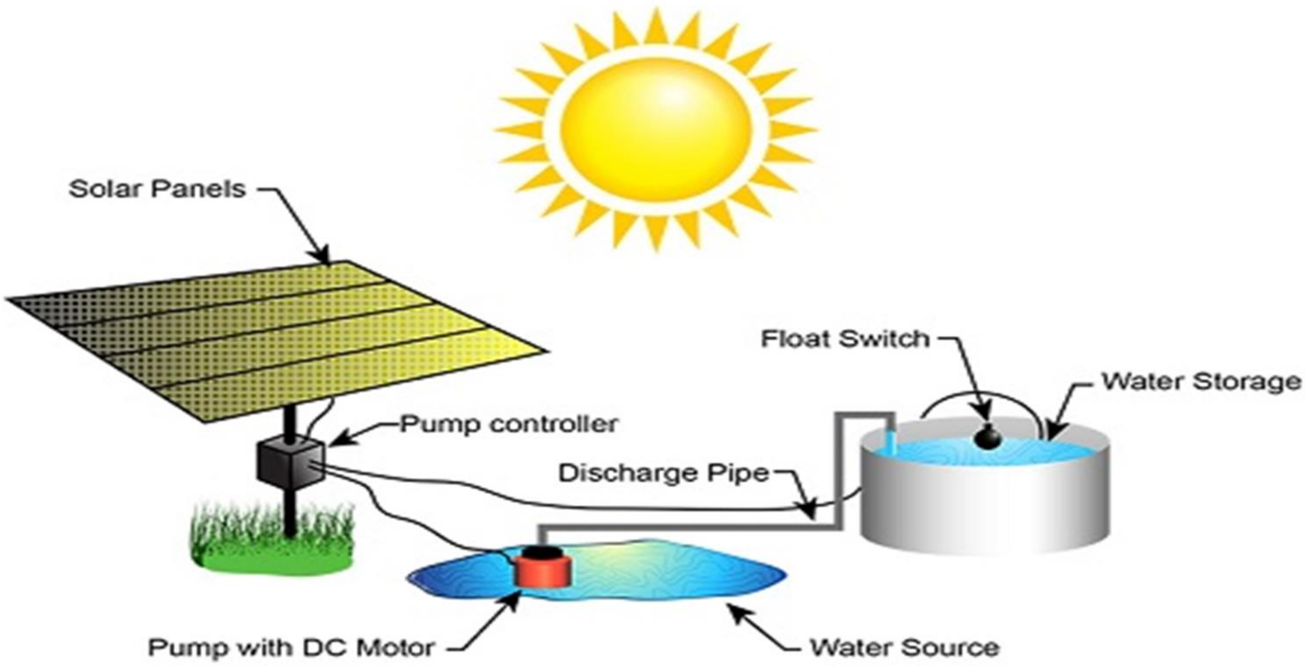


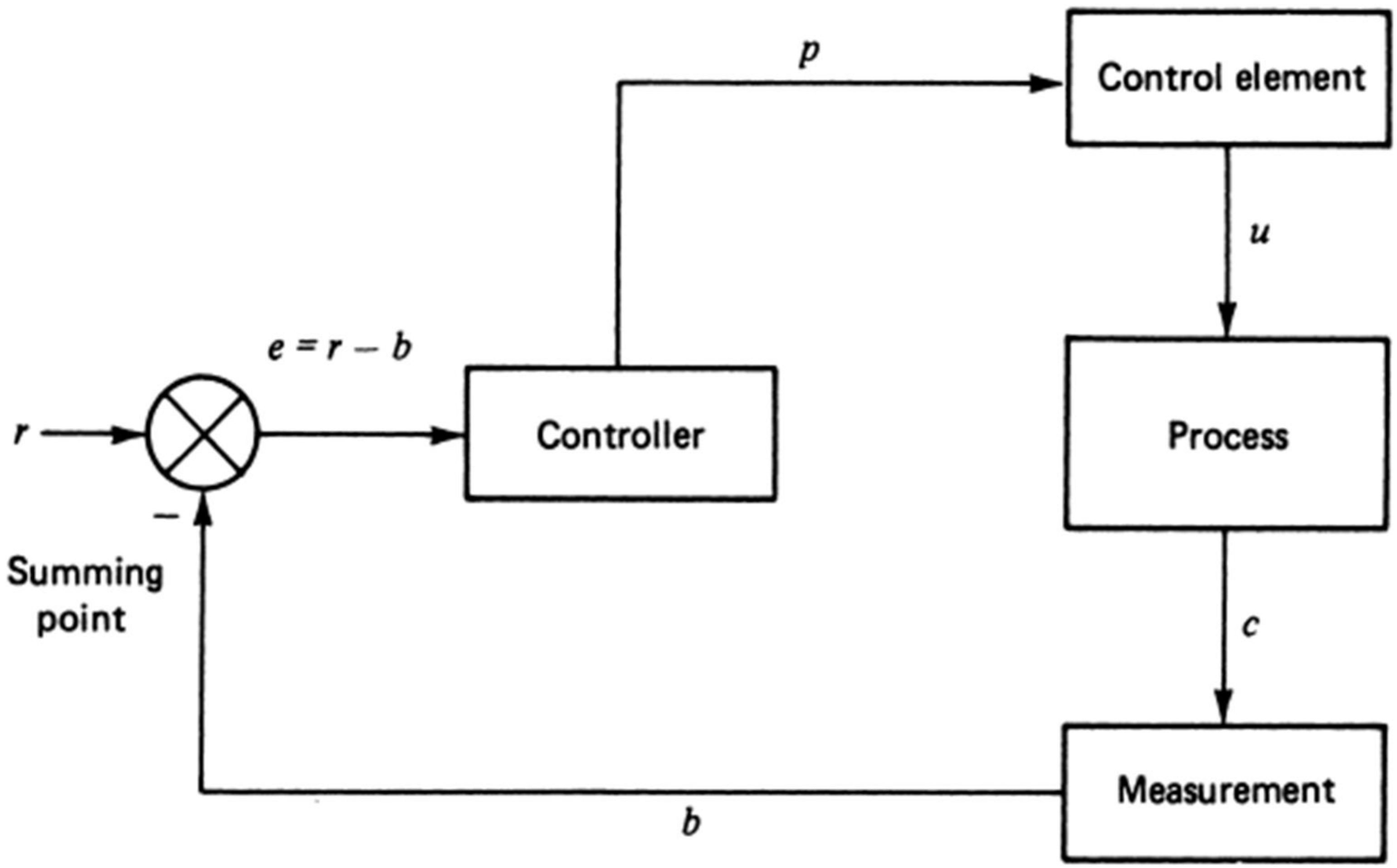
Control System

Control Action

Content

- Review of Last Lecture.
- Process Control System.
- Discontinuous Mode Control action.
- Continuous Mode Control action
- Composite Controllers

Process Control System

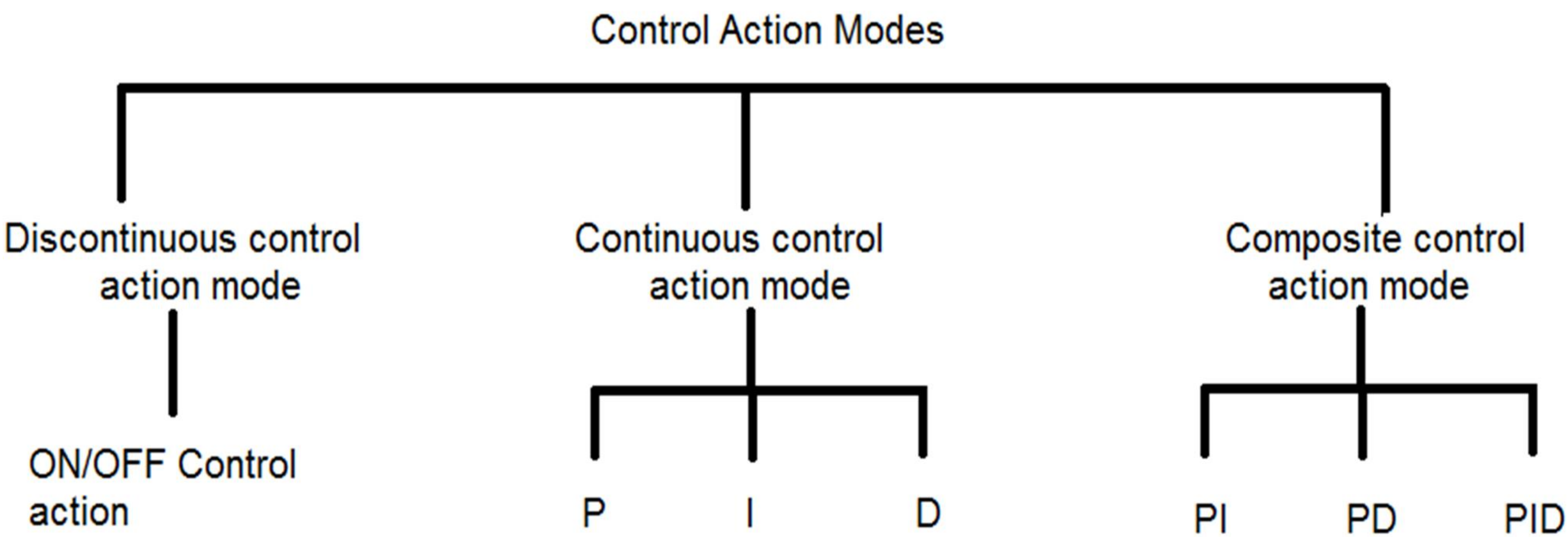


Process Control System

- The controlled variable in the process is denoted by c and the measured representation of the controlled variable is labeled b.
- Controller uses the error input to determine an appropriate output signal, p, which is provided as input to the control element.
- The control element operates on the process by changing the value of the controlling process variable, u.
- The error detector is a subtracting-summing point that outputs an error signal, $e = r - b$, to the controller for comparison and action.

Control Action

- An automatic controller compares actual value of plant output with desired value, determines the deviation and produces a control signal which will reduce deviation to zero or to small value. The manner in which automatic controller produces control signal is called control action.



Related terms

- ✓ **Continuous Controller:** Controller that responds to continuous input variables are called continuous controller.
- ✓ **Discrete Controller:** Controller that responds to discrete signal are called discrete controllers.
- ✓ **Process Equation:** A process equation describes the mathematical relationship among the input and output variables.

Related terms

- ✓ **Control Lag :** Control lag refers to the time for the process control loop to make necessary adjustment to the final control element.
- ✓ **Dead Time :** Another time variable associated with process control is a function of both process control system and the process. This is the elapsed time between the instant of deviation (error) occurs and when the corrective action first occurs.
- ✓ **Cycling :** Oscillation of error about the zero value. This means the dynamic variable cycling above and below the set point. For cycling we are interested in amplitude and period of oscillation.

Two-Position or ON/OFF Controller

- In this, changes in input error signal there is a discontinuous changes in controller output

- When error signal e(t) is greater than set point r(t) i.e. reference point, the output u(t) of controller is zero (OFF).

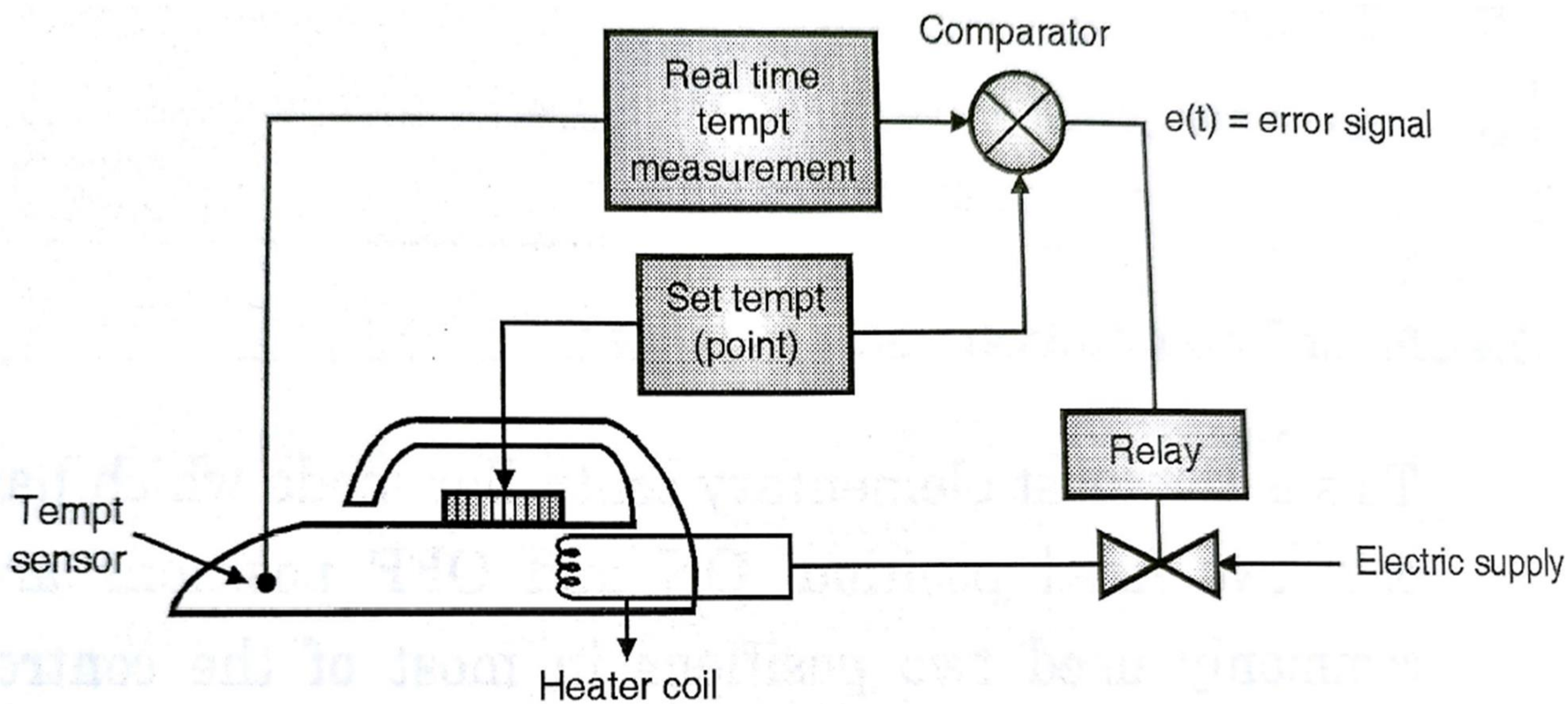
- When the error signal is less than set point the output is maximum (ON).

- Mathematically it is given by;

$$u(t) = 0\%(\text{OFF}) \quad \text{for } e(t) > 0$$

$$u(t) = 100\%(\text{ON}) \quad \text{for } e(t) < 0$$

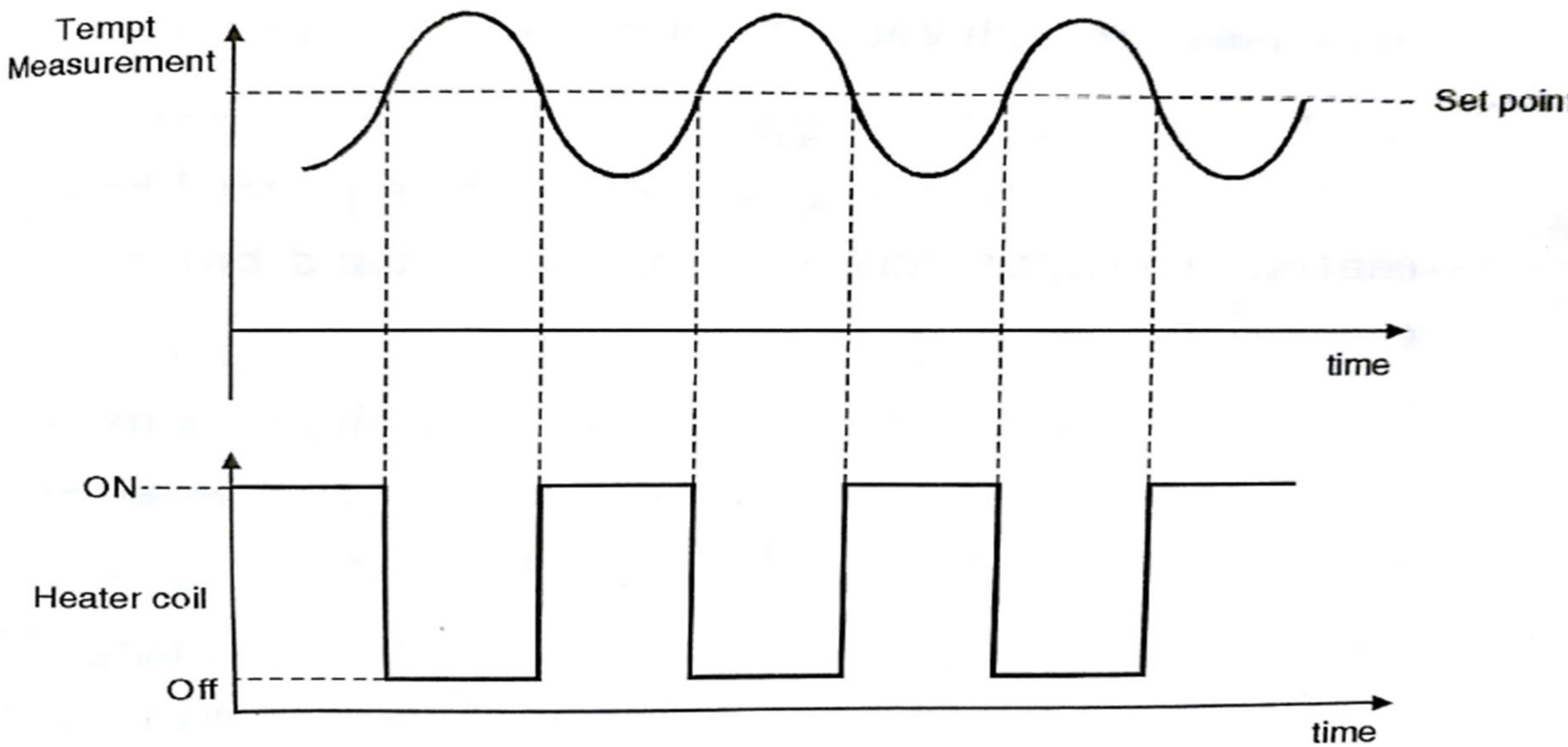
Two-Position or ON/OFF Controller



Electric iron , an example of ON/OFF control action, in this case only two stages of output are possible i.e either heater coil turn ON or OFF.

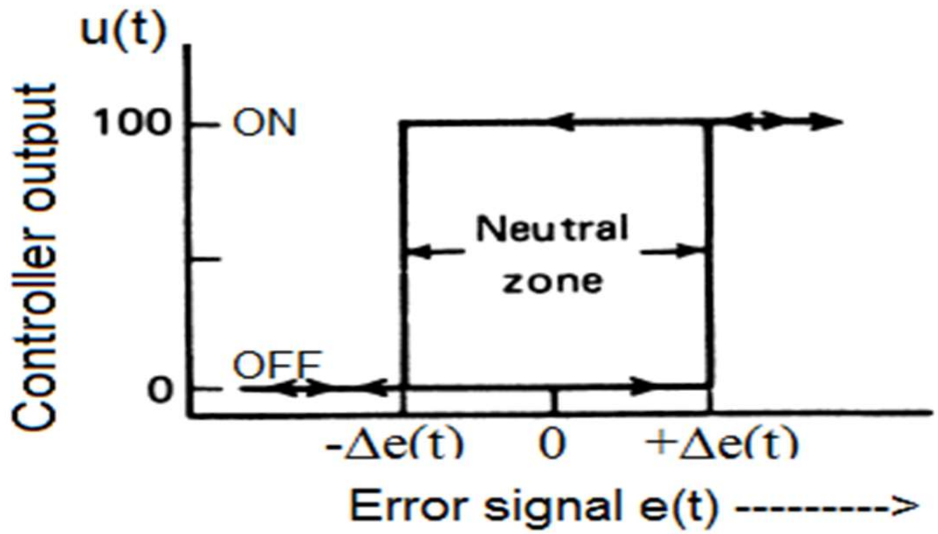
Two-Position or ON/OFF Controller

- Real time temperature is compared with set point and error signal is generated by controller to activate the relay, which will turn coil supply on/off.



Neutral Zone

- In any practical implementation of the two-position controller, there is an overlap as error signal e(t) increases through zero or decreases through zero. In this span, no change in controller output occurs.



- The range to 2Δe(t), which is referred to as the neutral zone or differential gap, is often purposely designed above a certain minimum quantity to prevent excessive cycling.

Proportional Control Mode

- In multiple-step modes, more divisions of controller outputs versus error are developed.

- Natural extension of this concept is the proportional mode, where a smooth, linear relationship exists between the controller output and the error.

- Range of error to cover the 0% to 100% controller output is called the proportional band, Since one-to-one correspondence exists only for errors in this range.

Proportional Control Mode

- This mode can be expressed by,

$$P = K_P\, e(t) + p_0.$$

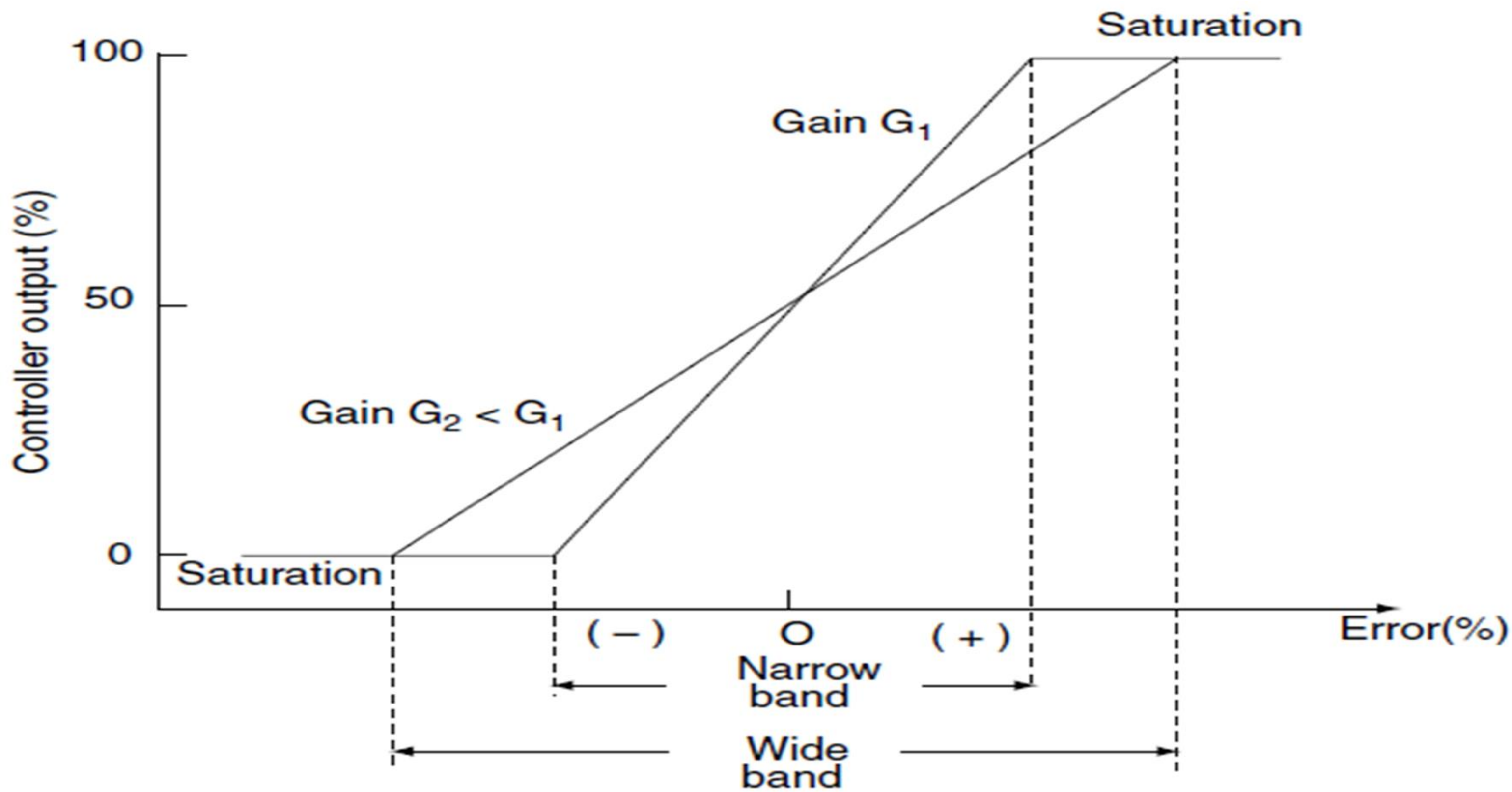
Where, K_P - proportional gain between error and controller output (% per %).

p_0 - controller output with no error (%).

- If measured value b increases above the setpoint r, the error e(t) will be negative and the output will decrease. That is, the term KP e(t) will subtract from p0 . Thus, above equation represents reverse action.

- Direct action would be provided by putting a negative sign in front of the correction term.

Proportional Control Mode



- Here, p_0 has been set to 50% and two different gains have been used. Note that the proportional band is dependent on the gain.

Characteristic of Proportional Control Mode

- In general, the proportional band is defined by the equation,

$$PB = 100/K_P.$$

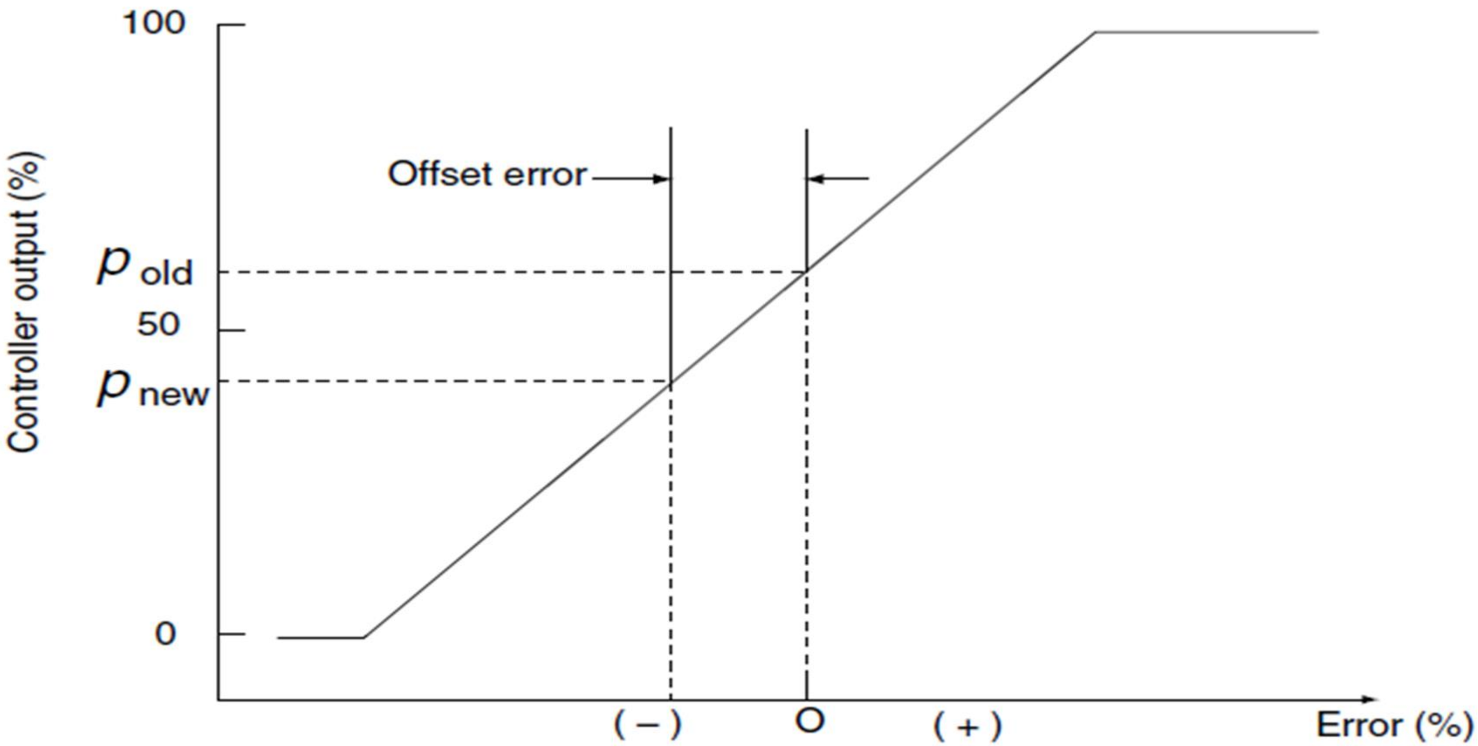
1. If the error is zero, the output is a constant equal to p0 .

2. If there is error, for every 1% of error, a correction of Kp percent is added to or subtracted from p0, depending on the sign of the error.

3. There is a band of error about zero of magnitude PB within which the output is not saturated at 0% or 100%.

Offset

- Proportional control mode produces a permanent residual error in the operating point of the controlled variable when a change in load occurs. This error is referred to as **offset**



Integral-Control Mode

- Integral mode eliminates offset problem by allowing the controller to adapt to changing external conditions by changing the zero-error output.

- Need for integral action shows up when it is noted that even with proportional action correction, the error does not go to zero in time.

- Integral action is provided by summing the error over time, multiplying that sum by a gain, and adding the result to the present controller output.

Integral-Control Mode

- If the error makes random excursions above and below zero, the net sum will be zero, so the integral action will not contribute.

- If the error becomes positive or negative for an extended period of time, the integral action will begin to accumulate and make changes to the controller output.

- Mode is represented by an integral equation,

$$P(t) = K_I \int e(t)\,dt + p(0)$$

where , p(0) - controller output when the integral action starts.

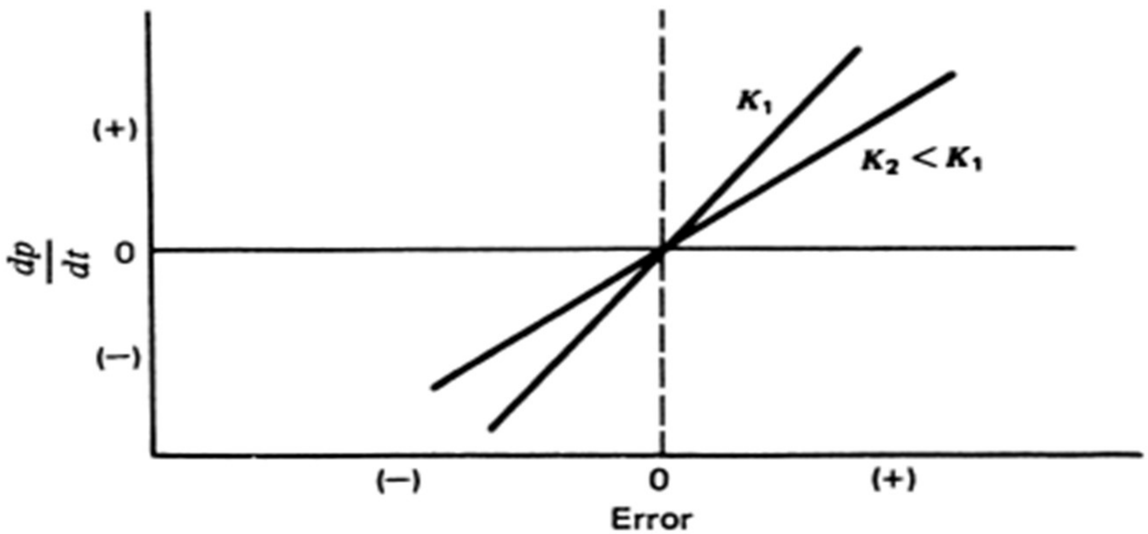
KI - Gain for every percent-time accumulation of error.

Integral-Control Mode

- Another way of thinking of integral action is found by taking the derivative of above equation.

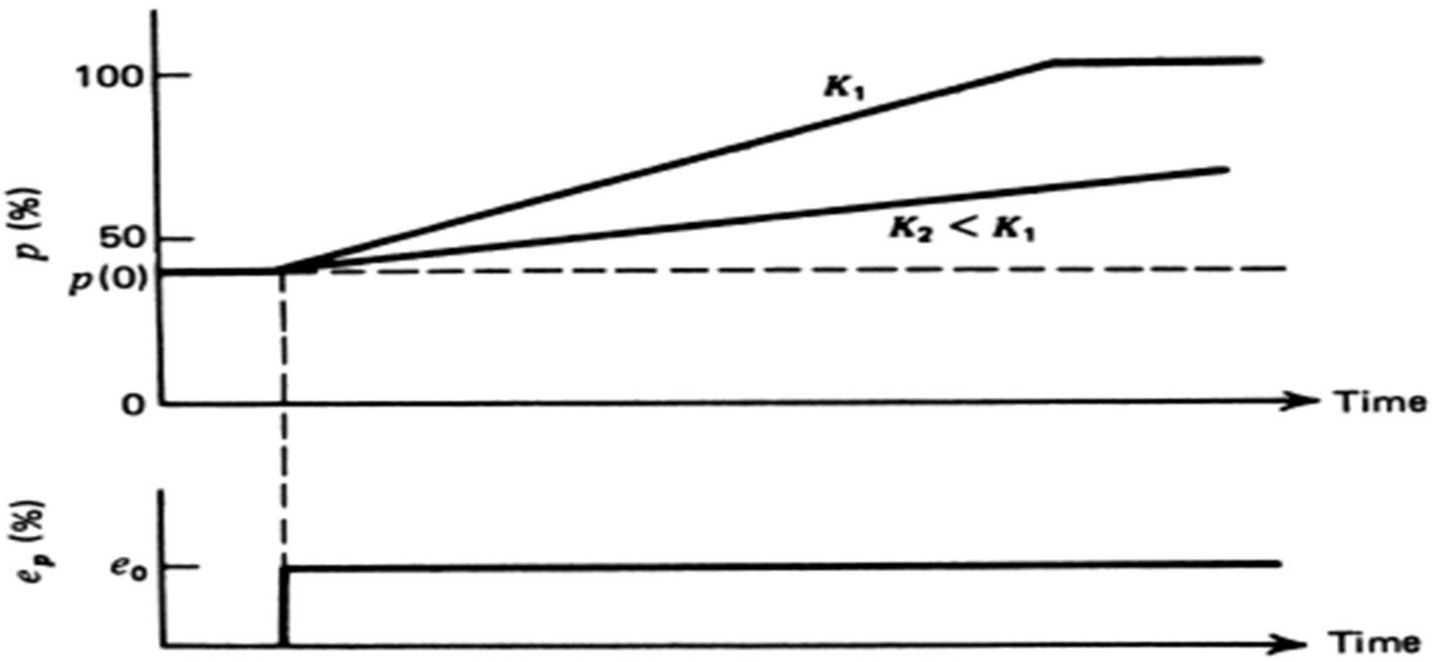
$$dp/dt = KI\ e(t)$$

- Here, controller begins to increase (or decrease) its output at a rate that depends upon the size of the error and the gain.



(a)

Integral-Control Mode



(b)

- Controller output begins to ramp up at a rate determined by the gain. In the case of gain , the output finally saturates at 100%, and no further action can occur.

Characteristics of Integral Mode

1. If the error is zero, the output stays fixed at a value equal to what it was when the error went to zero.

2. If the error is not zero, the output will begin to increase or decrease at a rate of KI percent/second for every 1% of error.

Derivative-Control Mode

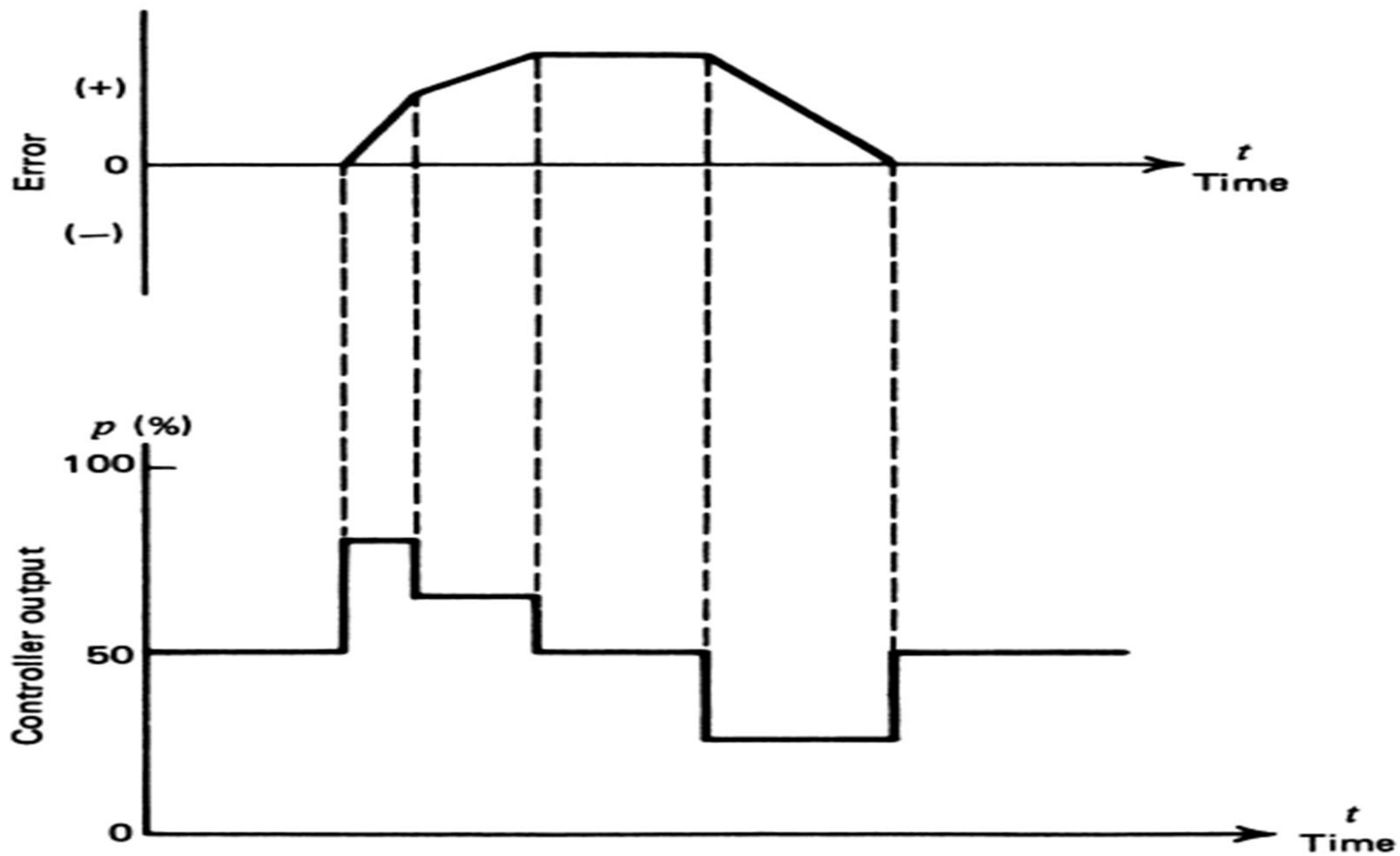
- Derivation controller action responds to the rate at which the error is changing— that is, the derivative of the error.

- Equation for this mode is given by the expression,

$$P(t) = KD\ de(t) / dt$$

- Derivative action is not used alone because it provides no output when the error is constant.

Derivative-Control Mode



- Derivative action is not used alone because it provides no output when the error is constant.

Derivative-Control Mode

- When the error changes very rapidly with a positive slope, the output jumps to a large value.
- When the error is not changing, the output returns to 50%.
- Finally, when the error is decreasing—that is, has a negative slope—the output discontinuously changes to a lower value.

Characteristics of Derivative Mode

1. If the error is zero, the mode provides no output.
2. If the error is constant in time, the mode provides no output.
3. If the error is changing in time, the mode contributes an output of percent for every 1%-per-second rate of change of error.
4. For direct action, a positive rate of change of error produces a positive derivative mode output.

Proportional-Integral Control (PI)

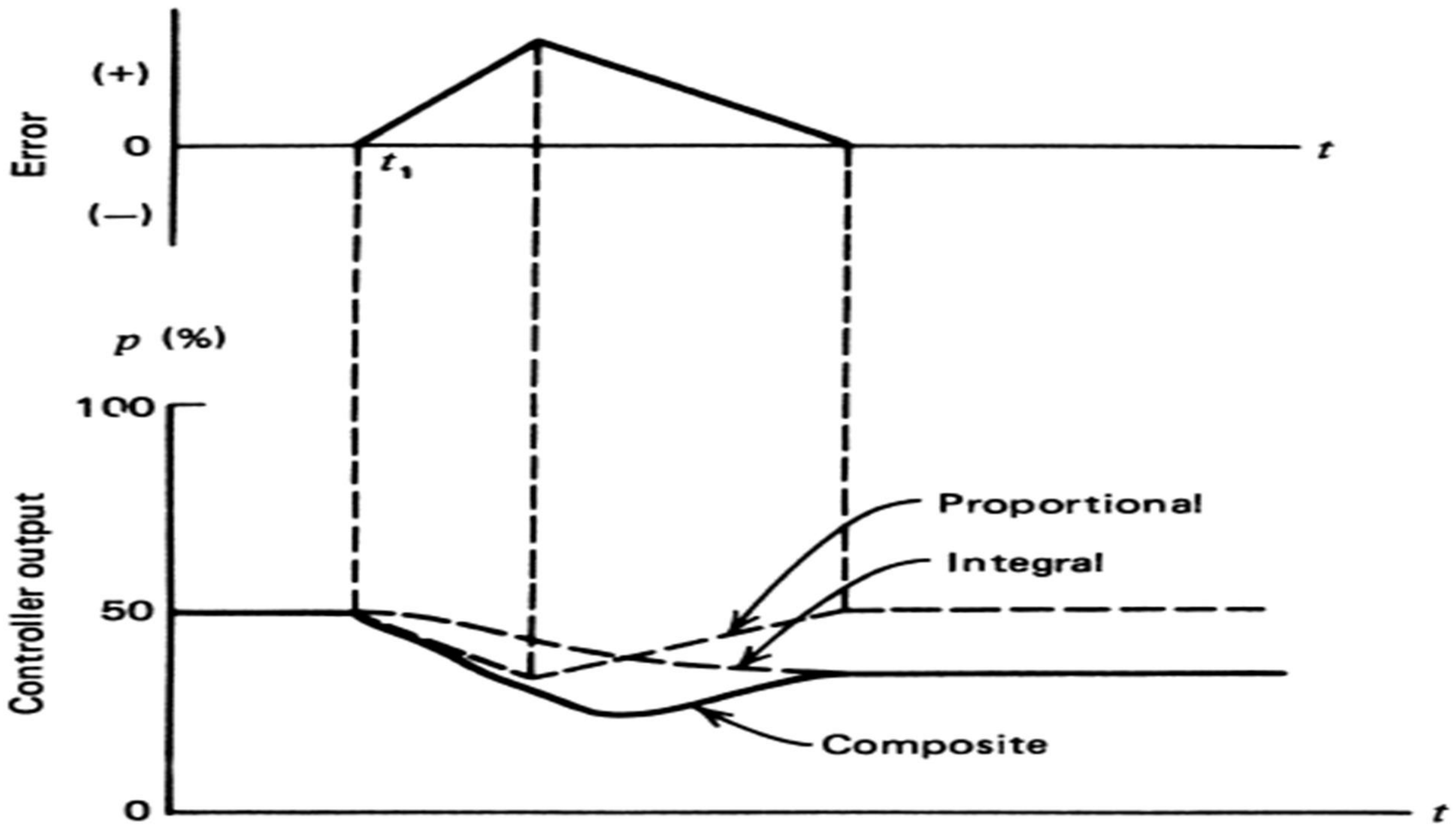
- Analytic expression for this control process is found from a series combination of Proportional equation and Integral equation

$$P = KP\ e(t) + KP\ KI \int e(t)\ dt + pI\ (0).$$

- Here, one-to-one correspondence of the proportional mode is available and the integral mode eliminates the inherent offset.

- Integral function provides the required new controller output, thereby allowing the error to be zero after a load change

Proportional-Integral Control (PI)



Characteristics of the PI Mode

1. When the error is zero, the controller output is fixed at the value that the integral term had when the error went to zero. This output is given by pI(0) .

2. If the error is not zero, the proportional term contributes a correction, and the integral term begins to increase or decrease accumulated value [initially, pI(0)], depending on the sign of the error and the direct or reverse action.

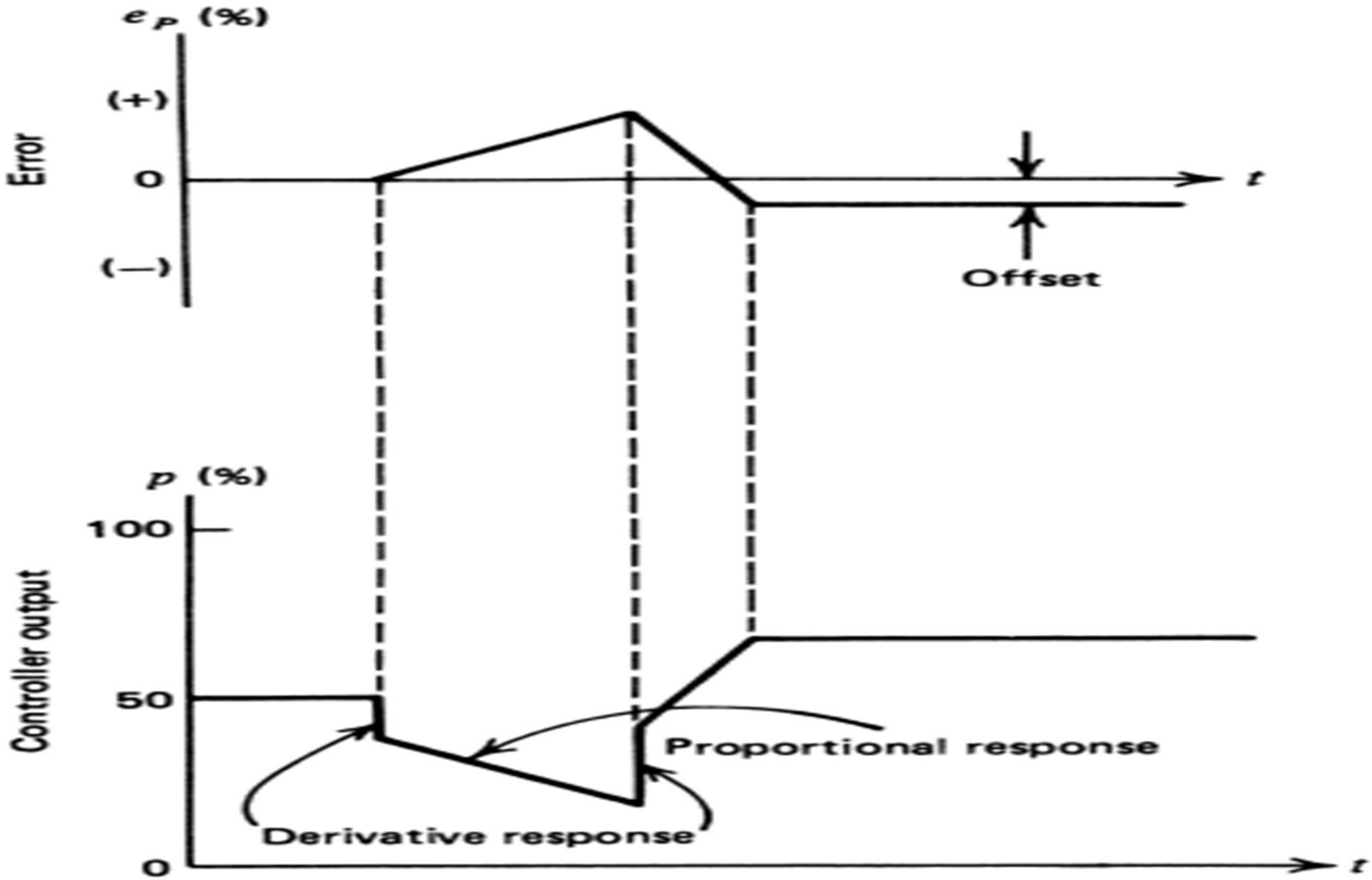
Proportional-Derivative Control (PD)

- Analytic expression for this control process is found from a series combination of Proportional equation and Derivative equation

$$P = KP\ e(t) + KP\ KD\ \ de(t)\ /\ dt + p\ (0).$$

- Here, system cannot eliminate the offset of proportional controllers. It can, however, handle fast process load changes as long as the load change offset error is acceptable.

Proportional-Derivative Control (PD)



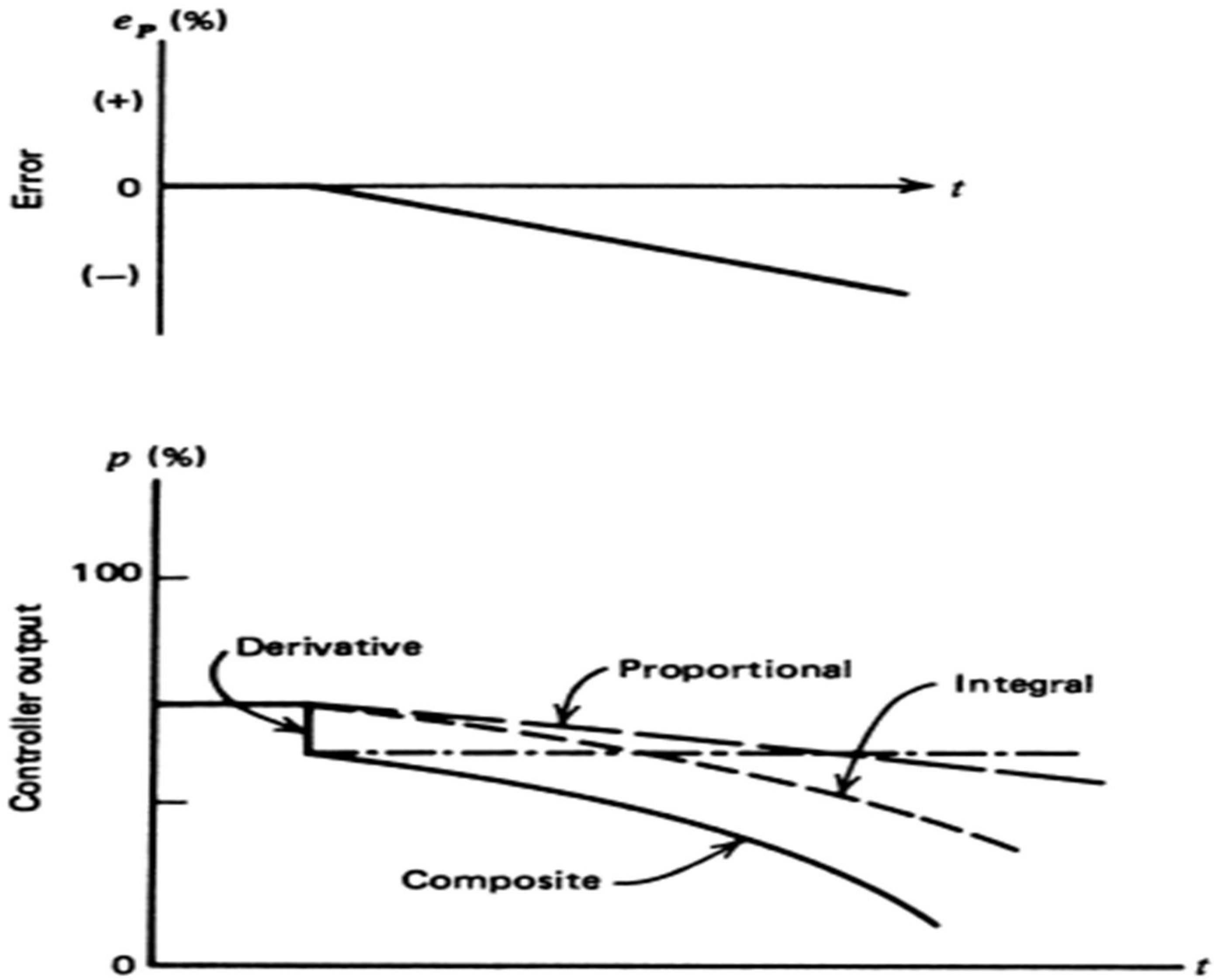
Proportional-Integral-Derivative Control (PID)

- Analytic expression for this control process is found from a series combination of Proportional equation ,Integral equation and Derivative equation

$$P = KP\ e(t) + KP\ KI \int e(t)\ dt + KP\ KD\ \ de(t) / dt + pI\ (0).$$

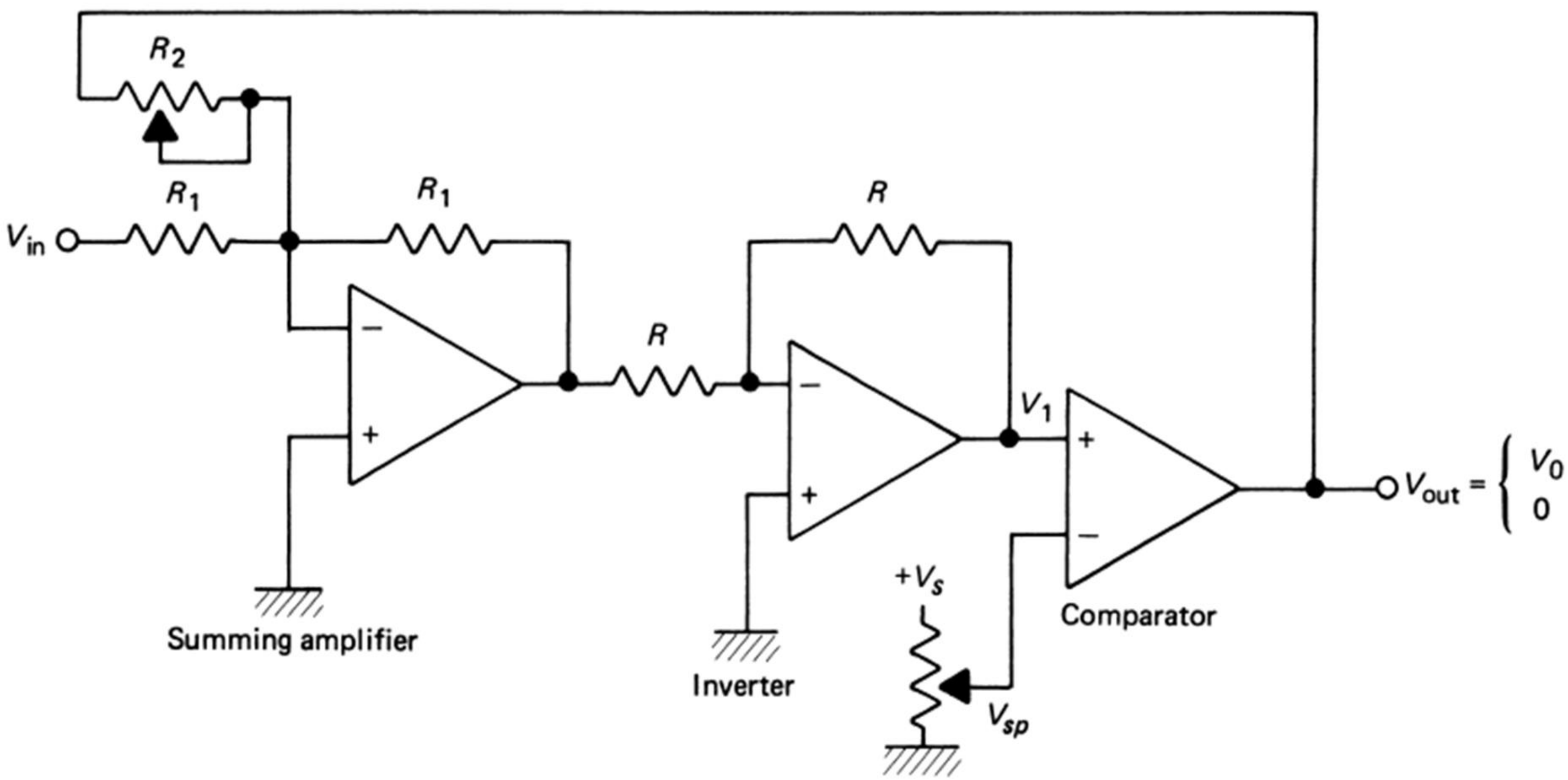
- Here, this mode eliminates the offset of the proportional mode and still provides fast response.

Proportional-Integral-Derivative Control (PID)



Electronic On/Off Controller

- Method using op amp implementation of ON/OFF control with adjustable neutral zone is designed.



Electronic On/Off Controller

- If the controller input voltage, V, reaches a value VH, then the comparator output should go to the ON state.

- When the input voltage falls below a value VL, the comparator output should switch to the OFF state.

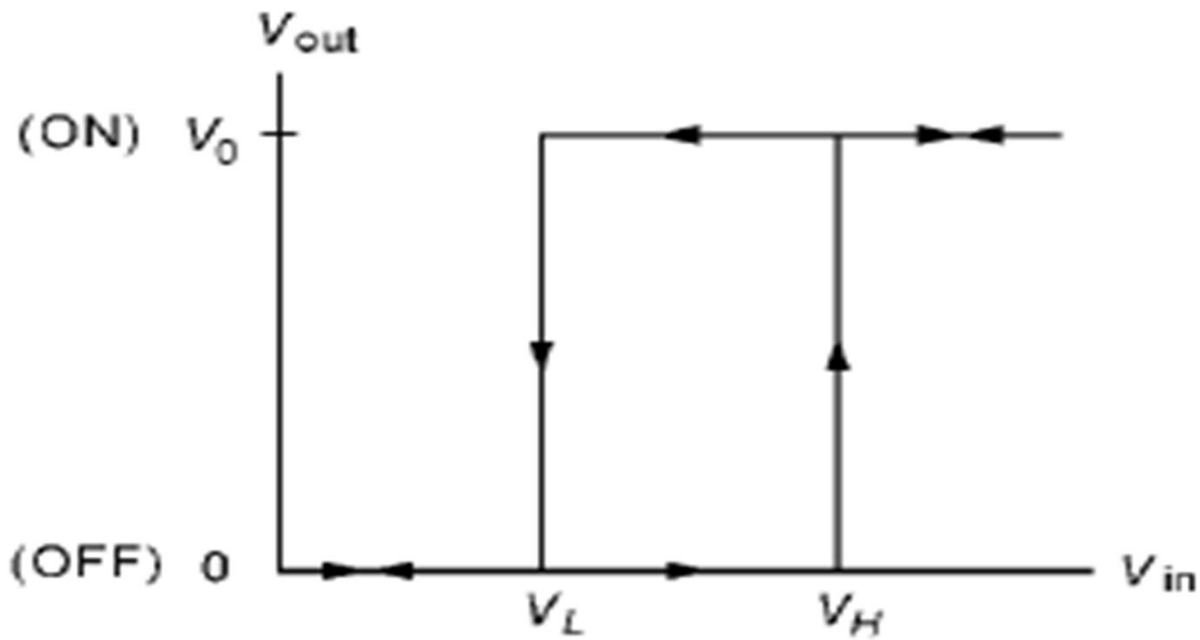
- Analysis of this circuit shows that the high (ON) switch voltage is,

$$V_H = V_{SP}$$

- Low (OFF) switching voltage is,

$$V_L = V_{SP} - (R_1/R_2)\,V_0$$

Electronic On/Off Controller

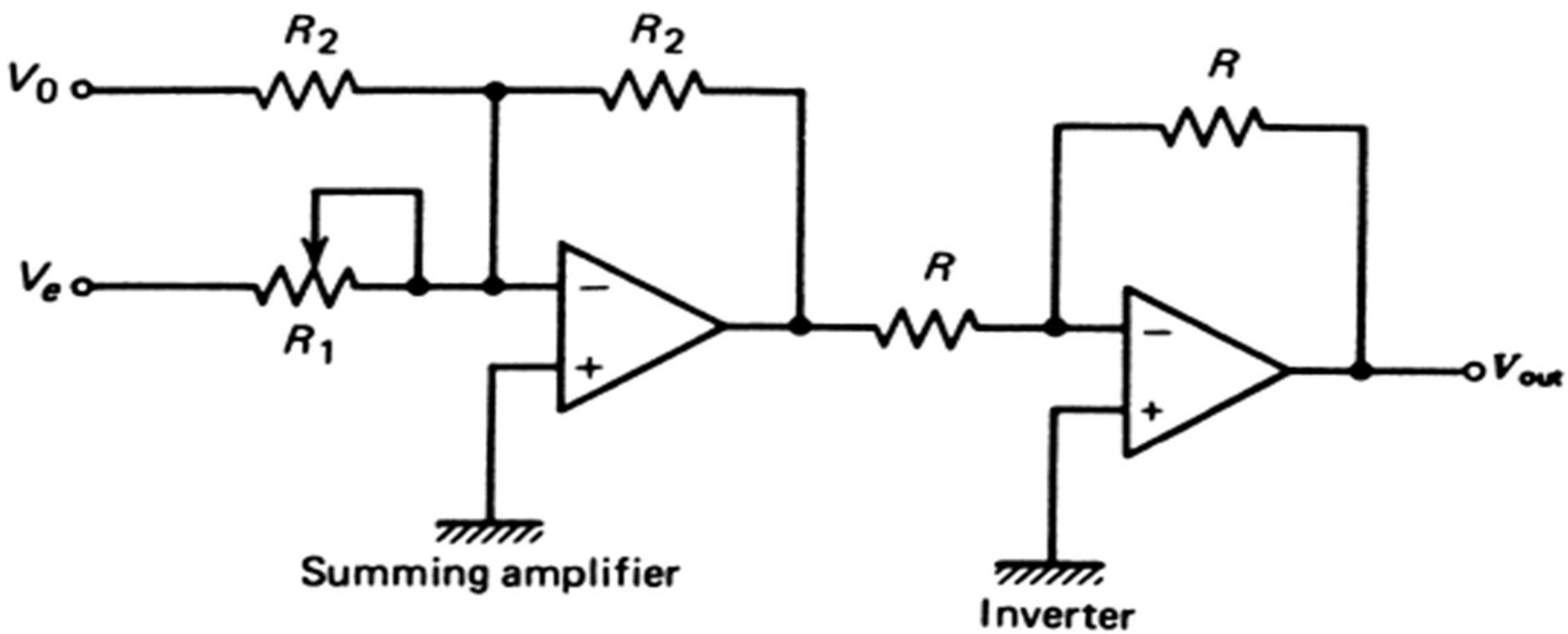


- The width of the neutral zone between VH and VL can be adjusted by variation of R2. The relative location of the neutral zone is calculated from the difference between equations
-

Electronic P Controller

- Implementation of this mode requires a circuit that has a response given by

$$P = KP\ e(t) + p0$$



Electronic P Controller

- For an electronic proportional controller, the analog electronic equation for the output voltage is

$$V_{out} = G_P V_e + V_0$$

Where, V_{out} = output voltage

$G_P = R2/R1$ = gain

V_e = error voltage

V_0 = output with zero error

- The relationship between GP and K is given by,

$$G_P = K_P (\Delta V_{out} / \Delta V_m)$$

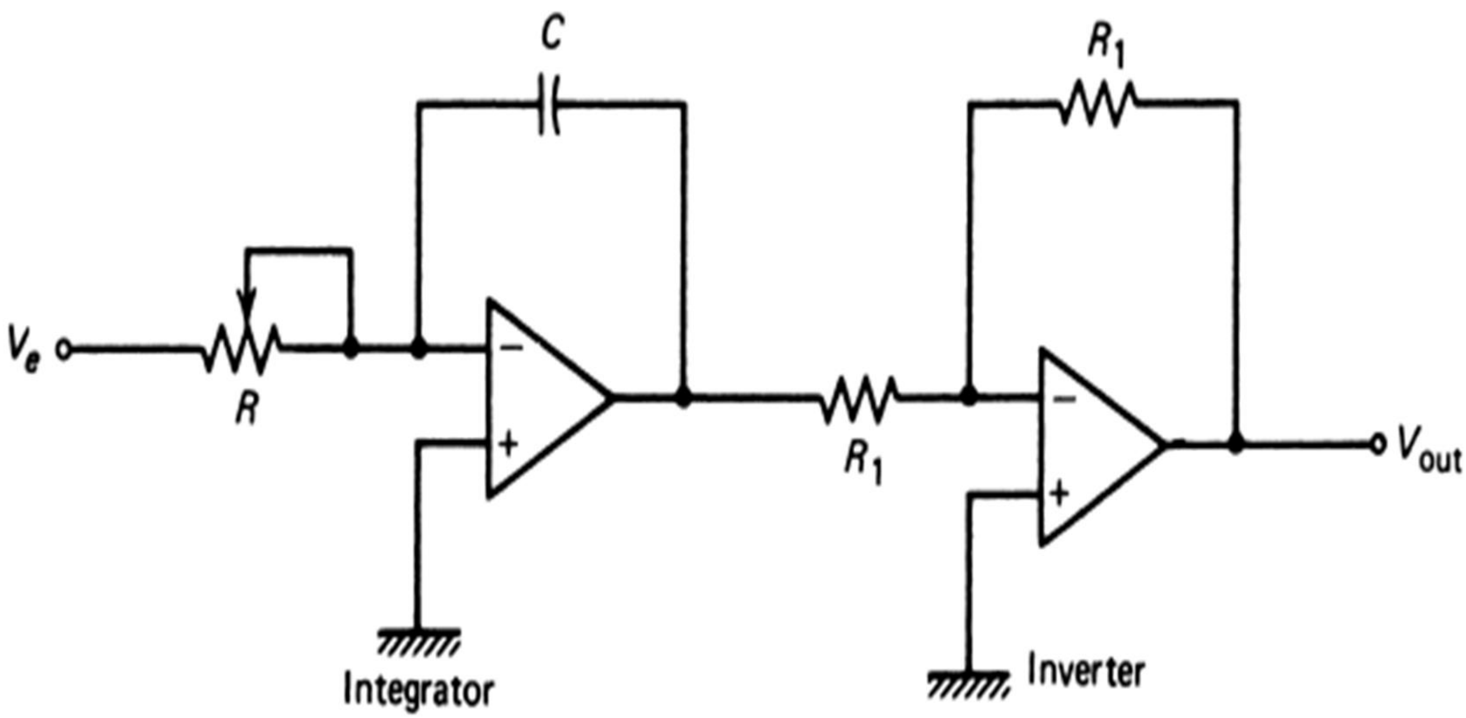
Where, V_{out} - the range of output voltage

V_m - the range of measurement voltage

Electronic I Controller

- Integral mode was characterized by an equation of form,

$$P(t) = KI \int e(t)\, dt + p(0)$$



Electronic I Controller

- The corresponding equation relating input to output is

$$Vout = GI \int Ve\, dt + Vout\ (0)$$

Where,

Vout = output voltage

GI = 1/RC = integration gain

Ve = error voltage

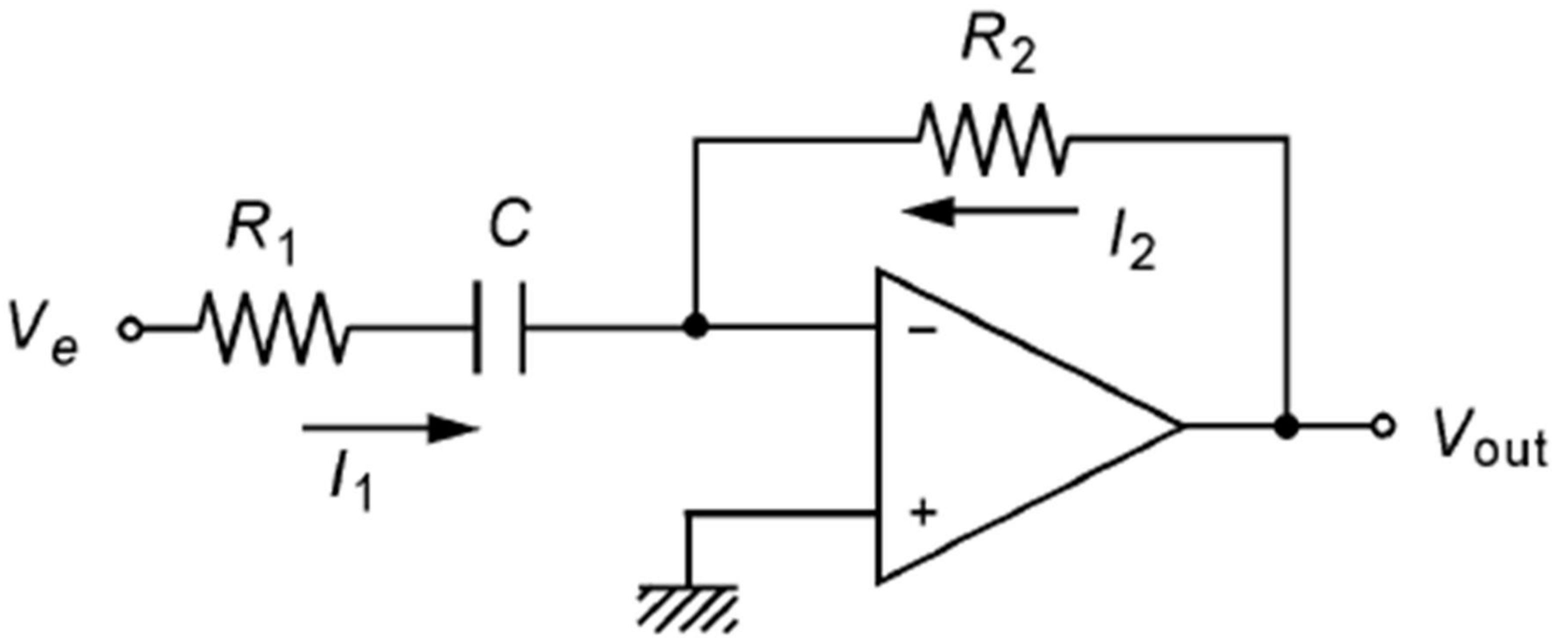
Vout (0) = initial output voltage

- The values of R and C can be adjusted to obtain the desired integration time. The initial controller output is the integrator output at t=0
- Integration time constant determines the rate at which controller output increases when the error is constant.

Electronic D Controller

- Derivative mode was characterized by an equation of form,

$$P(t) = KD\ de(t) / dt$$



Electronic D Controller

- The corresponding equation relating input to output is

$$Vout = -RC\ dVe/dt$$

Where,

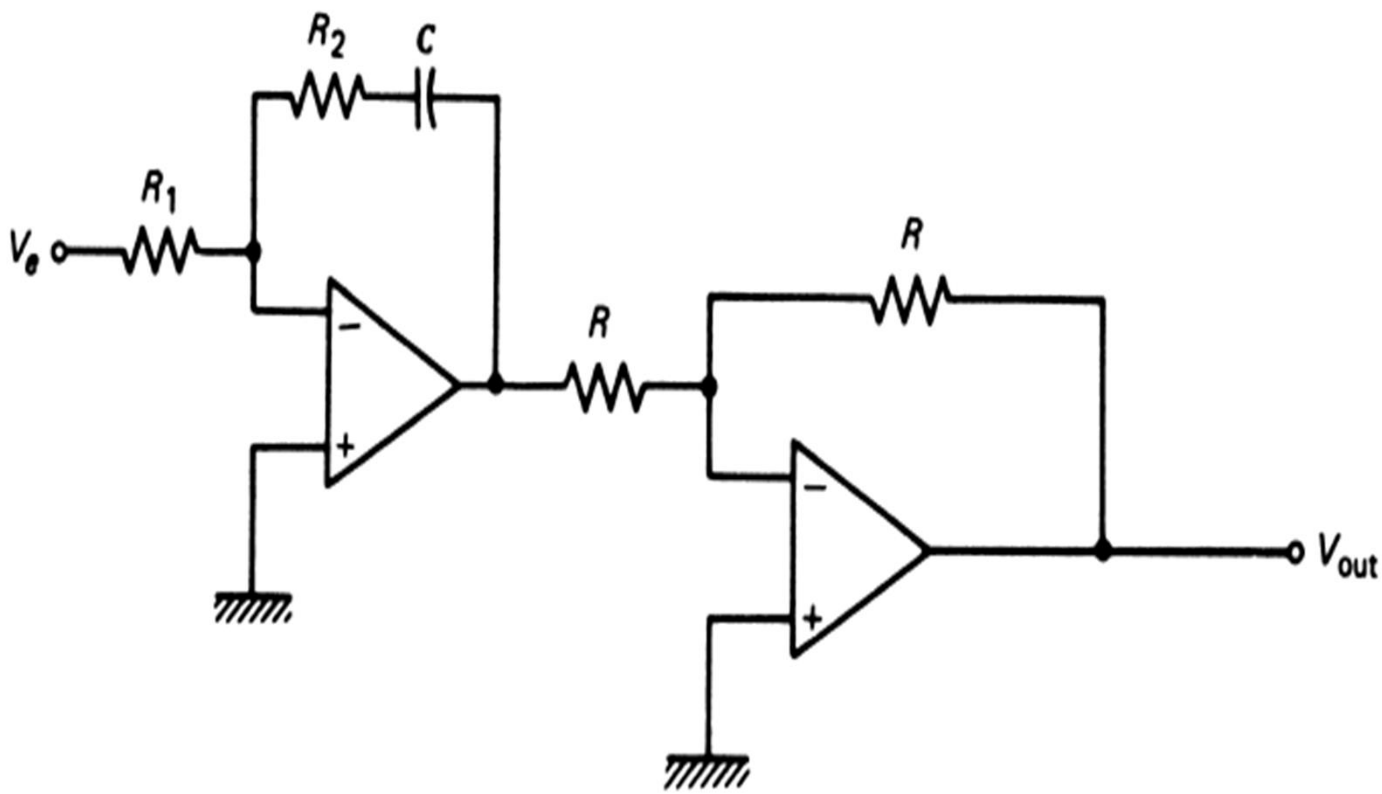
Vout = output voltage

Ve = error voltage

- where the input voltage has been set equal to the controller error voltage.

Electronic PI Controller

- Simple combination of the proportional and integral circuits provides the proportional-integral mode of controller action



Electronic PI Controller

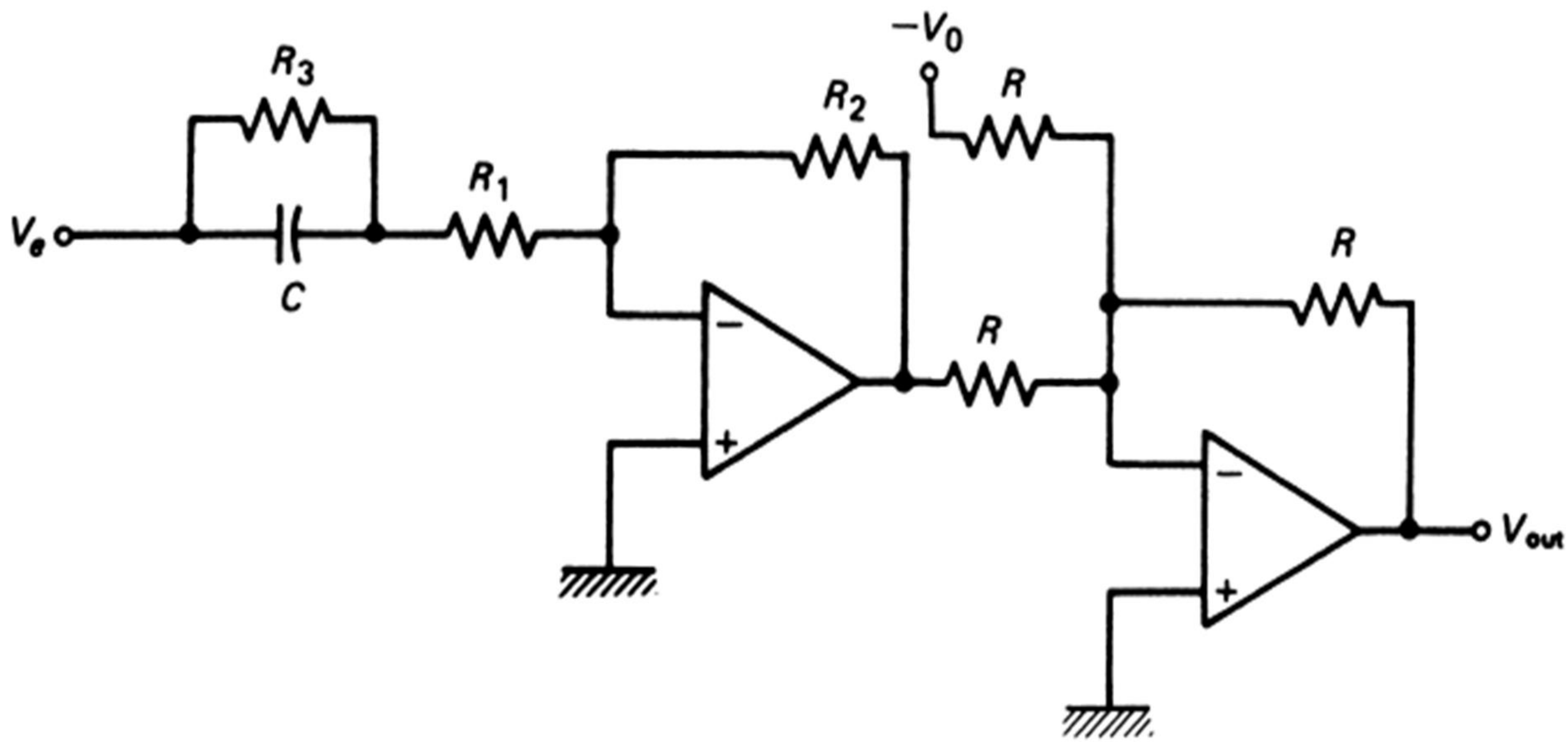
- The relation between input and output is most easily found by applying op amp circuit analysis,

$$V_{out} = \left(\frac{R_2}{R_1}\right) V_e + \left(\frac{R_2}{R_1}\right) \frac{1}{R_2 C} \int_0^t V_e \, dt + V_{out}(0)$$

- The adjustments of this controller are the proportional band through GP=R2/R1 , and the integration gain through GI=1/R2C .

Electronic PD Controller

- Powerful combination of controller modes is the proportional and derivative modes, is implemented using a circuit



Electronic PD Controller

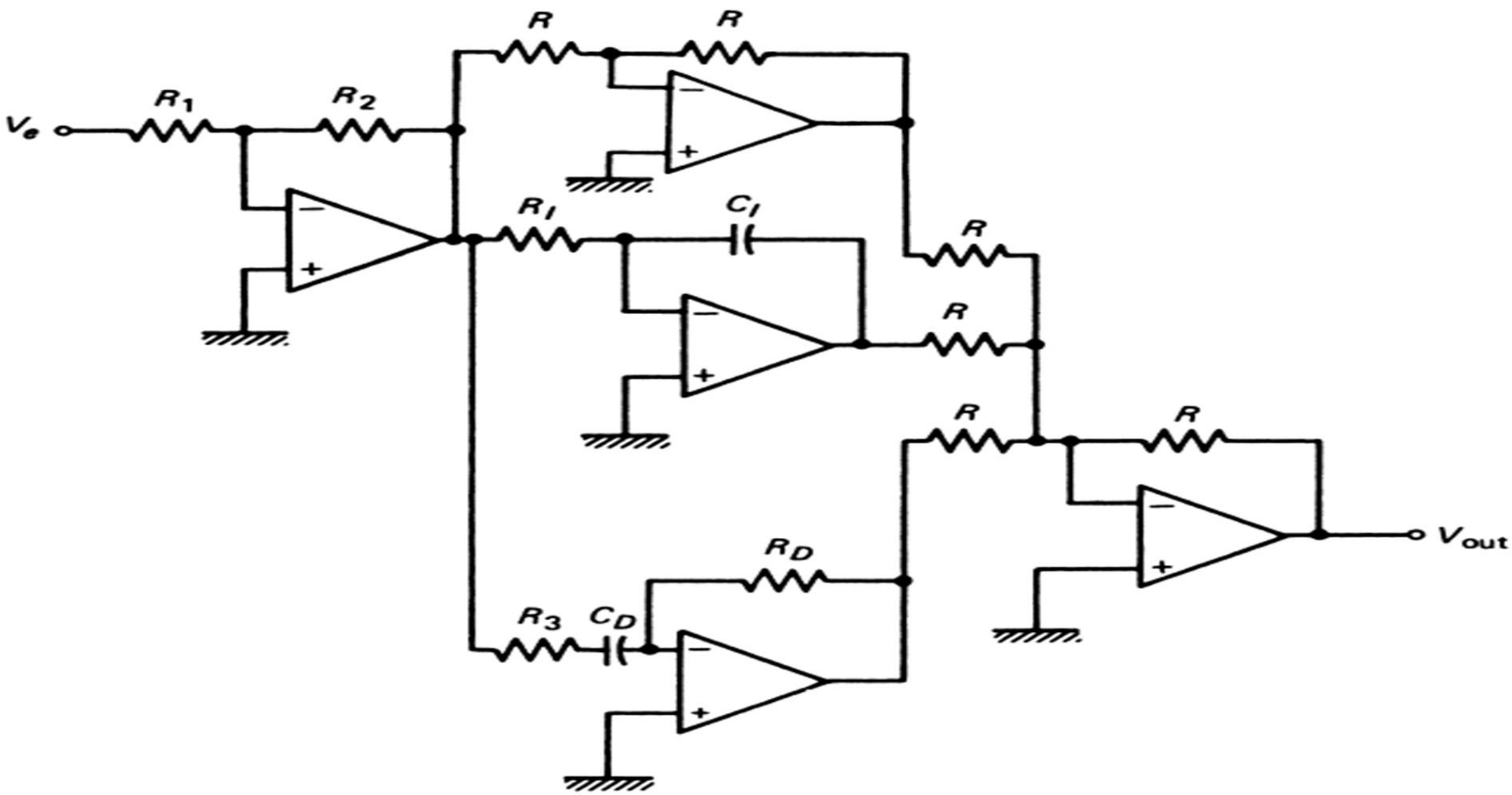
- The relation between input and output is most easily found by applying op amp circuit analysis,

$$V_{out} = \left(\frac{R_2}{R_1 + R_3}\right) V_e + \left(\frac{R_2}{R_1 + R_3}\right) R_3 C \frac{dV_e}{dt} + V_0$$

- The adjustments of this controller are the proportional band through GP=R2/ (R1 + R3) , and the derivative gain through GD=R3C .

Electronic PID Controller

- Ultimate process controller, exhibits proportional, integral, and derivative response to the process-error input.



Electronic PID Controller

- Analysis of the circuit shows that the output is

$$-V_{out} = \left(\frac{R_2}{R_1}\right)V_e + \left(\frac{R_2}{R_1}\right)\frac{1}{R_I C_I}\int V_e\,dt + \left(\frac{R_2}{R_1}\right)R_D C_D\frac{dV_e}{dt} + V_{out}(0)$$

- Where R3 has been chosen from 2πfmaxRC= 0.1 for stability

GP=R2/R1, GI=1/RICI and GD=RDCD

Summary

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