CHAPTER II

REPRESENTATION OF THE SYSTEM

The real power generated in an electric power system is controlled by means of the prime mover torque. The torque is affected by opening or closing the main steam valve in the case of a steam turbine or the water gate in the case of a hydroturbine. The movement of this valve or gate is the final result of the speed governing system.

A Dynamic Model of Speed Governor and Turbine Generator

Fig. 1 shows schematically a typical turbine control mechanism. All in cremental movements of X_A ... X_E are assumed positive in the direction indicated.

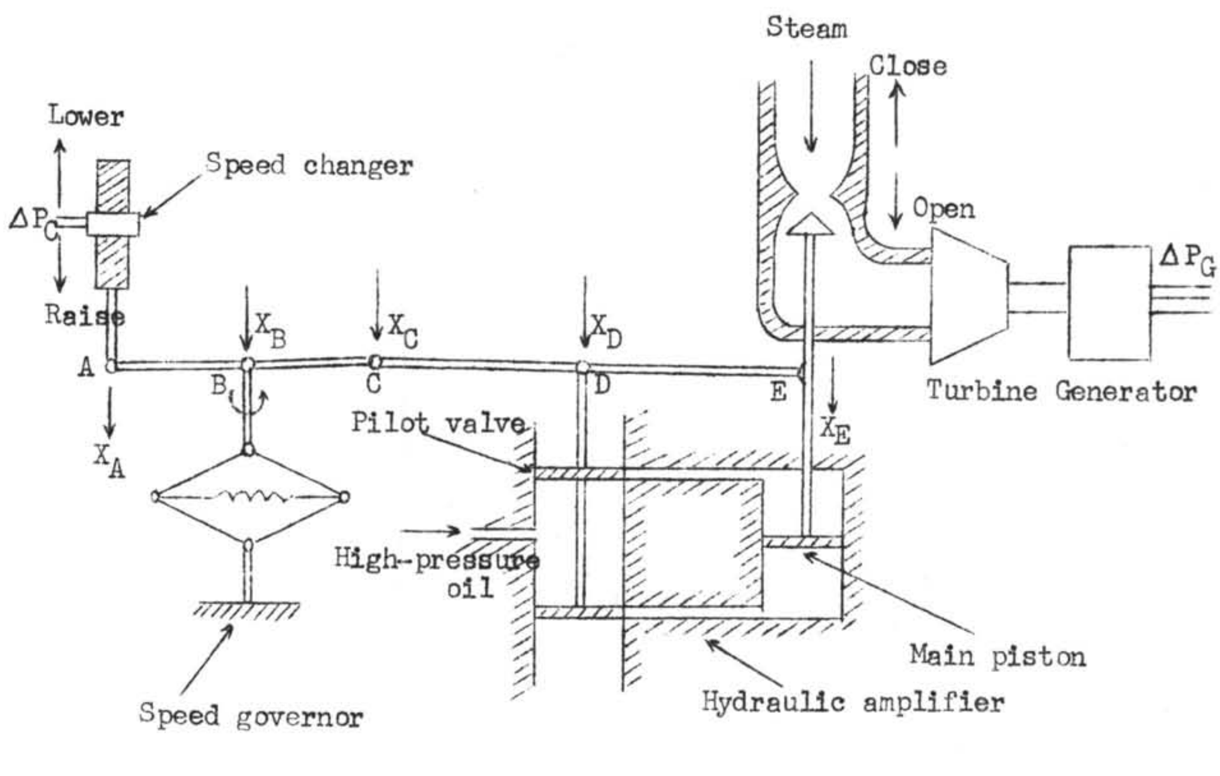

Figure 1. A typical real power-control mechanism.

By controlling the position measured by the displacement X_E of the governor controlled valve, the flowing of steam to turbine can be controlled and thus the turbine torque which determines the generator real power output. The displacement X_E results from the flowing of high pressure oil through pilot valves to a hydraulic amplifier. The diagram shows only one stage of the hydraulic amplifier, which in practice, may consist of many stages.

The position of the main piston X_E is the output of this amplifier. The input is the position X_D of the pilot valves. The movement of the pilot valves can be affected from the linkage system in three ways :

1. Directly, by moving of point A resulting from the command signals of the speed changer.

2. Indirectly, from the action of feedback, due to position changes of the main piston.

3. Indirectly, from the action of feedback, due to position changes of point B resulting from speed changes.

A study of this system by Elgerd[5] reveals that for small perturbations about the nominal setting, the system in Fig.1 can be represented by the block diagram of Fig. 2, and its characteristic is shown in Fig. 3. (Neglect, for the time being, the speed-governor dead band which will be considered later).

In the block diagram of Fig. 2, the governor and turbine have been represented by the time constant T_G and T_T respectively. The turbine is a steam turbine of nonreheat type. The response of the generator is, practically, instantaneous. Thus, ΔP_G, the incremental power output of the generator is instantaneous. This is a fundamental representation of the system.

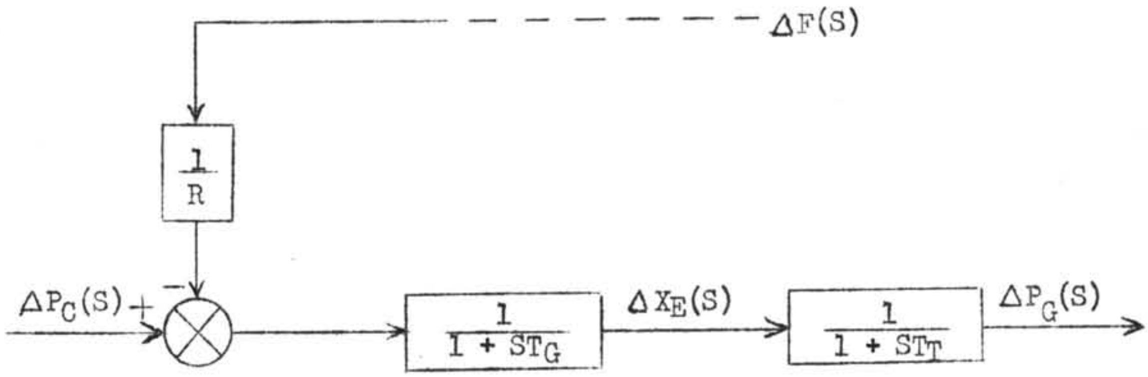

Figure 2. A block diagram of turbine generator with speed governor.

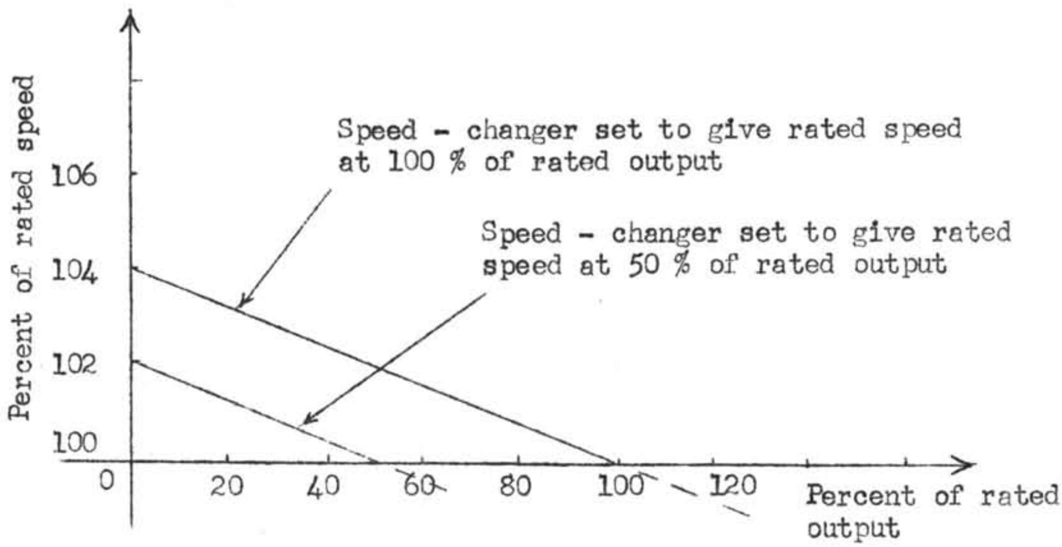

Figure 3. Static speed - load characteristics of a turbine generator with speed governor.

Fig. 3 shows the speed regulation of the system with a speed drop of 4 %. The drop characteristic is represented by R in the block diagram. The constant R measured in H_Z / pu MW is a measure of the static speed drop of the uncontrolled turbine generator. The uncontrolled system means that the command signal ΔP_C to the speed changer is zero.

A Control Area

A control area is a portion of an electric power system to which a common generation control is applied. All generators in a control area is expected to regulate its own load change. A typical control area will have many generating units of varying types, sizes, and ages, with varying speed regulation characteristics and dead bands. Taken in the aggregate, operating units of an area may be regarded as having a composite governing characteristic. A control area would include all the generating units, loads, and lines that fall within its prescribed boundaries.[3] A simplified schematic of a control area is shown in Fig 4. All the control areas taken together should account for all the generation, load, and ties of the

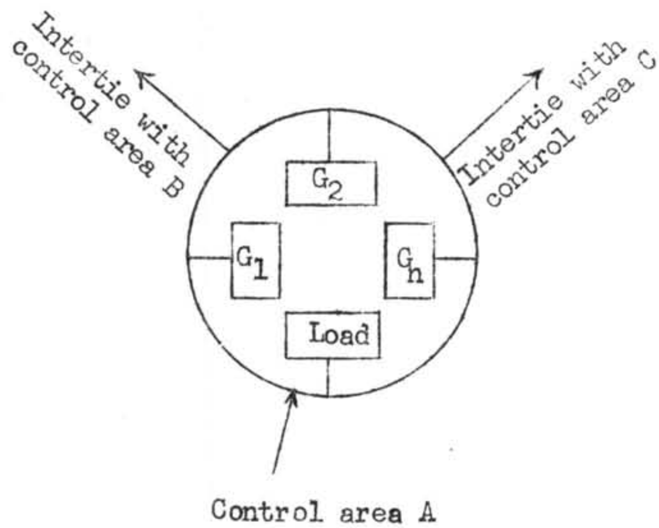

Figure 4. A simplified schematic of a control area.

interconnected system.

In this research an isolated system is equivalent to the control area A as shown in Fig. 4 with no interties. In the analysis to follow, we will strickly think of an isolated system in this sense.

Incremental Power Balance of an Isolated Power System

An isolated power system is represented by system parameters and variables as in Fig. 5,

An isolated system
characterized by
system parameters
H, D, T_T, T_G, R, P_r
and system variables
Δf, ΔP_G, ΔP_C, ΔP_L

Figure 5. An isolated power system.

where

H	=	Inertia constant
D	=	Load frequency constant
T_T	=	Time constant of steam turbine
T_G	=	time constant of speed governor
R	=	Speed governor regulation
Δf	=	Frequency deviation
ΔP_G	=	Incremental power generation

ΔP_L = Incremental load

ΔP_C = Command signal to speed changer.

When the system experiences a real load change of magnitude ΔP_L MW, due to the action of the governor, the system increases its output by an amount of ΔP_G MW. The net power surplus in the system therefore equals $\Delta P_G - \Delta P_L$ MW, and this power will be absorbed by the system in two ways : [6]

1. By increasing the system kinetic energy W_{Kin} at the rate $\frac{d}{dt} W_{Kin}$.

2. By an increased load consumption. All typical loads, because of the dominance of motor loads, experience an increase, $D = \frac{\partial P_L}{\partial f}$ MW/H_Z, with speed or frequency. This D parameter can be found empirically.[5] Express in mathematical form, so

$$\Delta P_G - \Delta P_L = \frac{d}{dt} W_{Kin} + D \Delta f. \qquad (1.1)$$

The kinetic energy W_{Kin} of the system varies directly as the square of frequency, i.e.,

$$W_{Kin} \propto f^2$$

or $$W_{Kin} = K f^2.$$

At nominal frequency $f^{\bullet}$, $W_{Kin} = W^{\bullet}_{Kin}$; so

$W^{\bullet}_{Kin} = K f^{\bullet 2}$; $K = W^{\bullet}_{Kin} / f^{\bullet 2}$; and thus at any frequency f;

$$W_{Kin} = \left(\frac{f}{f^{\bullet}} \right)^2 W^{\bullet}_{Kin} . \qquad (1.2)$$

$\overset{\bullet}{W}_{Kin}$ is the system kinetic energy measured at nominal frequency $f^{\bullet}$. Since f is the instantaneous frequency of the system, thus

$$f = f^{\bullet} + \Delta f .$$

Substituting f into eq. (1.2);

$$W_{Kin} = \left(\frac{f^{\bullet} + \Delta f}{f^{\bullet}} \right)^2 \overset{\bullet}{W}_{Kin} ,$$

$$\simeq \left(1 + 2 \frac{\Delta f}{f^{\bullet}} \right) \overset{\bullet}{W}_{Kin} .$$

Thus; $$\frac{d}{dt} W_{Kin} = 2 \overset{\bullet}{W}_{Kin} \frac{d}{dt} \Delta f. \quad (1.3)$$

Substitution of eq. (1.3) in eq. (1.1) yields

$$\Delta P_G - \Delta P_L = 2 \overset{\bullet}{W}_{Kin} \frac{d}{dt} \Delta f + D \Delta f. \quad (1.4)$$

The term $D \Delta f$ is the load consumption. If an existing load in the system is, for example, motor load and if there is a change in frequency, the existing load also change accordingly. This helps in the governing action of the system, because when system frequency drops due to an added load the existing load will decrease. The decrease in consumption of the existing load leaves power available for the newly added load. This means that the system picks up lesser generation. The total natural governing characteristic of the system is the combination of the generation characteristics and the load characteristic.[4]

Dynamic Model Representation of an Isolated Power System

Dividing all terms of equation (1.4) by P_r, the total megawatt rating of the system, then

$$\Delta P_G - \Delta P_L = \frac{2H}{f^{0}} \frac{d}{dt}\Delta f + D\,\Delta f \qquad (1.5)$$

where

$$H = W^{0}_{Kin} / P_r .$$

The variables ΔP_L , ΔP_G and D are now measured in per unit of P_r .

The quantity H, with the dimension in seconds, is a per unit inertia constant with a desirable property in that it is practically independent of the system size. Typical H values lie in the range from 2 to 8. Taking the Laplace transform of eq. (1.5), we obtain

$$\Delta P_G(S) - \Delta P_L(S) \quad \frac{K_P}{1 + ST_P} = \Delta F(S) \qquad (1.6)$$

where new parameters have been introduced :

$$K_P = \frac{1}{D} \; H_Z / \text{pu MW}$$

$$T_P = \frac{2H}{f^{0} D} \; \text{sec.}$$

From eq. (1.6), a block diagram representing an isolated system can be written as shown in Fig. 6.

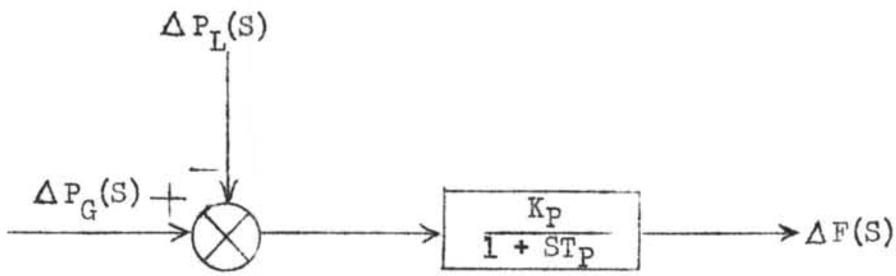

Figure 6. A block diagram of an isolated system.

By combining Fig. 2 and Fig. 6, the isolated system can be represented by the block diagram as shown in Fig. 7. It is noted that time constant T_K associated with the speed changer is also included in this block diagram.

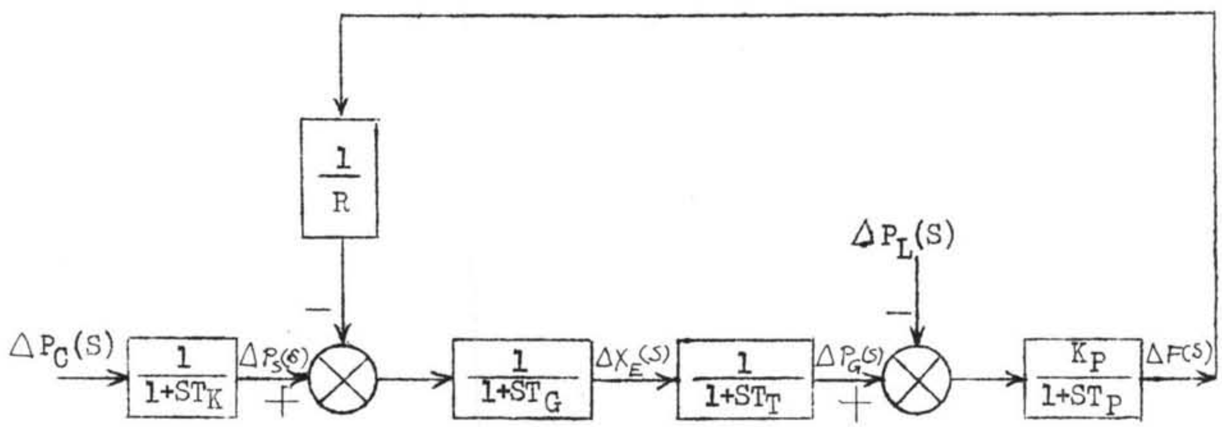

Figure 7. The complete block diagram of an isolated system.

<u>The System Model with Speed - Governor Dead Band</u>

Since speed - governor dead band has a great effect on the performance of the governor which, in turn, affects the frequency response of the system. This section will include the speed - governor dead band in the model for an isolated power system.

The dead band is defined as the total magnitude of change in steady-state speed within which there is no resulting measurable change in the position of the governor controlled valve. It may arise from mechanical friction, backlash, and from valve overlap in the hydraulic relays. The nature of the dead band is shown in Fig. 8.

As the input signal increases, the governing system has no change until the input signal arrives at the upper edge of the dead band (point a). From this point on the output signal which is the governor response is less than the input signal by an amount depending on the original position in the dead band. As soon as the input signal starts to decrease at point b, the governing system is again in its dead band and output signal remains constant at its maximum value until the lower edge of the dead band is reached at point c. The operation is then continued as indicated in Fig. 8.

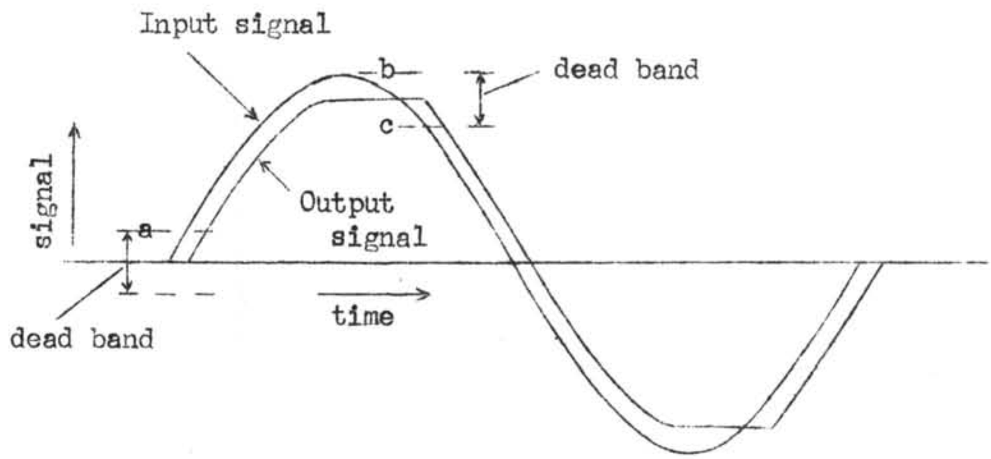

Figure 8. Physical nature of a dead band.

The physical nature of the speed - governor dead band presented in the system to be studied is shown in Fig. 9 a. Input and output signals are indicated by V_i and V_o respectively. The origin of the system in the dead band is set as shown in Fig. 9 b. The result of this setting is that the system has the poorest response.[8] Actually, the system could be any where within the dead band. The system model with speed - governor dead band is shown in Fig. 10. It will be noted that the dead band has been inserted between the input signal and the time constant of the speed governor. Evidently, the presence of the dead band results in the slower response of the speed - governor system.

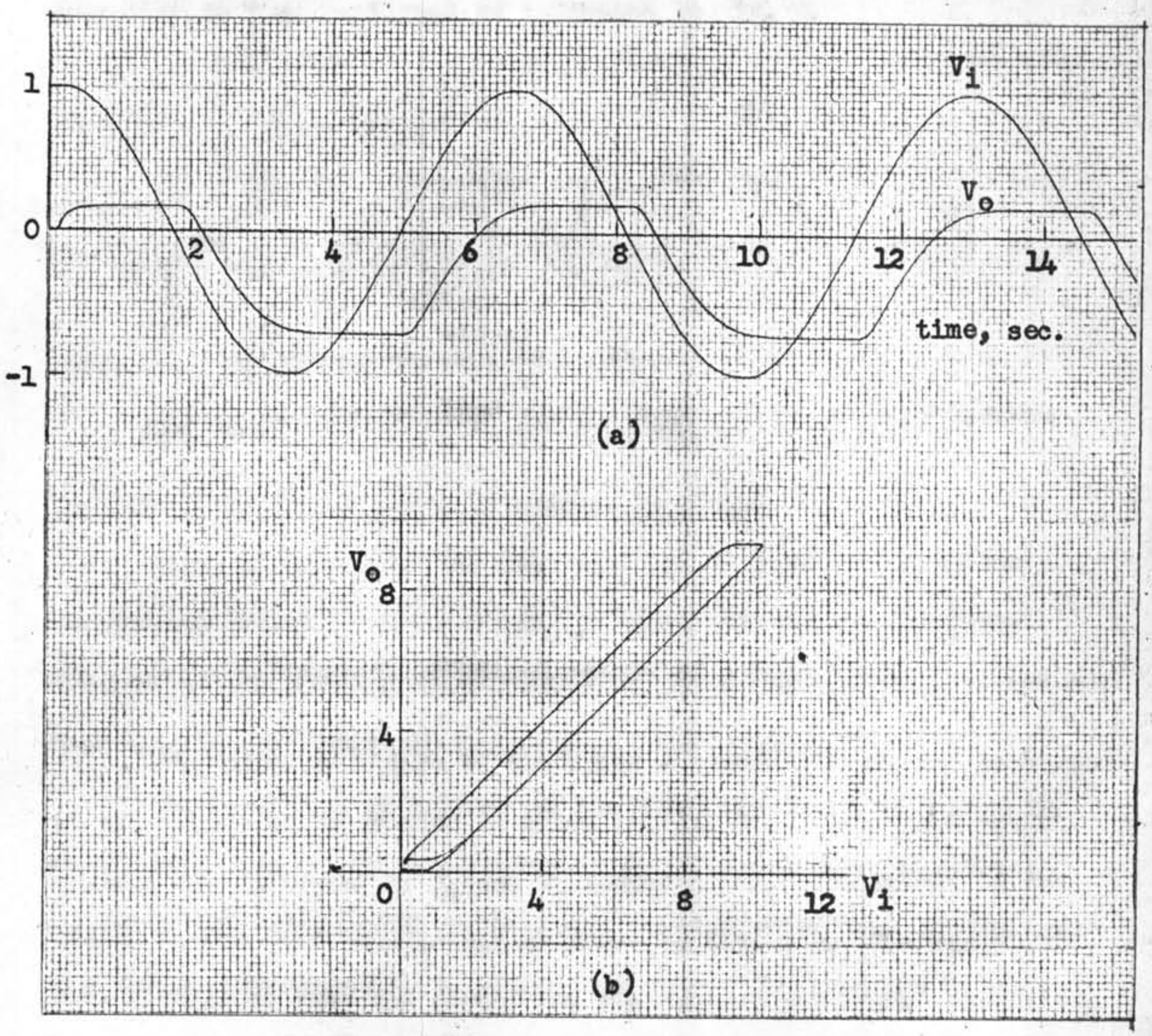

Figure 9. Physical nature of speed - governor dead band in the system to be studied.

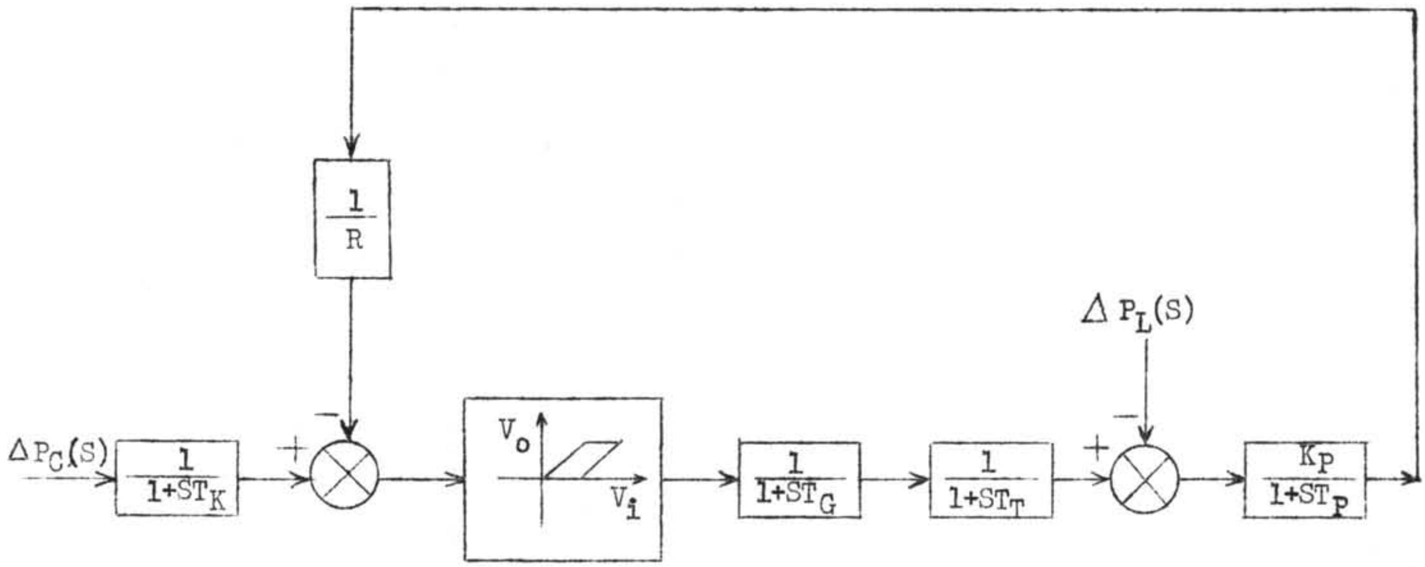

Figure 10. An isolated system model with speed - governor dead band.