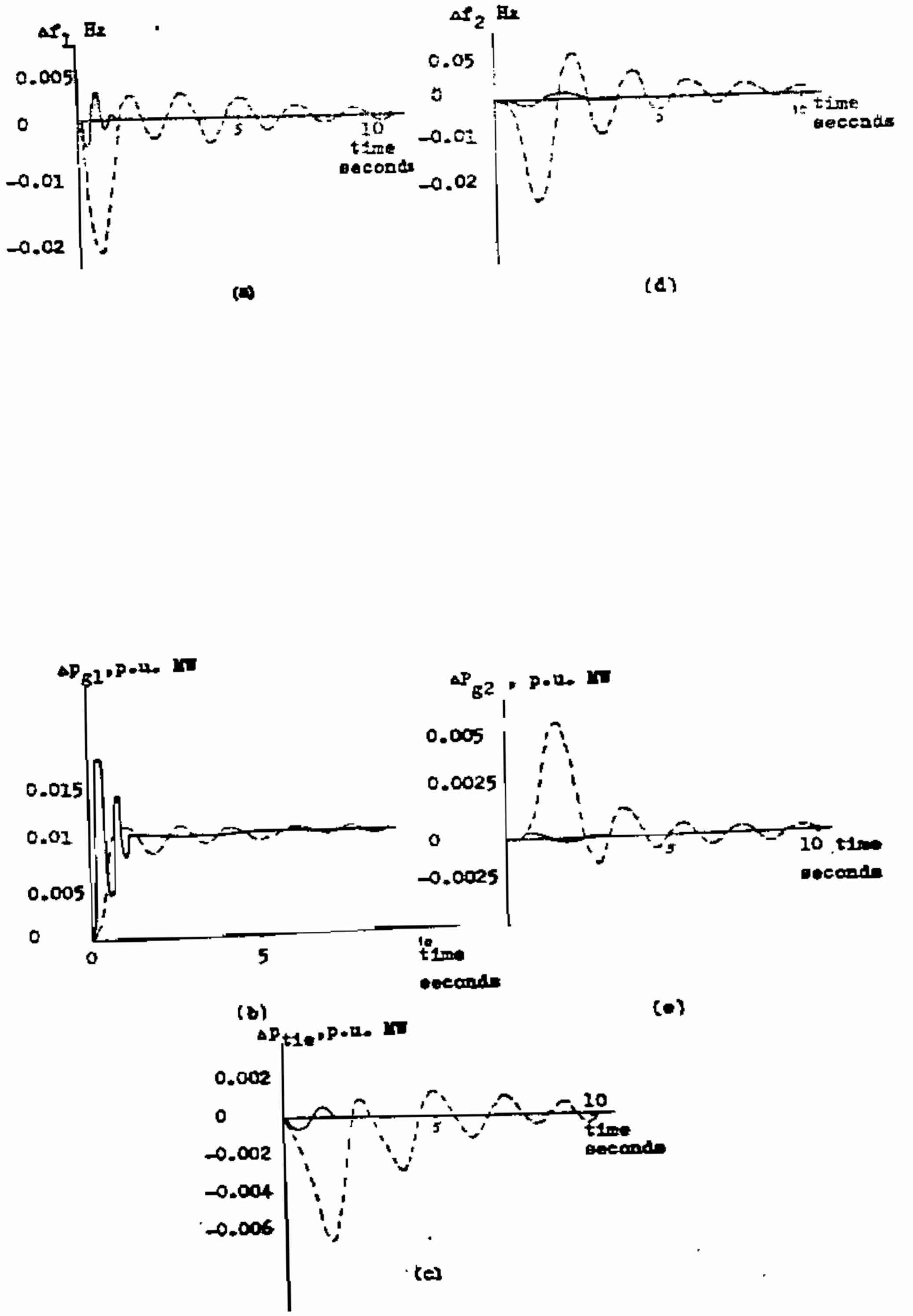

Fig. 6

— (VSS) Controller

— Conventional Controller