Unit 2

COMPONENTS OF CONTROL SYSTEM

BY

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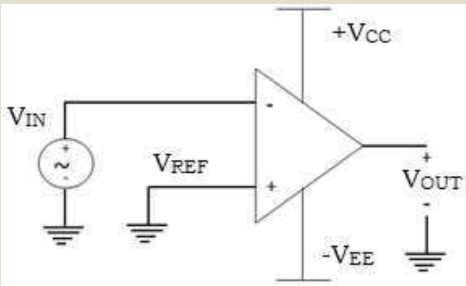
Introduction :

first unit was presented the various classification of control system and principles of various controller modes, advantages, disadvantages and applications of each controller modes. The aim of this chapter is to understand the realization of op-amp based circuits in the industrial processes control. In this chapter, you will learn the designing of the op-amp circuit that will carry out the proportional integral, proportional derivative, and proportional integral derivative control modes.

An **operational amplifier** (often **op-amp** or **opamp**) is DC-coupled high-gain electronic voltage amplifier with a differential, usually, a single-ended output. Operational amplifiers had their origins in analog computers. They were used in mathematical in many calculations such as linear, non-linear and frequency-dependent circuits. The popularity of the op-amp as a building block in analog circuits is due to its versatility. Due to negative feedback, the characteristics of an op-amp circuit, its gain, input and output impedance, bandwidth etc. Op-amps are among the most widely used electronic devices today, being used in a vast array of consumer, industrial, and scientific devices.

1.1 Zero crossing detector

When the op-amp used in open loop configuration its output is usually one of its saturation state. A comparator is a circuit which gives the output when a varying signal reaches to some threshold value. In zero crossing detector this reference value is 0V.



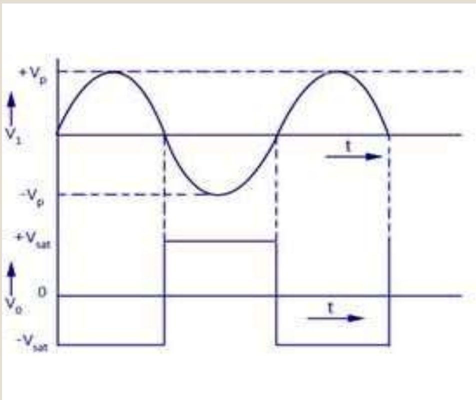
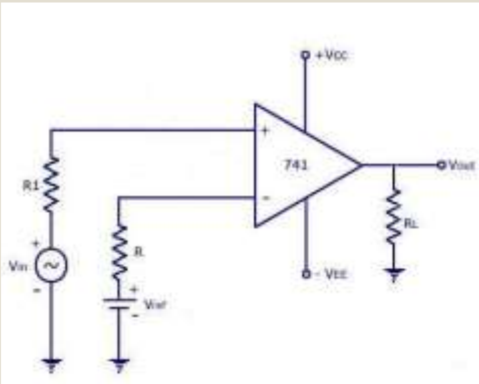


Figure 2.1(a). Zero Crossing Detector   Figure 2.1(b). Input output waveforms

When the input waveform crosses zero value and becomes the positive value, the difference voltage becomes positive and the output swings to $-V_{sat}$..when signal crosses the zero and become more negative the difference voltage becomes negative and the output swings to the $+V_{sat}$. The Zero crossing detector is also known as square wave generator.

1.2 Non inverting comparator

The figure 2.1(a) shows the non-inverting comparator. The input signal is applied the non- inverting terminal of the op-amp. When V_{IN} less than the V_{REF} the non-inverting terminal is at higher potential than the inverting terminal. The difference voltage V_{ID} is negative and the voltage swings to - V_{SAT}. when the applied voltage greater than the V_{REF} then the difference voltage V_{ID} is positive and output swings to $+V_{SAT}$. Figure 2.1(b) shows the input and output waveforms.



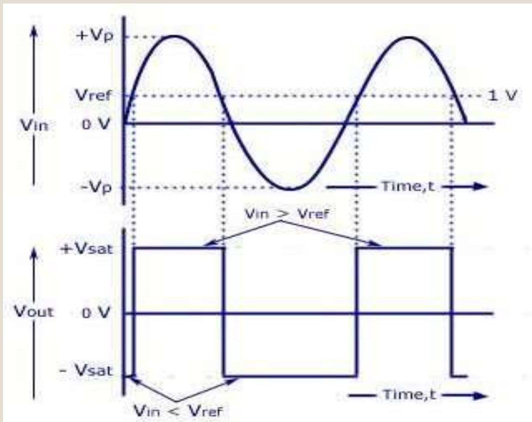
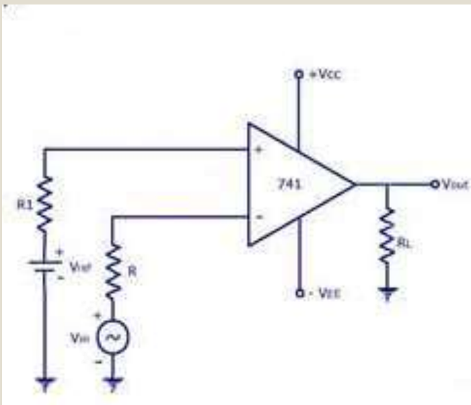


Figure 2.2(a). Non-inverting comparator   Figure 2.2(b). Input output waveforms

1.3 Inverting Comparator

Figure 2.3(a) shows the inverting comparator. Signal is applied to the inverting terminal of the op-amp. When V_{IN} is less than V_{REF}, the voltage at non-inverting terminal is higher than voltage at inverting terminal, V_{ID} difference voltage is positive the output swings to the $+V_{SAT}$. When input voltage is more than V_{IN}, difference voltage V_{ID} is negative, the output voltage swings to $-V_{SAT}$. Figure 2.3(b) shows input and output waveforms of inverting comparator.



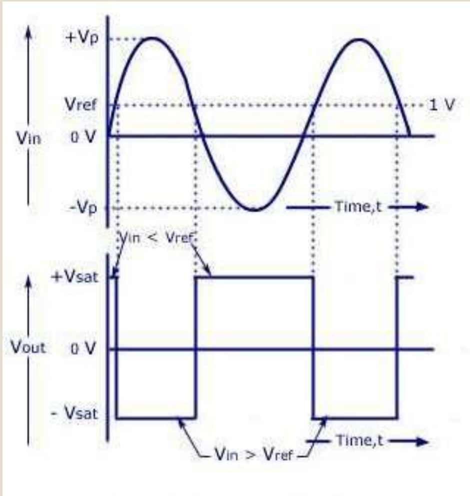


Figure 2.3(a). Non inverting comparator   Figure 2.3(b). Input output waveforms

1.4 Two Position Control Using Op-amp

Figure 2.4 shows the implementation of an ON/OFF controller using Op-Amp.

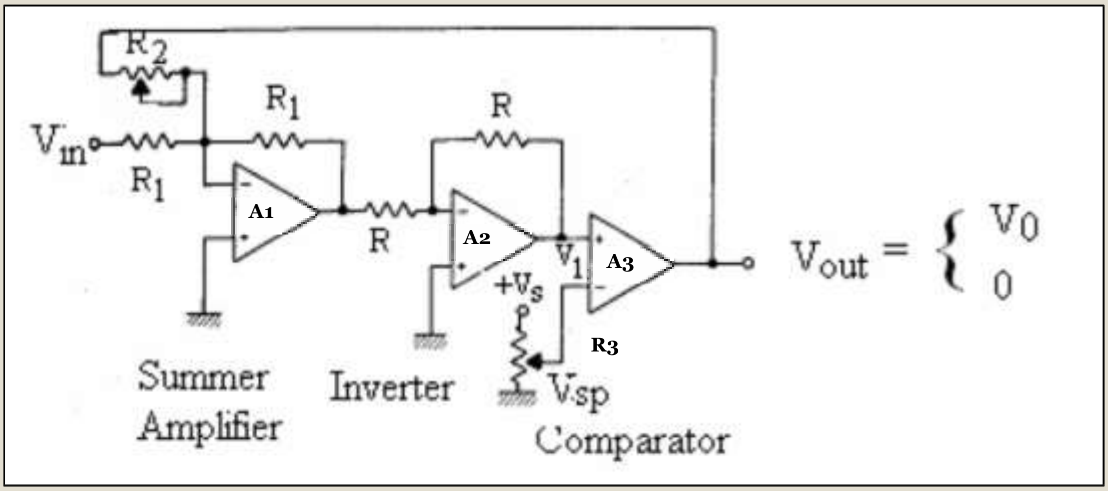


Figure 2.4(a). Two Position Control Using Op-amp

Two position controllers are used in many household equipment such as air conditioners, heaters and liquid level controls. These are very simple to design and are inexpensive. In these control if the controlled variable increases or decreases than a certain fixed value or called a set point then the actuation signals are generated. The two position controller is consisting of summing amplifier, inverting amplifier and a comparator. The op-amp A1 is a summing amplifier which has input signal V_{IN} and a V_{OUT} adjust the natural zone or differential band gap. This natural zone can be controlled by adjusting the value of R2. Op-amp A2 is unity gain inverting amplifier which change the sign of output voltage from summing amplifier. Op-amp A3 is a comparator which compare the value of the V_{IN} and V_{SP} (set point) voltage. Amplifier A3 is a non-inverting comparator. When the input signal potential is less than the V_L the V_{OUT} is high putting the circuit in ON state. When V_{IN} falls below the set point V_H, the circuit output goes low. Natural zone of the circuit can be set by varying the value of R3.

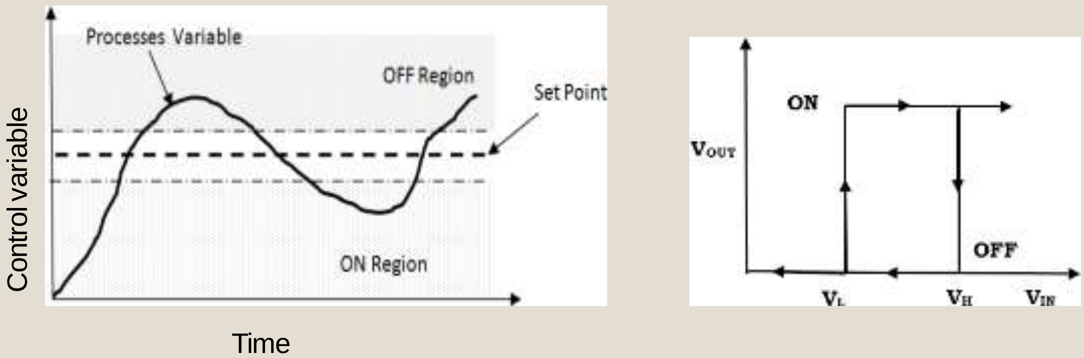


Figure 2.6. Response of Two Position Controller Time and Voltages

1.5 Proportional Controller

In proportional controller the controlled output is directly proportional to the error. The output of the circuit can be specified with the following equation 2.1.

$$V_{OUT} = G_P \times V_{ERROR} + V_0 \qquad (2.1)$$

Where,

V_{OUT} = output voltage

G_P = Proportional gain

V_{ERROR} = error voltage

V_0 = controller output with zero error

The circuit for proportional controller implemented using above equation. It consists of summing amplifier and an inverter. Summing amplifier adds V_0 and amplified error signal. Gain of an amplifier can be varied by changing value of R1. Inverting amplifier is used to change the sign of the output because in proportional controller the controlled variable is equal in magnitude and opposite in direction. In proportional controller when the controlled variable deviates from the set value, controller generates the correction signal which is proportional to the deviation. Figure 2.6(a) shows the proportional controller using op-amp and figure 2.6(b) shows the response of the proportional controller with error.

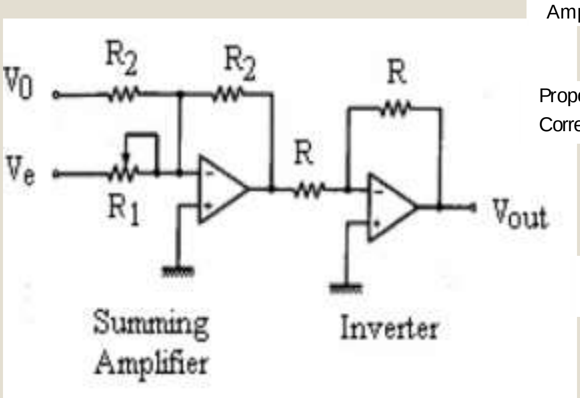


Figure 2.6(a). Proportional controller

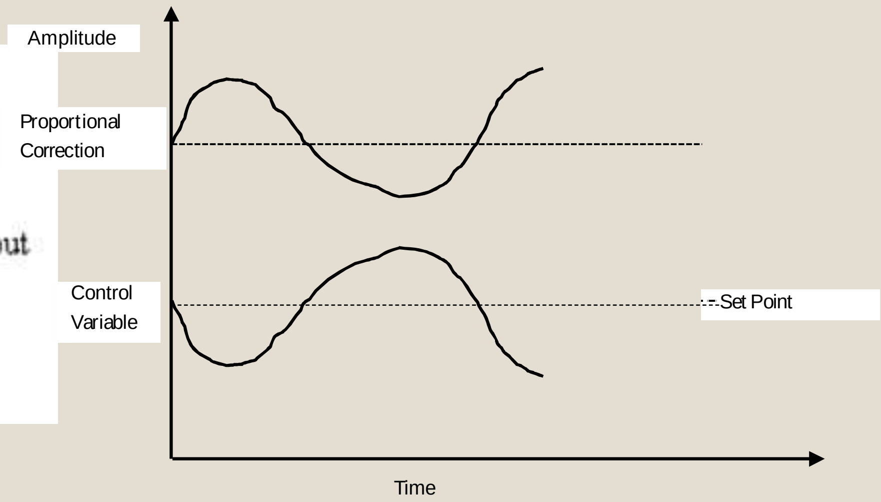


Figure 2.6(b). Response of P controller

1.6 Integral controller using op-amp

The figure 2.7 shows implementation of integral controller using op-amp. Output equation of the integrator controller can be given by following equitation 2.2.

$$V_{OUT} = G_I \int_0^T V_{ERROR} dt + V_{OUT}(0) \qquad (2.2)$$

Where

V_{OUT} =output voltage

V_{ERROR} = error voltage

V_{OUT} (0) initial output voltage

$G_I = \frac{1}{RC}$ integration gain

The circuit consists of integrator and inverting amplifier. Integration time of the circuit is designed with the different values of R and C combinations. The voltage across the capacitor is proportional to integral of the capacitor charging current with time. In integral controller the error is integrated over integration interval and then the output is generated. If the integration time is large the controller will be slow and if the integral time leads into overshoots. Integral controller has slow response.

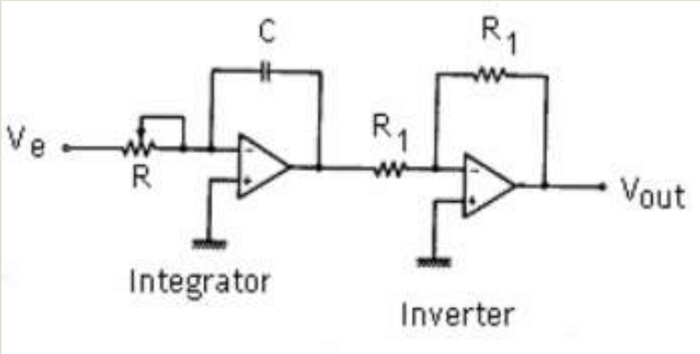


Figure 2.7. Integral Controller

1.7 Derivative controller using op-amp

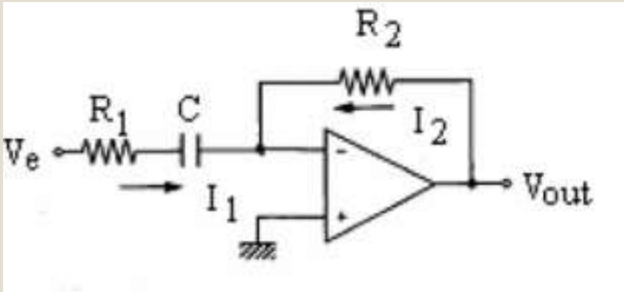


Figure 2.7(a). Derivative Controller

The output equitation for the derivative controller can be given by the following equitation 2.3.

$$V_{OUT} = -G_D \frac{dV_{ERROR}}{dt} \qquad (2.3)$$

Where,
G_D = RC Derivative gain
R- Timing resistance
C- Timing capacitance

The output of the circuit is equal to RC times negative instantaneous rate of change of error voltage. The derivative controller can generate output when there is sudden change in the error signal. Derivative controller is fast in response. Figure 2.7 shows the derivative controller using op-amp.

1.8 Proportional- Integral (PI) Controller

PI mode is a combination of Proportional + integral mode. Proportional integral controller is achieved by connecting integral followed by proportional controller. The output equitation is given by the following equitation 2.4. Figure 2.8(a) shows the implementation of PI controller using op-amp.

$$V_{OUT} = G_P \times V_{ERROR} + G_I \int_0^T V_{ERROR}\,dt + V_{OUT}(0) \qquad (2.4)$$

Where,
G_P- proportional gain
V_{OUT}- output voltage
V_{ERROR}- error voltage
G_I- integral gain
V_{OUT} (0) initial output voltage

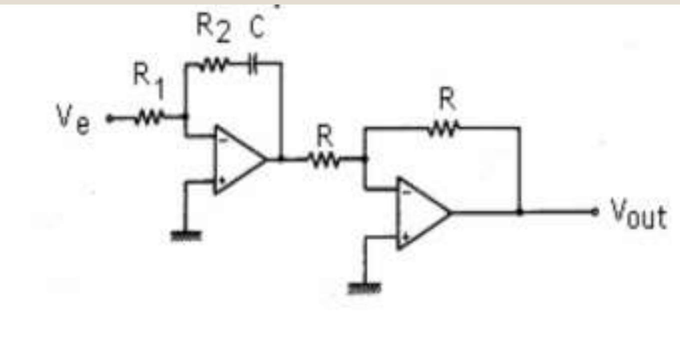


Figure 2.8(a). PI Controller

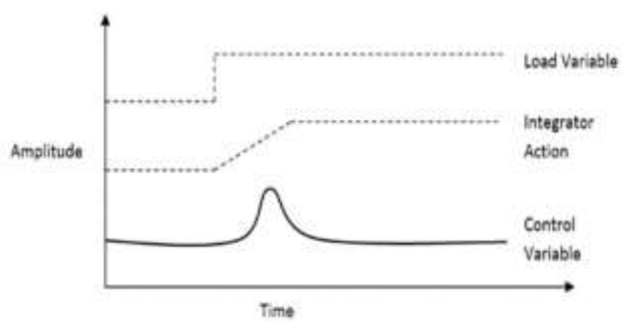


Figure 2.8(b). Input output waveforms

integral function is used to minimize the offset error. The disadvantage of the PI controller is its slow in response. it cannot minimize the sudden error. PI controllers are very often used in industry, especially when speed of the response is not an issue.

1.9 Proportional- Derivative (PD) Controller

Derivative mode is used when prediction of the error can improve control or when it necessary to stabilize the system. PD controller is the combination of proportional and derivative mode of controllers. The general equitation of PD controller is given by the following equitation 2.5.

$$V_{OUT} = G_P \times V_{ERROR} + G_D \frac{dV_{ERROR}}{dt} \qquad (2.5)$$

This controller has proportional and derivative actions to achieve the set pint value. The proportional control has offset error and PI controller has slow response. The derivative produces the corrective action for the rate of change of error or the sudden error. The disadvantage of the PD controller is it cannot reduce the offset error as the offset error is constant. PD controllers are less popular because they are not stable Figure 2.9(a) shows the implementation of PD controller using op-amp.

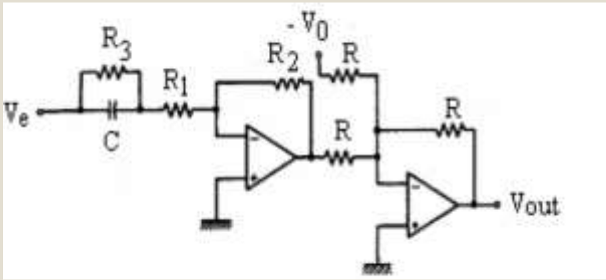


Figure 2.9(a). PD Controller

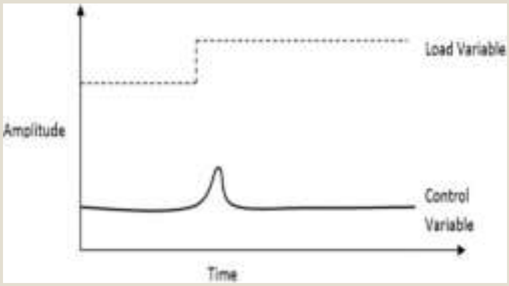


Figure 2.9(b). Input output waveforms

1.10 Proportional-Integral-Derivative (PID) Controller

Proportional-Integral-Derivative (PID) control is the most common control algorithm used in industry and has been universally accepted in industrial control. The controller attempts to minimize the error over time by adjustment of a *control variable*, such as the position of a control valve, a damper, or the power supplied to a heating element, to a new value determined by a weighted sum of proportional. Integral and derivative controller. The output equation is 2.6.

$$V_{OUT} = G_P \times V_{ERROR} + G_I \int_0^T V_{ERROR}\,dt + G_D \frac{dV_{ERROR}}{dt} + V_{OUT}(0) \qquad (2.6)$$

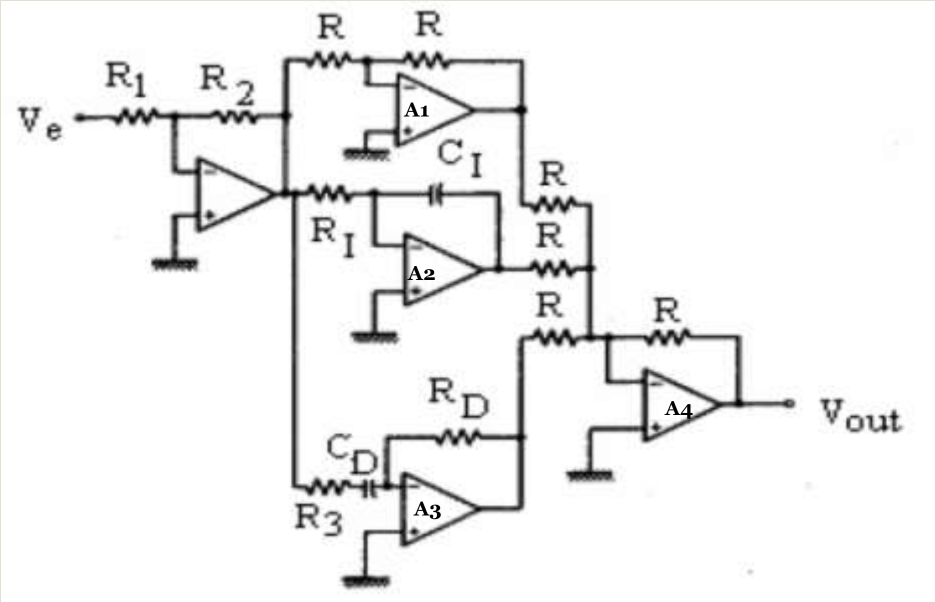


Figure 2.10. PID Controller using op-amp.

Where,

V_{OUT} =output voltage

V_{ERROR} = error voltage

V_{OUT} (0) initial output voltage

G_I integration gain

G_D derivative gain

G_P proportional gain

Amplifier A1 is proportional controller, A2 integrator, A3 is derivative controller and A4 is summing amplifier. Summing amplifier adds the control signal from three controllers to generate the control signal. Figure 2.10 shows the implementation of PID controller using op-amp.