CHAPTER IV

SIMULATIONS OF THE CONTROL SYSTEM

Two control strategies, i.e., the conventional and the optimal control, have been used to derive the control signals. The system can, now, be controlled by either control signal. However, the control system using the two control methods shows different responses as will be seen in the following.

Simulation of the Control System Using the Conventional Control Method

The signal used to control the system is

$$\Delta P_C \overset{\Delta}{=} -K_I \int \Delta f \, dt.$$

The control system block diagram is shown in Fig. 11. The uncontrolled system is added by the so-called integral control (dotted line). It is seen that, the speed changer is command by a signal

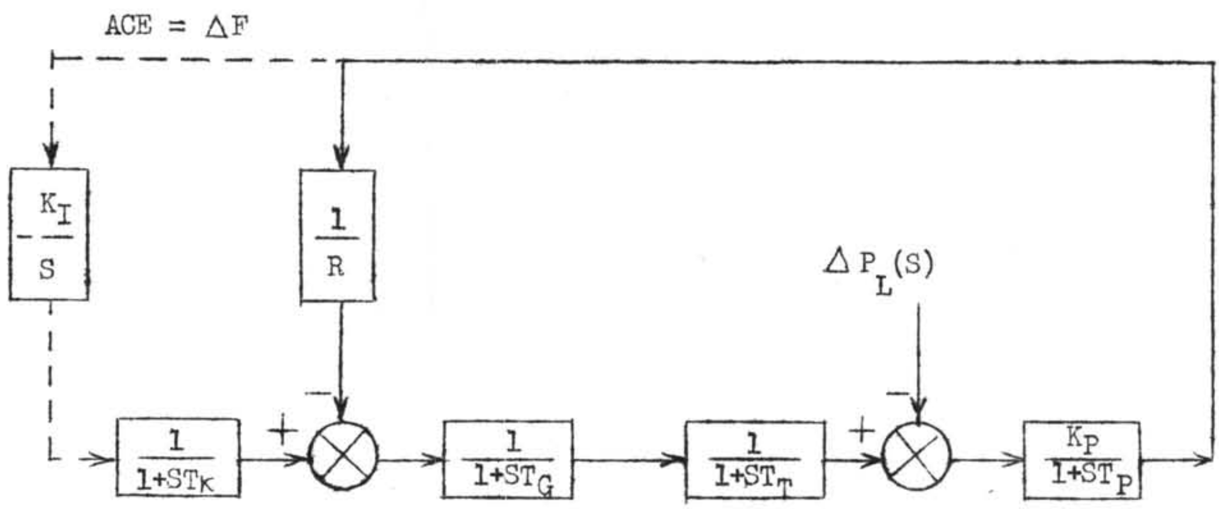

Figure 11. The conventional control system block diagram.

obtained by first amplifying and then integrating the frequency error.

The values of the various system parameters using through out the study are shown below :

R	=	Speed governor regulation = 2.4 H_Z/ pu MW		
T_K	=	Time constant of speed changer	= .26	sec
T_G	=	Time constant of speed governor	= .08	sec
T_T	=	Time constant of steam turbine	= .3	sec
H	=	System inertia constant	= 5	sec
P_r	=	Total rated system capacity	= 200	MW
P_L	=	Normal operating load	= 100	MW
$\dot{f}$	=	Normal operating frequency	= 50	H_Z
D	=	Load frequency constant	= $\frac{1}{100}$	pu MW/H_Z
K_P	=	$\frac{1}{D}$ = 100 H_Z/ pu MW		
T_P	=	$\frac{2H}{\dot{f}D}$ = 20 sec.		

The values of these parameters are mainly obtained from the system study in Reference 6. Substituting these values in block diagram of Fig. 11, the analog computer program can be written as shown in Fig. 1 of Appendix C. Curves showing the system responses are plotted.

Fig. 12 shows the responses of Δf for different values of the gain setting K_I for a fixed step load change. Fig. 13 shows effects of varying step load changes for a fixed K_I. The family of curves in Fig. 14 a, b show comparatively the effects of varying K_I for a fixed load, and varying loads for a fixed K_I. It can be seen from Fig. 14 a

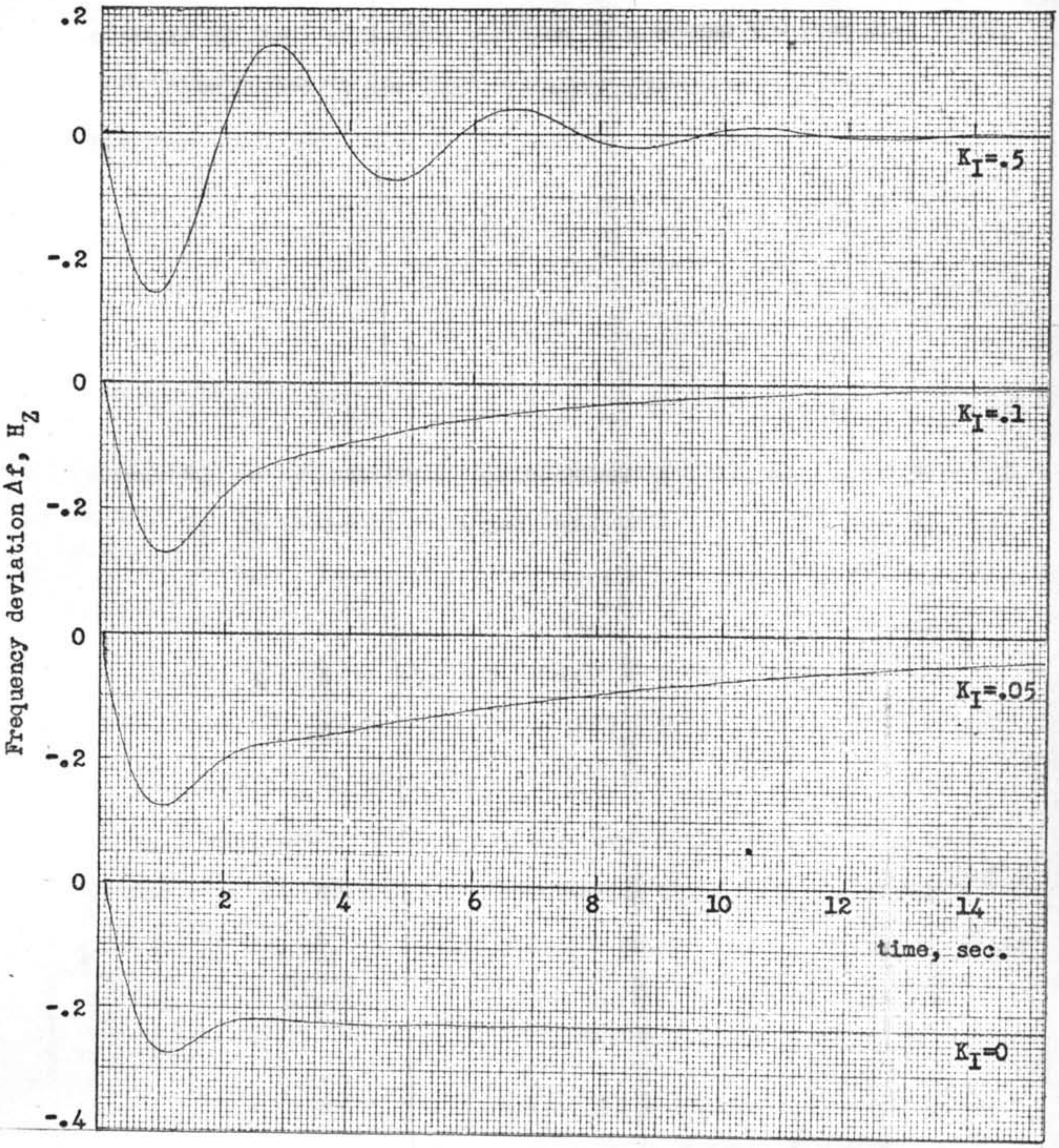

Figure 12. Effect of varying integral gain K_I on Δf for a step load added $\Delta P_L = 0.1$ pu.

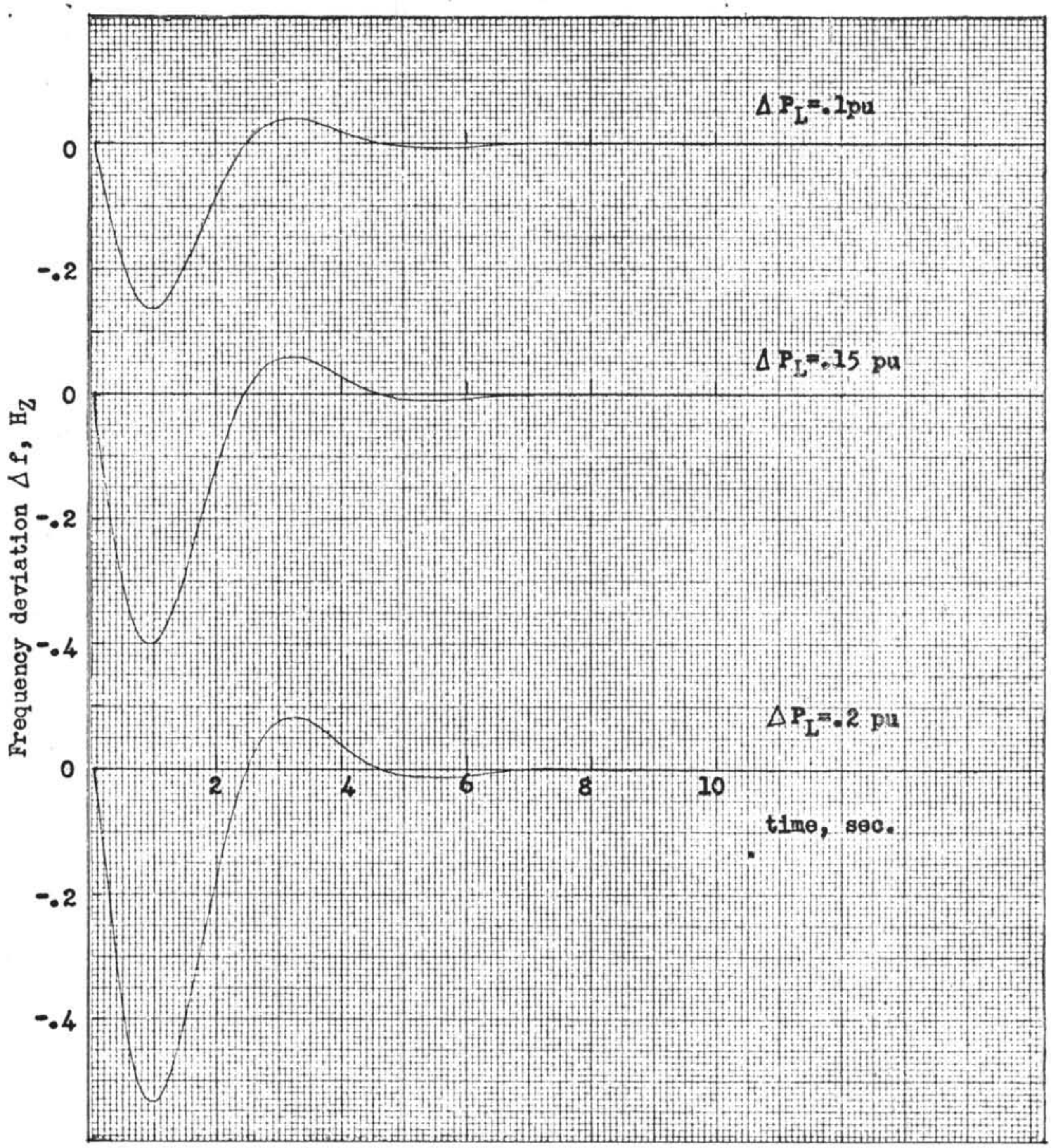

Figure 13. Effect of increasing load disturbance on Δf with fixed K_I=.3.

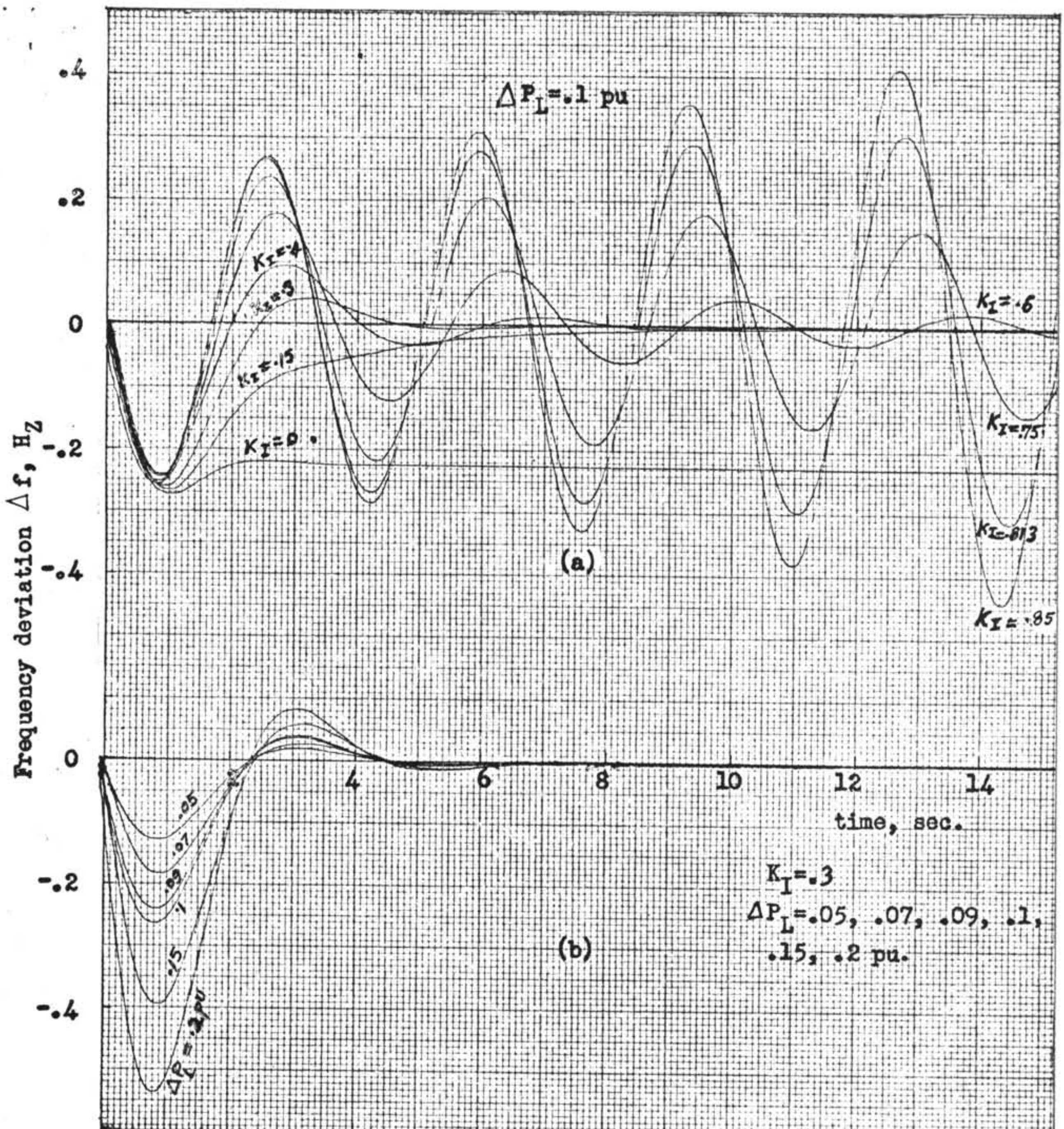

Figure 14. The comparison of Δ f-responses : (a) for a fixed ΔP_L=.1 pu and varying K_I; (b) for a fixed K_I=.3 and varying ΔP_L.

that the best response of Δf is obtained at the value of $K_I = .3$. At this value of K_I the response of the system frequency shows a good compromise between rapidity and stability. Fig. 15 shows the best responses of Δf, by setting $K_I = .3$, at different values of loads. The responses of Δf in Fig. 15 will be used to compare with those of the optimal control method. Figs. 16 and 17 show the responses of Δf for different step load changes with $K_I = .05$. These two figures show the effects of reducing the value of K_I.

Fig. 18 is the plot for showing the feedback control signal of the system. Curves A, B, C, D and E are the plot taking at the corresponding points in Fig. 1 of Appendix C. Signal A and B are the same signal except that A delays from B. Signal D is the effect of the speed governor regulation which will have the value whenever Δf is not zero, i.e., there is frequency deviation from nominal value. Signal C is obtained from the integration of signal A (minus), as soon as A equal zero C will be constant. Signal E is the sum of signal C and D.

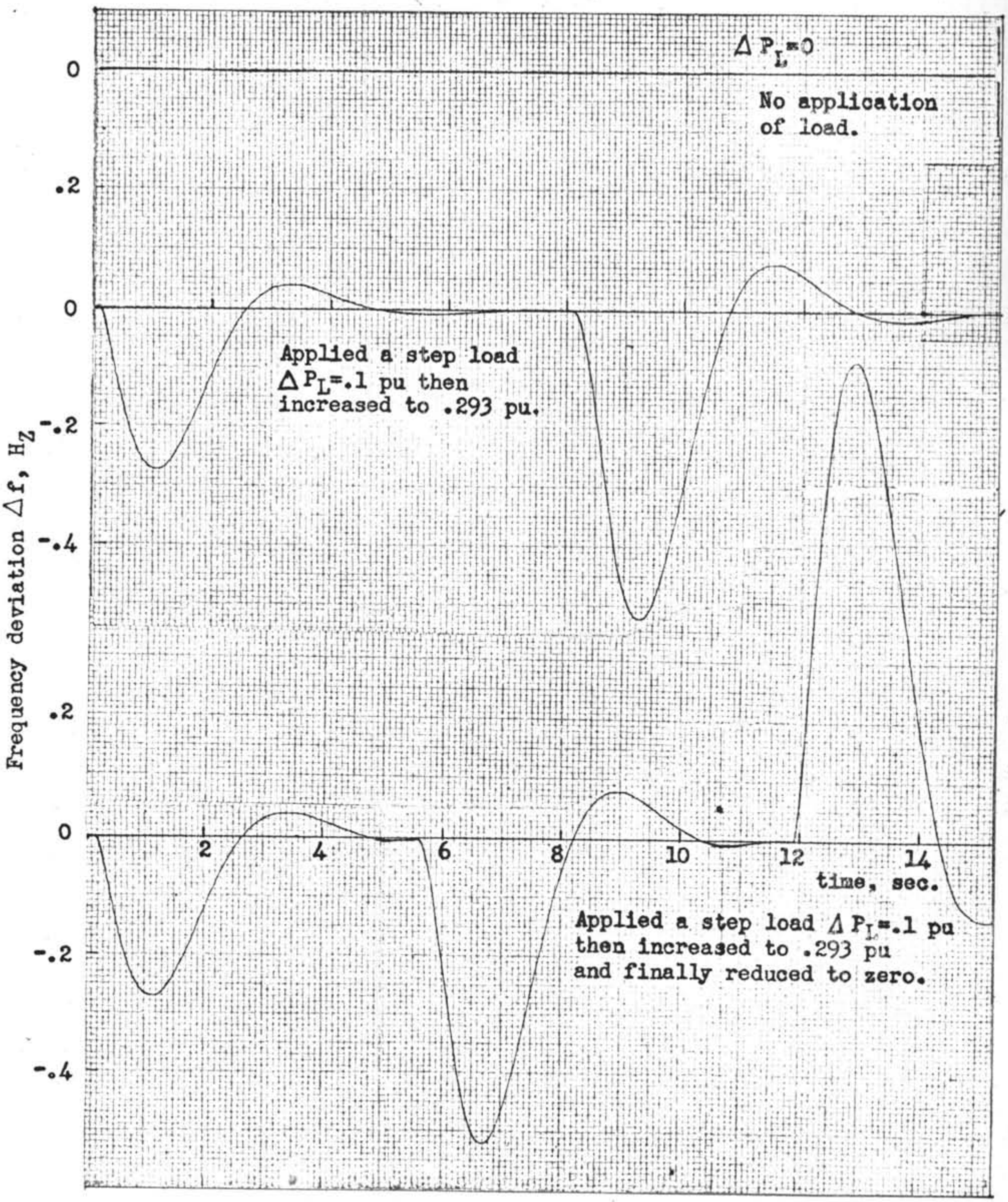

Figure 15. Responses of Δf for a fixed $K_I = .3$.

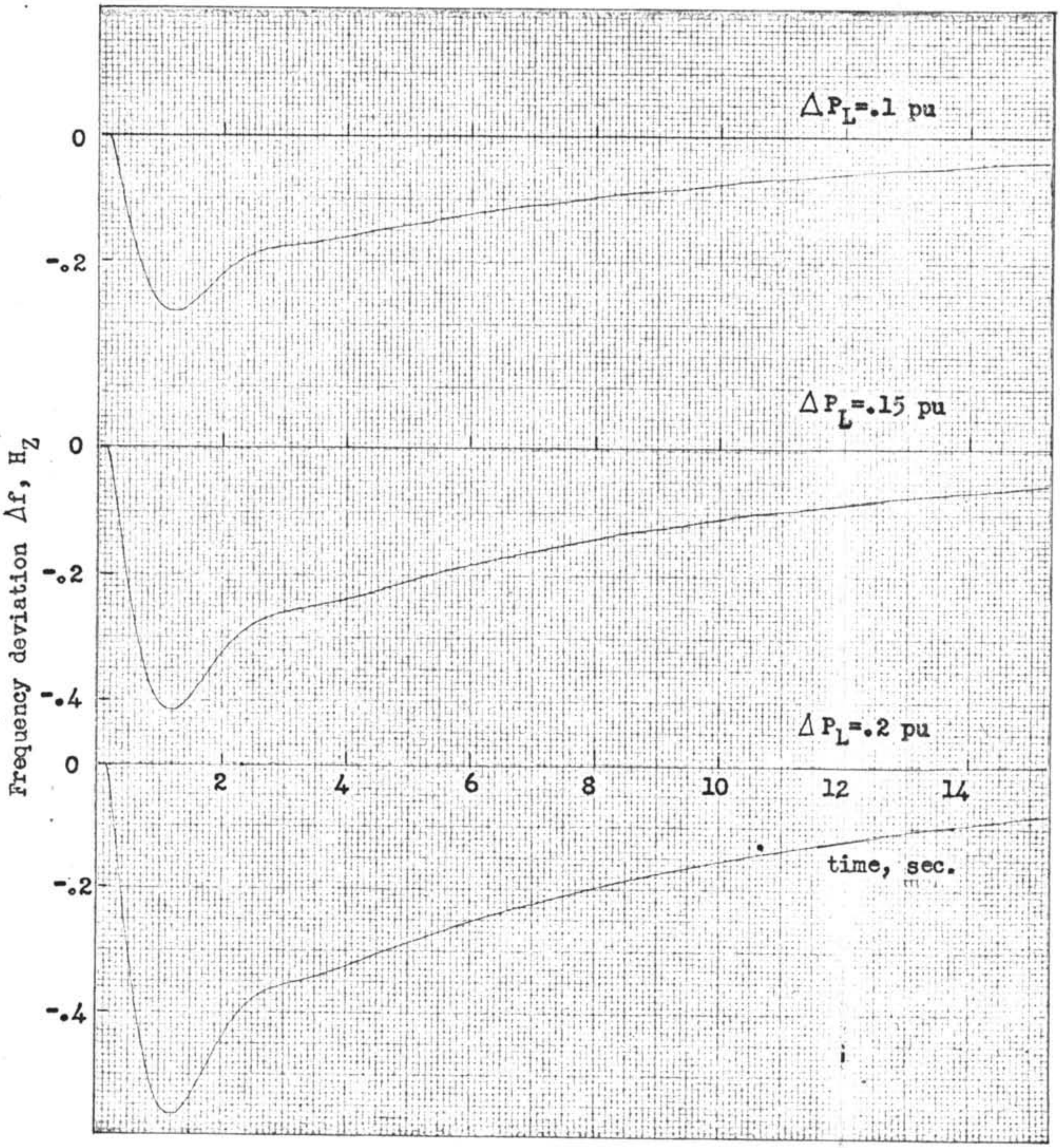

Figure 16. Effect of increasing load disturbance on Δf with a fixed K_I = .05.

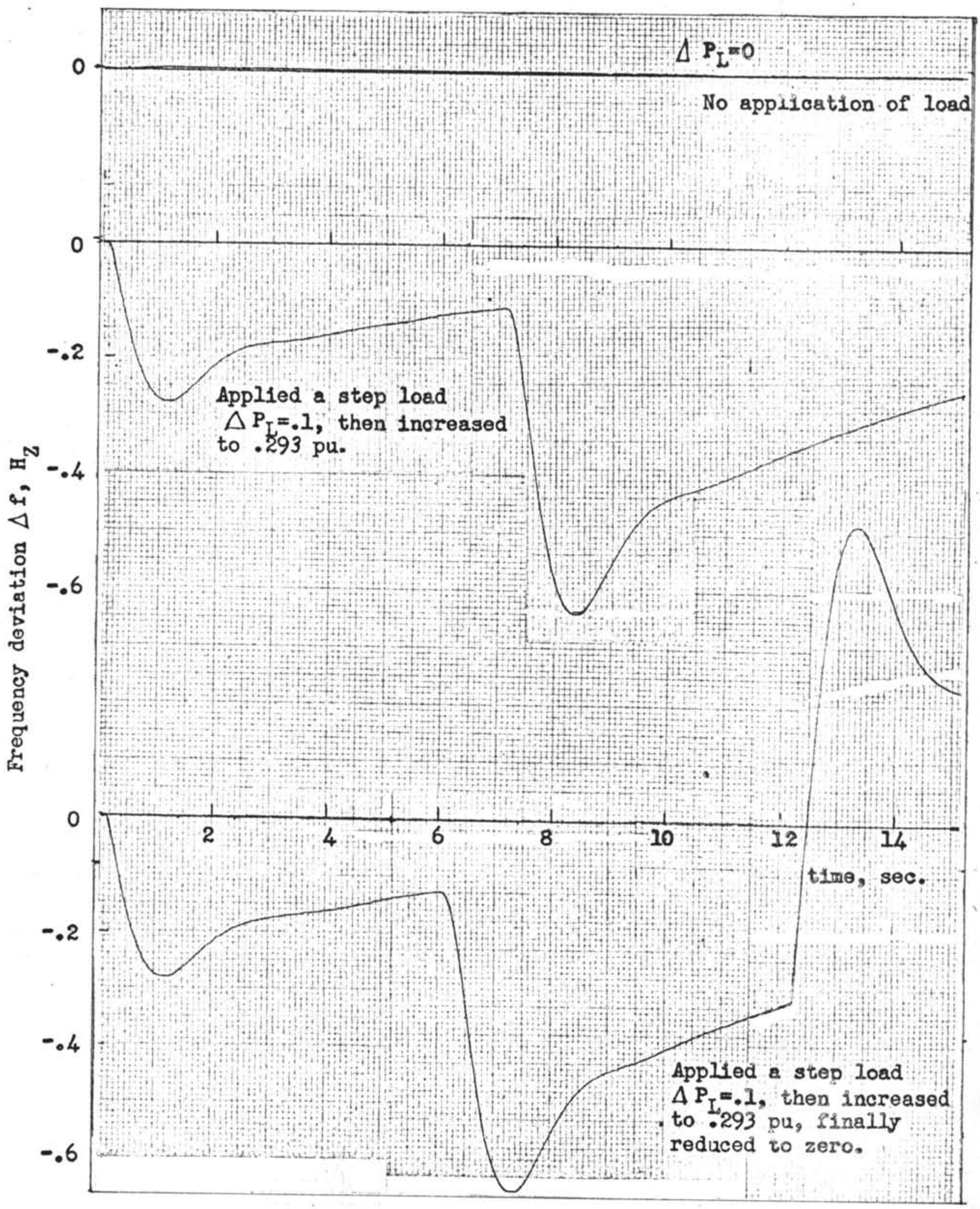

Figure 17. Responses of Δf, for a fixed K_I = .05.

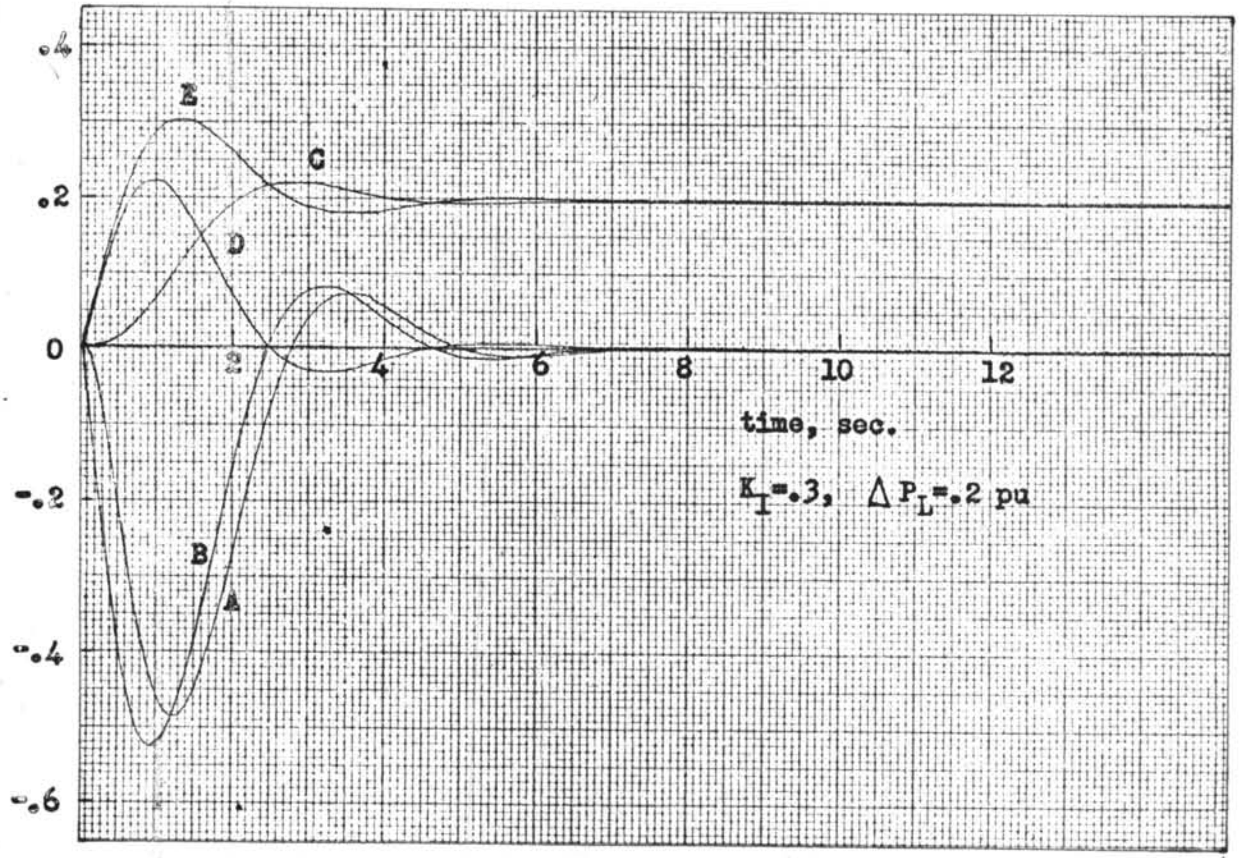

Figure 18. Showing the signals used to control the system. Curves A, B, C, D and E are the plot taking at the corresponding points in Fig. 1 of Appendix C.

By studying the curves having been plotted, the general comments about the conventional control may be as follows:

1. For low value of K_I, the system response is slow and nonoscillatory. This means that the time error will be relatively large.

2. For larger value of K_I the speed of Δf-response is increased but it turns oscillatory.

3. A careful study of the response curves of Fig. 14a, reveals the following :

As soon as the sudden load increase is applied the frequency start falling off at the same exponential rate as for the uncontrolled case ($K_I = 0$). During the initial period, the integral controller has not yet acted the system response is in its uncontrolled manner. After a certain time, the integral control come into action and finally lifts the frequency back to its original value.

Simulation of the Control System with Speed - Governor Dead Band

The preceding section presents a study of the dynamic performance of the frequency control of an isolated power system based upon linearized analysis. The effects of speed - governor dead band on the frequency response of the system are investigated in this section. The control system using the conventional control strategy is shown in Fig. 19

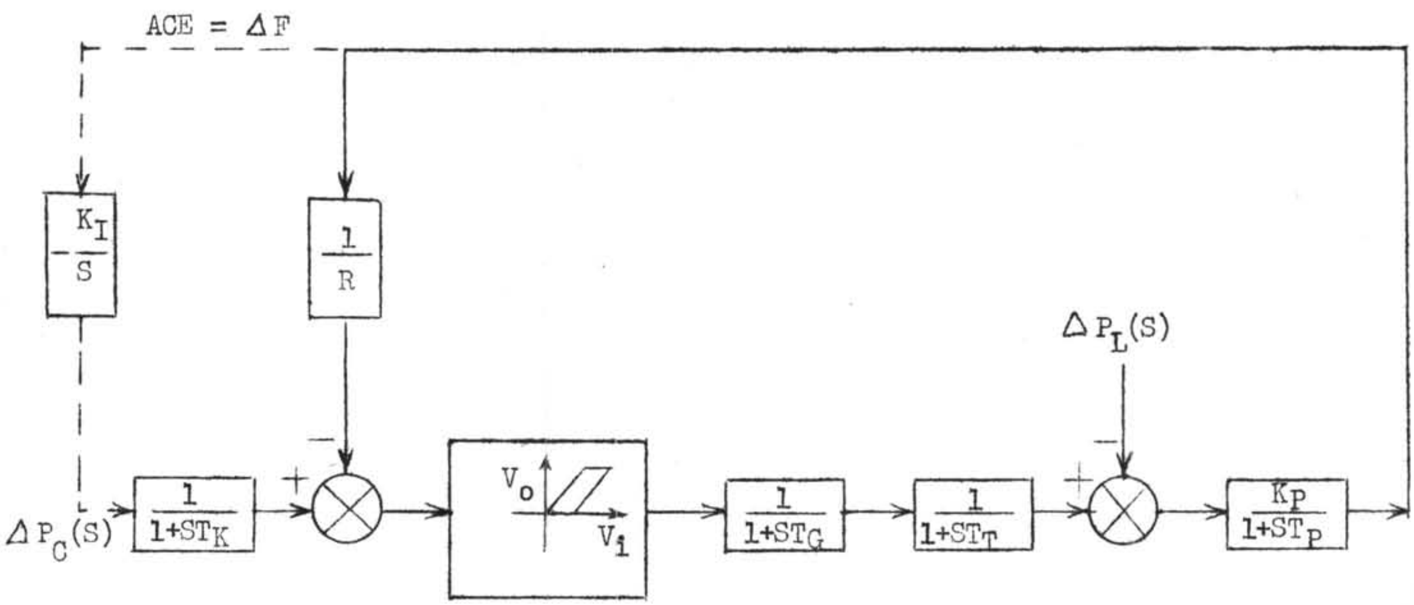

Figure 19. The conventional control system block diagram with speed - governor dead band.

The program for an analog computer is written as shown in Fig. 2 of Appendix C. The simulation results are plotted. Fig. 20 shows the effects of varying the integrator gain K_I for a fixed step load change. It is seen that for $K_I = 0$, the system is uncontrolled. The higher the gain K_I the faster response and the larger in magnitude of the oscillation are obtained. At $K_I = .3$ the response is so highly oscillatory that it can not be shown in Fig. 20. Comparing to the system without dead band this value of K_I gives the best response. It is seen that the best Δf - response of the system with dead band is obtained at $K_I = .05$. Fig. 21 shows the best responses with $K_I = .05$, for different values of the step loads applied. The best responses of of Fig. 21 may be compared to those of the linear system in Fig. 13. At the value of $K_I = .05$ which gives the best response of the system with dead band, while at the same K_I setting in the linear system gives the poor response as shown in Fig. 16. Fig. 22 shows the best response of the system for the different values of loads both increasing and decreasing. These responses may be compared to those of the linear system in Fig. 15.

In the system with dead band, without any load applied, i.e., $\Delta P_L = 0$, the system will oscillate as shown in Fig. 22a. In the linear system there is no such oscillation for no load as can be seen in Fig. 15a.

The study of curves reveals that the effects of speed - governor dead band are the introduction of, in every case, the continuous low frequency oscillation. The magnitude and speed of oscillation depend

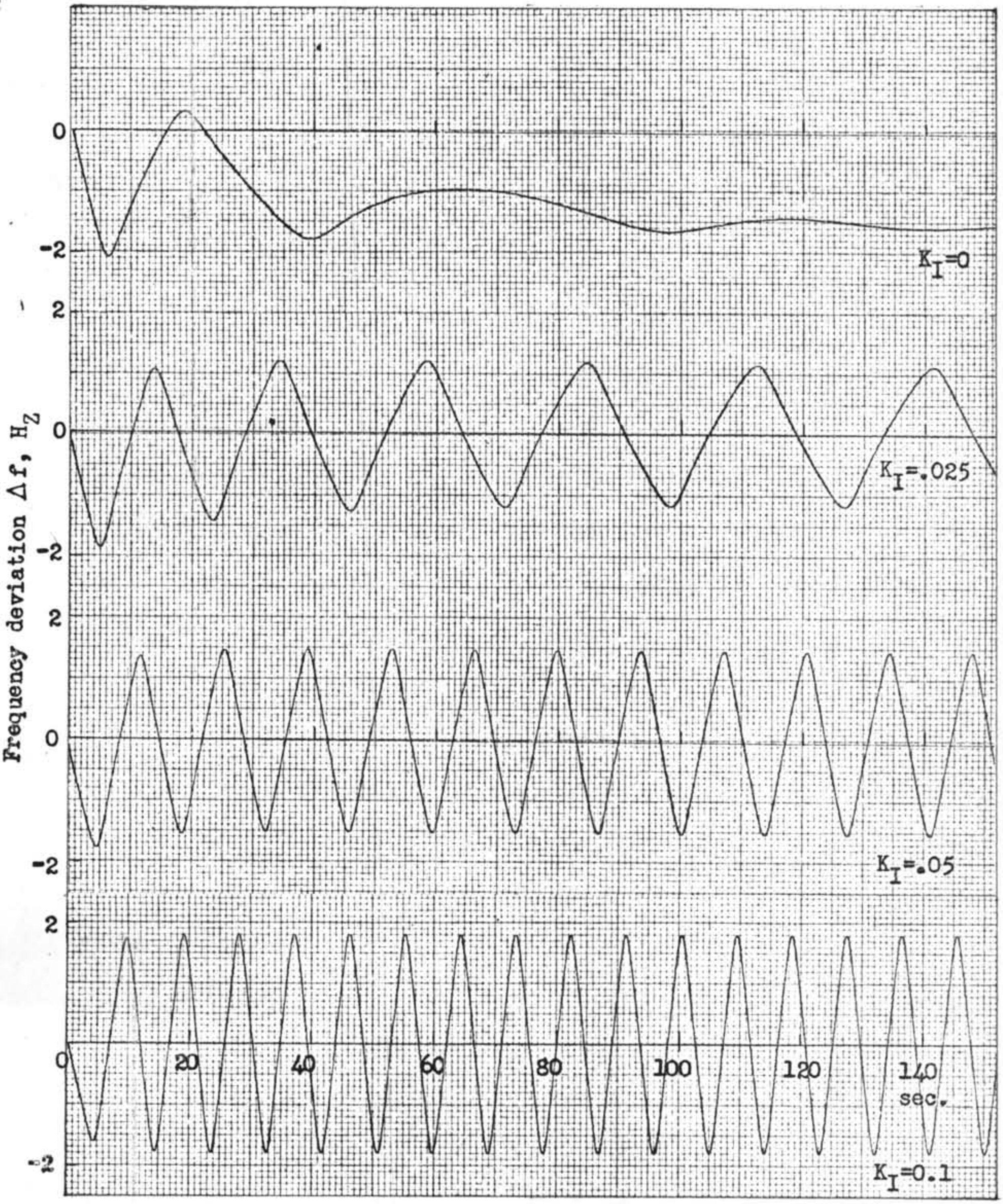

Figure 20. Effect of varying K_I on the system with dead band; ΔP_L = .1 pu.

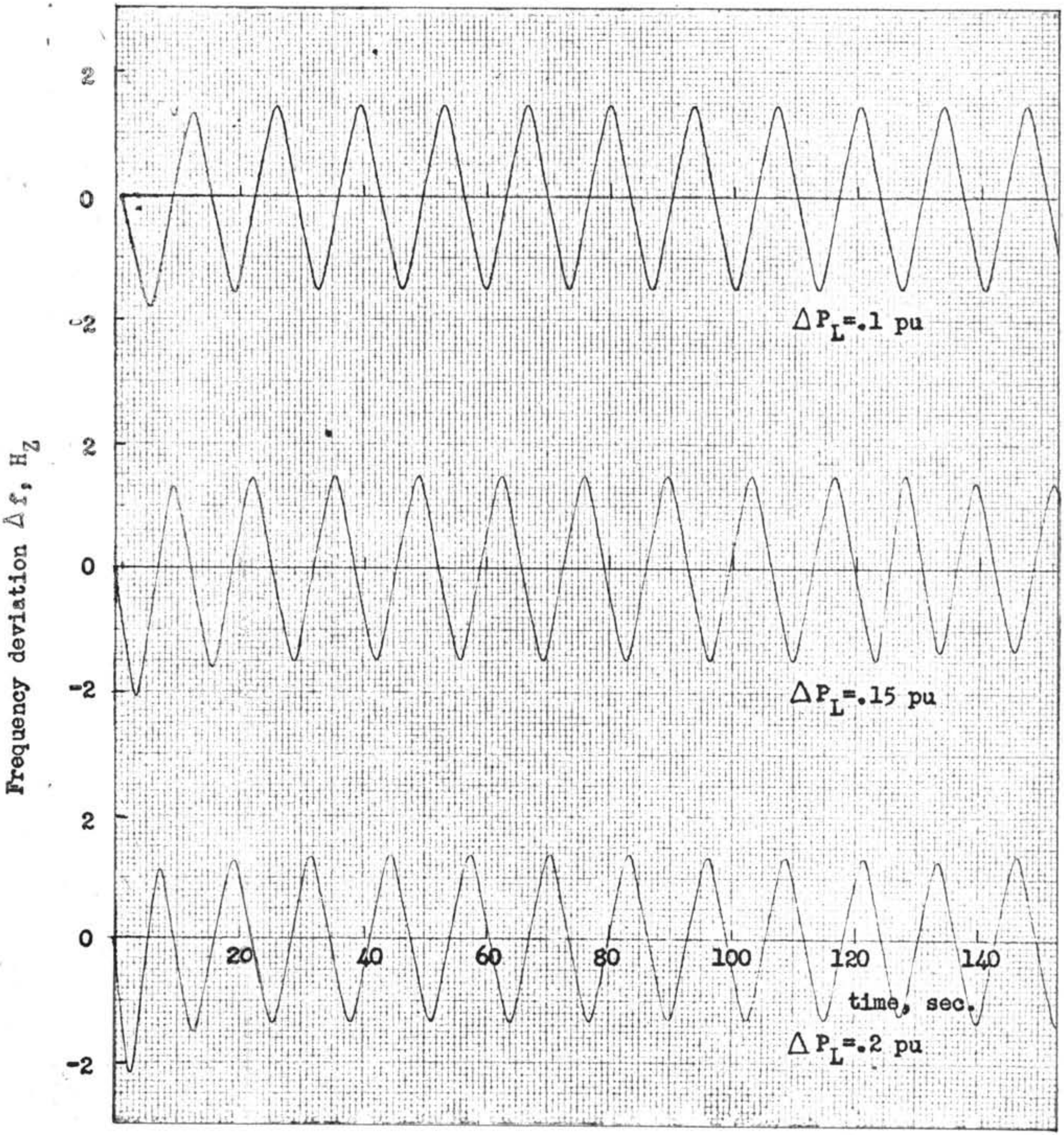

Figure 21. Effect of increasing load disturbance on Δf for a fixed $K_I = .05$, of the system with dead band.

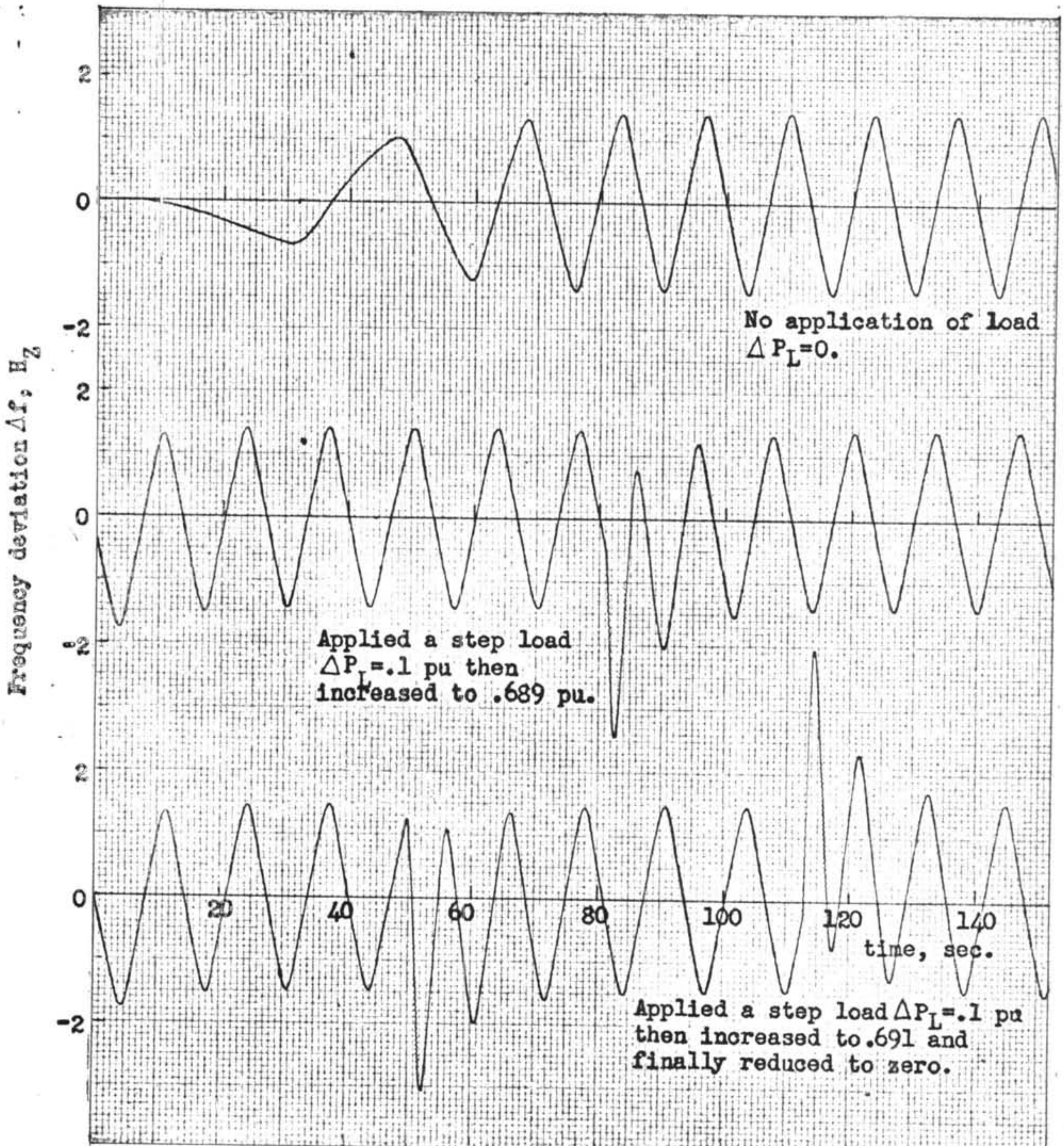

Figure 22. Responses of the system with dead band for K_I = .05.

very much on the value of K_I. The presence of the dead band requires a reduction in the gain K_I in order to obtain a good system response. The minimization of the speed - governor dead band results in a better control of the system frequency.

Simulation of the Control System Using the Optimal Control Method

The state model represented the isolated system to be studied is

$$\dot{\bar{X}} = A\bar{X} + B\bar{U} \tag{4.1}$$

$$\bar{Y} = C\bar{X} . \tag{4.2}$$

The superscript " ' " has been dropped for simplicity. The system is completely controllable (see Appendix A). The cost functional is

$$J = \frac{1}{2}\int_0^{\infty} (\bar{X}^T Q\bar{X} + \bar{U}^T R\bar{U}) \ dt. \tag{4.3}$$

The optimal controller $\hat{\bar{U}}$ that minimizes the cost functional is

$$\hat{\bar{U}} = -R^{-1}B^T K\bar{X} \tag{4.4}$$

where K is obtained by solving the Riccati equation;

$$- KA - A^T K + KBR^{-1}B^T K - Q = 0. \tag{4.5}$$

By digital computer, the program is shown in Appendix D, then

$$K = \begin{bmatrix} .41118 & .34949 & .07492 & .10978 \\ .34949 & .43422 & .10487 & .20128 \\ .07492 & .10487 & .02622 & .05427 \\ .10978 & .20128 & .05427 & .13911 \end{bmatrix} .$$

By the substitution of the system parameters, then

$$A = \begin{bmatrix} .05 & 5 & 0 & 0 \\ 0 & -3.33333 & 3.33333 & 0 \\ -5.20833 & 0 & -12.5 & 12.5 \\ 0 & 0 & 0 & -3.84615 \end{bmatrix}$$

$$B = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 3.84615 \end{bmatrix} , \qquad C = \begin{bmatrix} 1 & 0 & 0 & 0 \end{bmatrix}$$

and $R = [1]$.

Substituting R, B, K into eq. (4.4), so

$$\hat{U} = - [1] [0 \quad 0 \quad 0 \quad 3.84615] [K] \quad \bar{X} .$$

Thus, $$\hat{U} = - .42223X_1 - .77415X_2 - .20873X_3 - .53504X_4 . \quad (4.6)$$

This is the optimal controller which will control the system in such a way that the cost functional J is minimized. Since the cost functional J as previously defined, composes of Δf and U, thus it can be stated that Δf is kept minimum without excessive expenditure of the control energy U. Analog computer program is shown in Appendix C, Fig. 3.

It is very important to note that the optimal controller $\hat{U}$ in eq. (4.6) is, actually, of the transformed state model of eq. (3.12a), i.e., $\hat{U}'$ but neglected "'" . Thus the actual controller to control the system is, from eq. (3.12b), $U = \hat{U} + \Delta P_L$. By the same reason the state variables $\bar{X}$ in eq. (4.1), really $\bar{X}'$, is equal to $\bar{X} - \bar{X}_{SS}$ or $\bar{X} - \Delta P_L$, since $\bar{X}_{SS} = \Delta P_L$. All these can be seen in the analog computer program in Appendix C, Fig. 3.

For the sake of comparison with the conventional control method, the optimal control system is also simulated on an analog computer. Fig. 23 shows the responses of Δf when subjected to different values of step load changes. When compared with Fig. 13, it is seen that at an equal increased load, the magnitude of the frequency deviation in the optimal control system is less than that of the conventional control system. The response in the optimal control system is faster and with a smaller degree of oscillation. This means that when there is a load change occurs, the system with the optimal control can control the system frequency and bring it back to the schedule faster and with less oscillation than the conventional system can.

Fig. 24 shows the optimal feedback control signals. At start, the magnitude of these signal rises sharply about two times of the applied load, then decreases exponentially and finally equal to load. These sudden rising of the signals at start result in fast lifting of the drop in frequency due to the application of loads. In the case of the conventional control method, the control signal gradually rises as can be seen in Fig. 18 curve C.

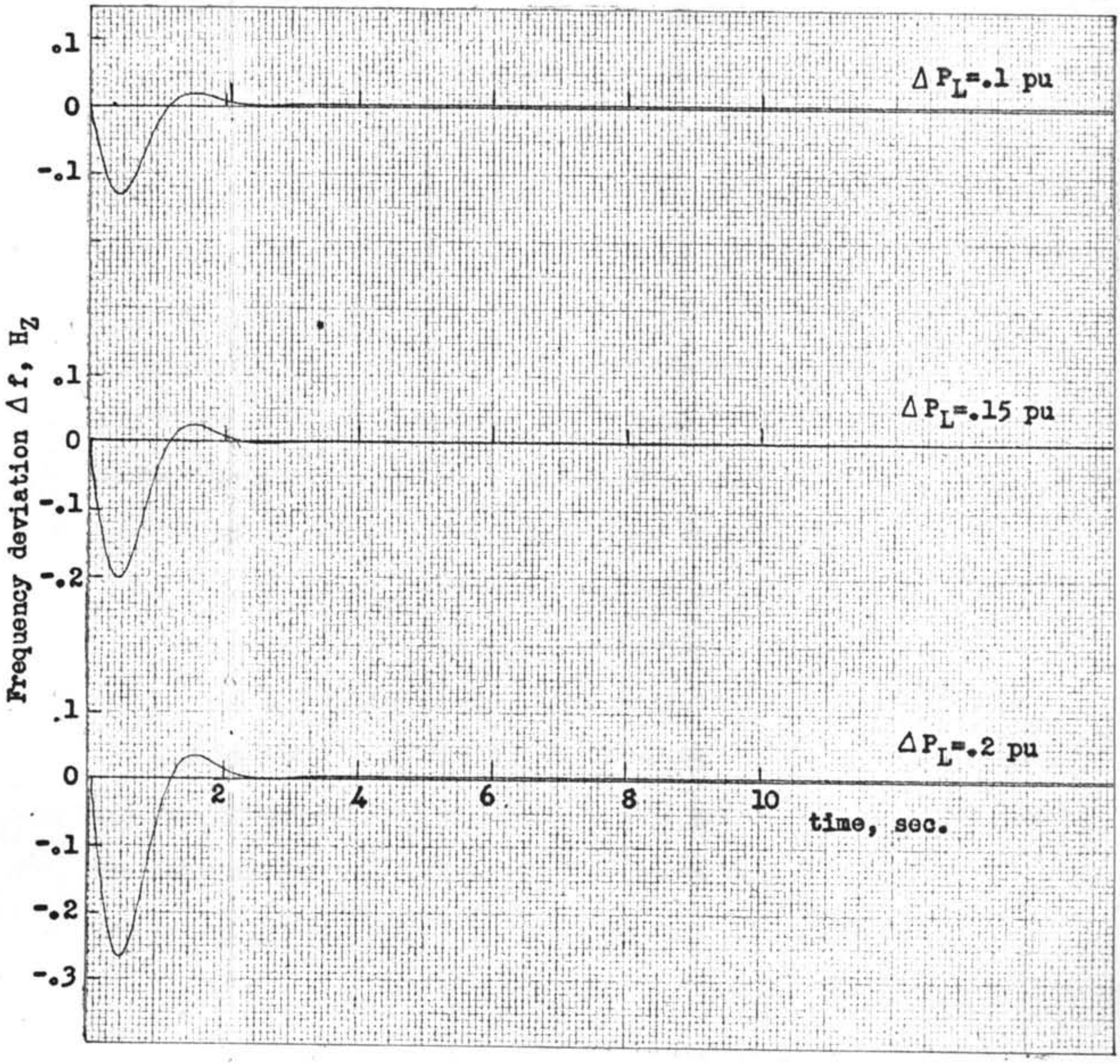

Figure 23. Effect of increasing load disturbance on the optimal control system.

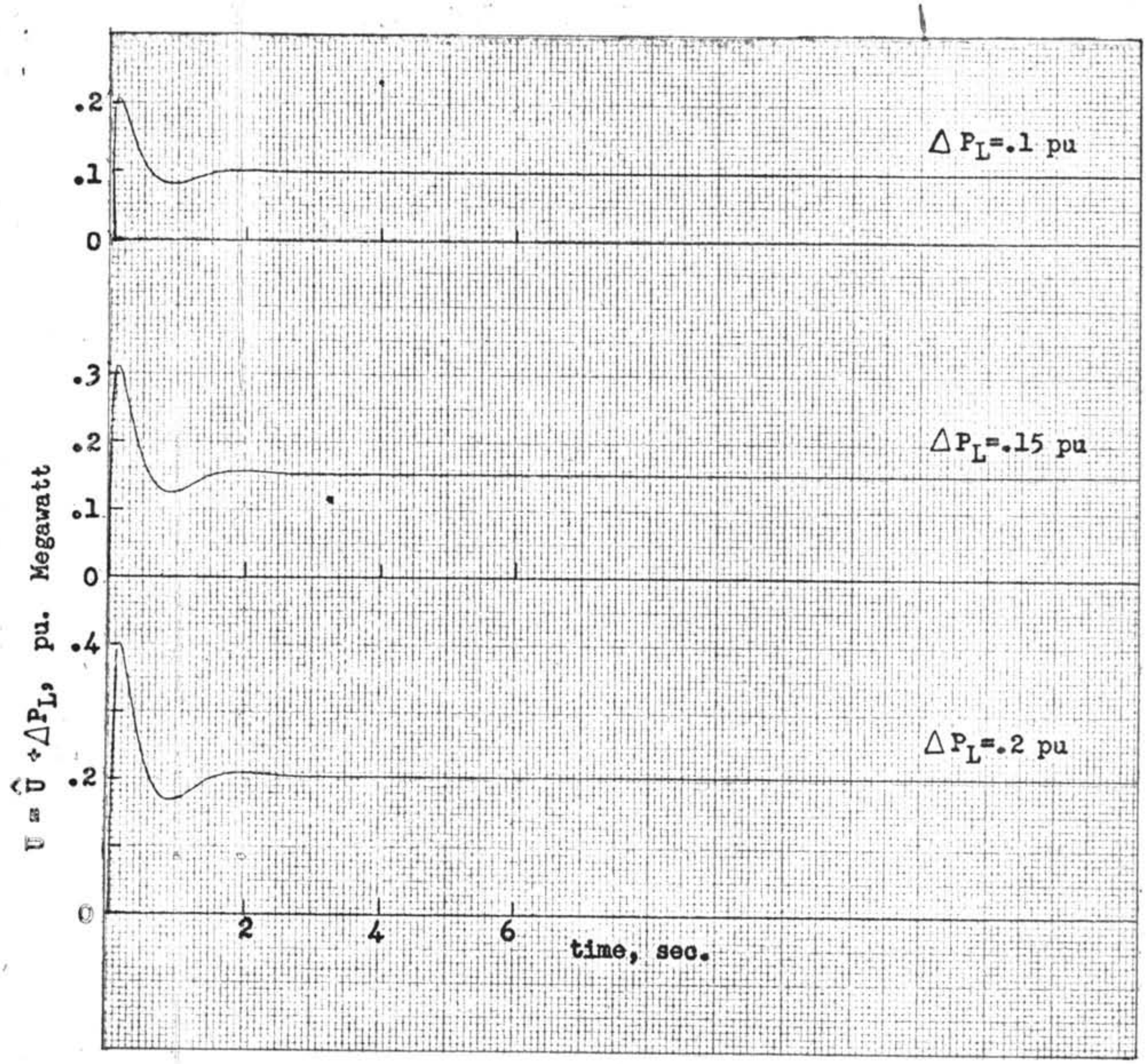

Figure 24. Control signals of the optimal control system $U = \hat{U} + \Delta P_L$.

Fig. 25 shows the frequency responses for different values of loads. These Δ f-responses may be compared to the best Δ f-responses of the linear system using the conventional control method in Fig. 15. It can be seen that the responses are better in this control method.

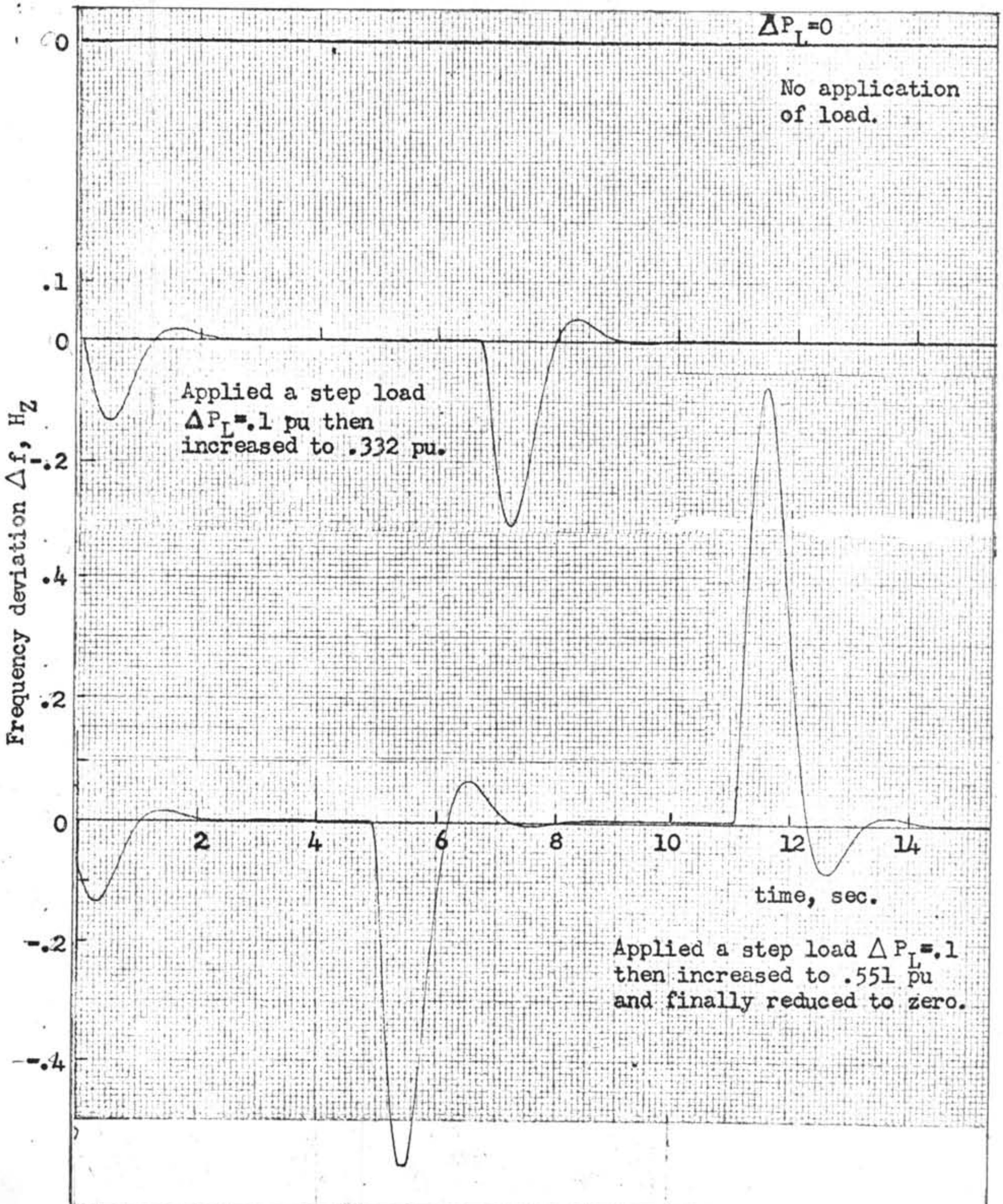

Figure 25. Responses of Δf of the optimal control system.

It should be noted that in the case of no load the Δf-responses in these two control systems are always equal to zero, i.e., there is no frequency deviation from schedule. But, if including the spead - governor dead band, although no load, the system goes into a sustained oscillation as have seen in Fig. 22.

Fig. 26 shows the comparison of Δ f-responses when the system subjected to the different load changes. The magnitude of the frequency deviation is changed corresponding to the applied load. The speed of the Δ f-response also varies according to the applied load, i.e., the

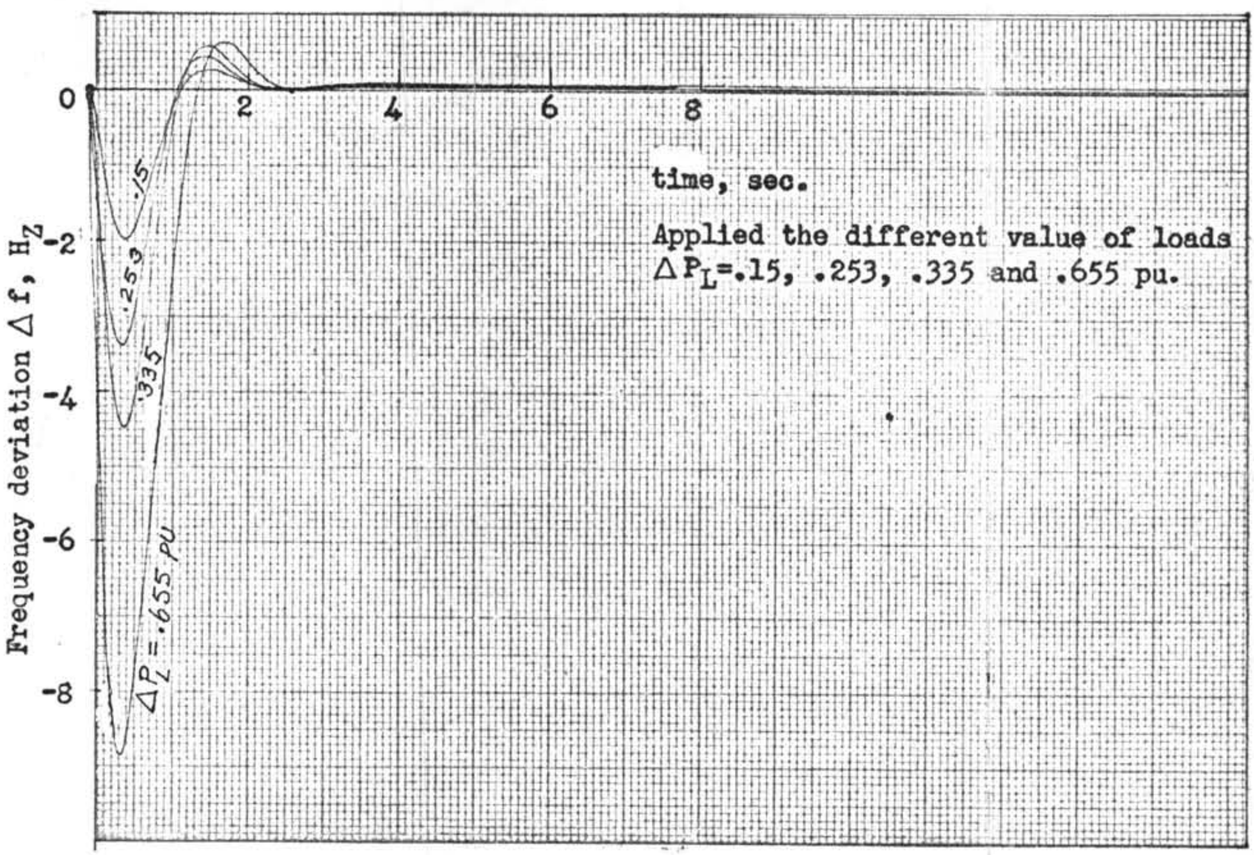

Figure 26. The comparative Δ f-responses of the optimal control system with different values of ΔP_L.

larger the load the slower the speed of the response. In the case of the conventional control system, for a given value of K_I the speed of response is the same for any value of loads.

From the study of responses obtained by the simulation, one could see that the frequency control of the system is improved by the optimal control method. The frequency deviation in the optimal control system is less than in the conventional control system when subjected to an equal load change. That is, the dynamic response and the system stability are improved. The faster responses with less oscillations in the optimal control system mean the better responses over the conventional control system. In the conventional control system K_I must be selected properly in order to obtain good responses. But in the optimal control system there is no problem converning with the choice of K_I, the responses are automatically optimum. Thus, with respect to the results obtained, it may be concluded that more improvements in frequency control are achieved by the optimal control method. However, the process of the optimal control method is not simple like the conventional control method. If one wants the best result regardless of the complication of the process he is recommended to use the optimal control method.