Construction and Circuit Operation

A. Electronic Controller Construction and Circuit Operation

1. Functions a controller may provide.

   a. Allow remote process control operation

   b. Provide signal isolation

   c. Provide signal conversion

   d. Provide signal comparison

   e. Receive a process variable signal, compare it to one the operator selects and adjusts on output signal used to operate a final control element.

   f. Provide process indication

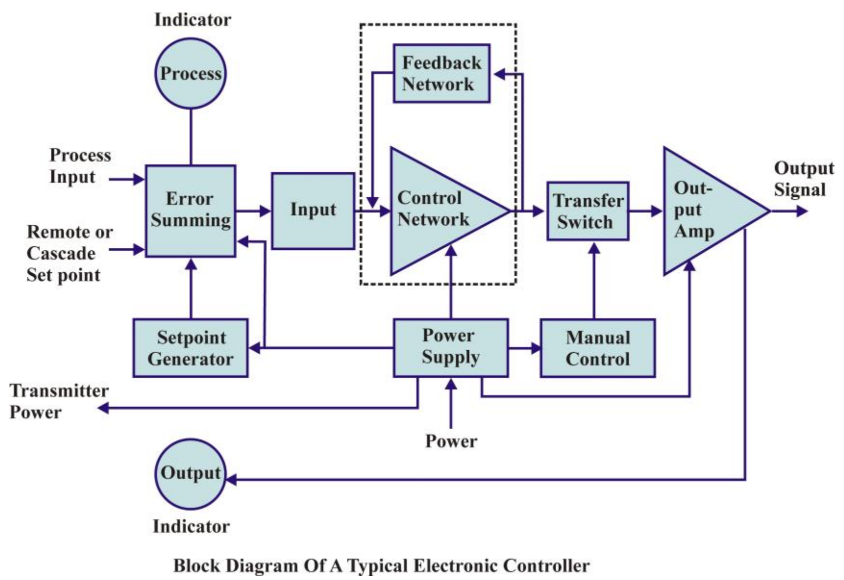
   g. Provide power supply to a transmitter or other loop instruments.

   h. Provide different control modes

   i. Provide local/remote control

   j. Provide alarms

2. Typical Construction and Circuit Operation



Picture 1, Block Diagram Typical Electronic Controller

a. Power supply

1) Used for all components in controller

2) May or may not provide power to the loop transmitter.

b. Error summing network

1) Controlled variable is compared with signal from set point generator

2) Operation

a) E = Csp - Cm

b) Cm = measured variables

Csp = setpoint

E = error signal

c) Example: if measured variable is 35% of span, and the setpoint is 40%, then the resulting error signal is:

E = Csp - Cm

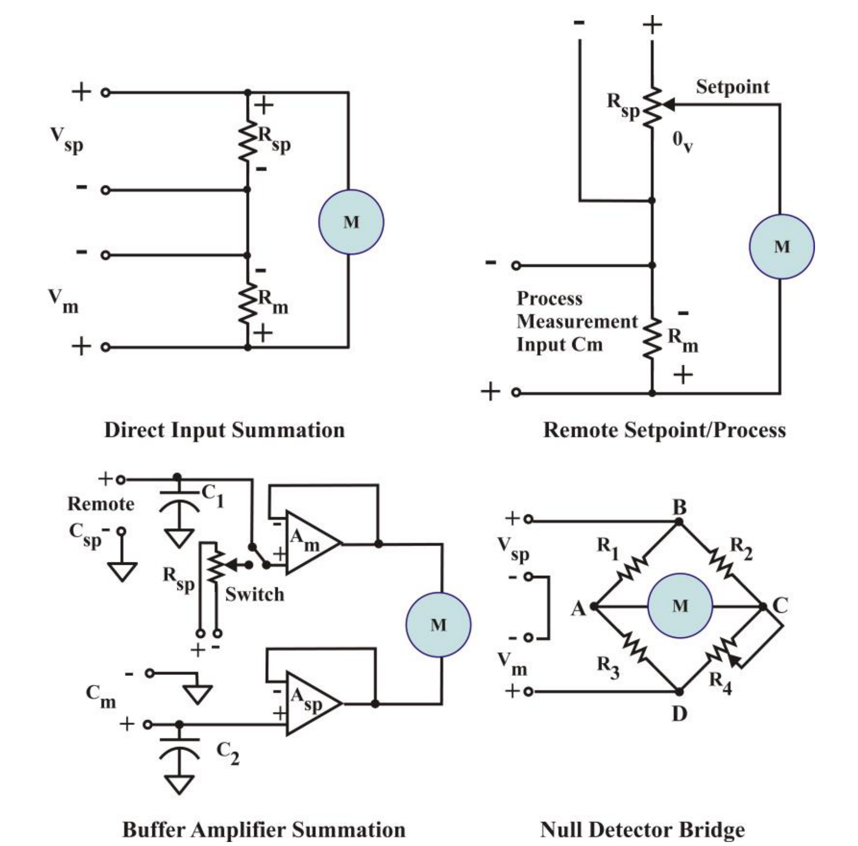
E = 40% - 35%

E = + 5%

c. Input networks

1) Provide input (error signal) to feedback and control network.

a) Direct Input Summation



Picture 2, Summation Circuits

(1) With Vsp = Vm, meter will be nulled

(2) Adjustable Setpoint Remote Setpoint/Process

(3) Remote variables impressed through Rsp (same value as Rm)

(4) Any various of voltage between Rm and Rsp seen as meter movement

b) Buffer Amplifier Summation

(1) C1 and C2 are filters

(2) Asp and Am have gain = 1 (Buffers)

(3) Move Rsp ↑ will have (+)voltage on top of deviation meter (positive error) - to cancel this error, the input signal from the controlled variable must ↑ (Cm↑)

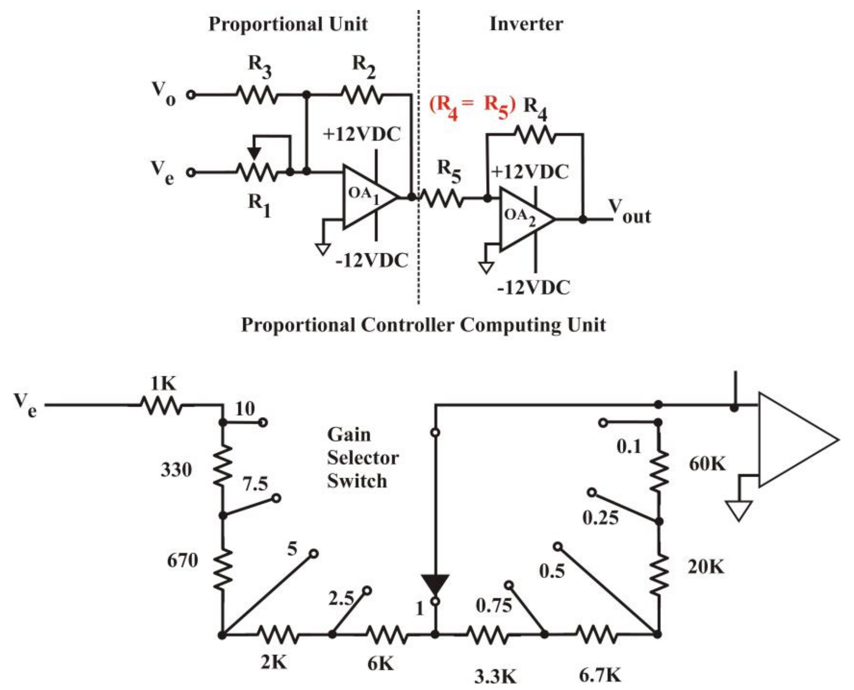
(4) Most widely used circuit

(5) Switch selects remote or local setpoint

c) Null Detector Bridge

(1) No error - meter is nulled

d. Control & Feedback Networks (Proportional only)



Picture 3, Circuit For Proportional Control

1) Circuit is inverting summer
2) QA2 is inverting amp with gain = 1
3) Vo = voltage used to establish controller output with zero error voltage (Ve)
4) R1 = R3, with Ve = 0, Vout = Vo
5) When error exists, Vout will increase or decrease in magnitude based on polarity of Ve

   a) P = Kp Ep + Po

   Kp = R2/R1

   Ep = Ve

   Po = (R2/R3) Vo

   if: R2 = R3

Then: P = (R2/R1) Ve + Vo

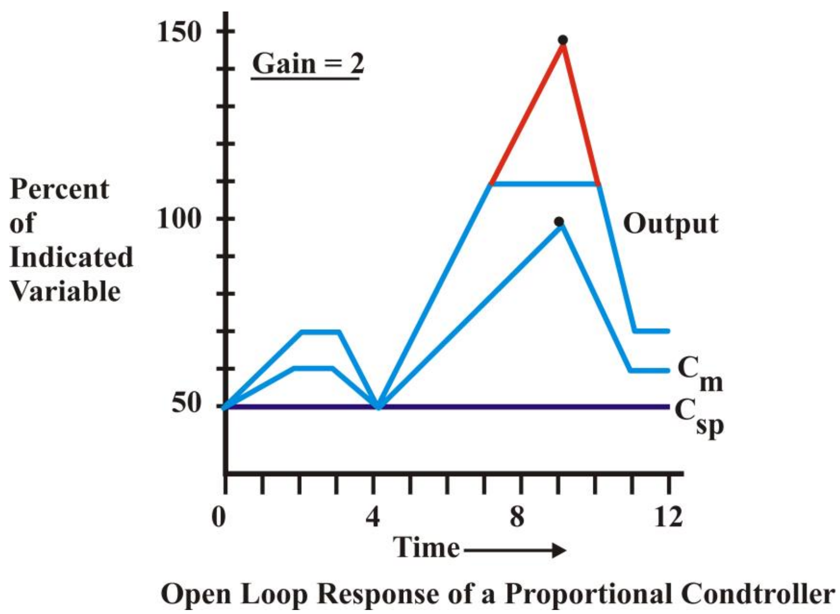
6) As measured variable increases, output decreases (reverse acting controller)

7) Vout at max corresponds to 100% of input and is 10V (for 0-10V output range)

8) Proportional band adjusted by changing R1.

9) Proportional band circuit can also use a rotary switch to select gain.

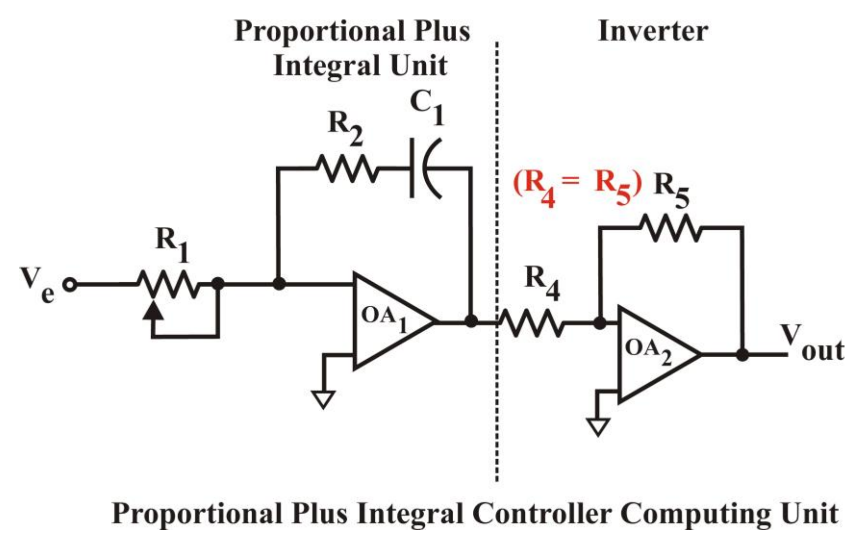
10) Open loop response of proportional only



Picture 4, Open Loop Response for a Proportional Controller

e. Proportional plus integral

Construction and Circuit Operation



Picture 5, Proportional Plus Integral Circuit

1) Designed to solve equation.

   a) $P = Kp\ Ep + Kp\ K1 \int Ep\ \Delta t + Po$

   b) For a step change in input signal

      P = Kp Ep + KpK, Ep□t + Po

      P = controller output in % of span

      Kp = proportional gain

      KI = integral gain

      Ep = error signal

      t = time difference

      Po = initial controller output

2) Circuit that solves the equation

   a) Combination of inverting amp and integrator

   b) Using operational calculus it can be proven that:

Kp = R2/R1

KI = 1/(R2 C1)

c) Recall that RxC has units of seconds and the seconds are converted to minutes and K1 has units of inverse minutes (repeats per minute) so:

d) Equation can be rewritten as

P = (R2/R1) EP + (R2R1)

1/(R2C1) Epdt + Po

(1) Proportional gain adjusted with R1 without affecting integral gain

Kp = proportional gain = R2/R1

KI = integral gain = 1/(R2/C1)

(2) Integral gain adjusted with C1 without affecting proportional gain.

Assume Kp = 2 and KI = 2 repeats/min.

R2 = 300KΩ and find R1 and C1

KP = R2/R1

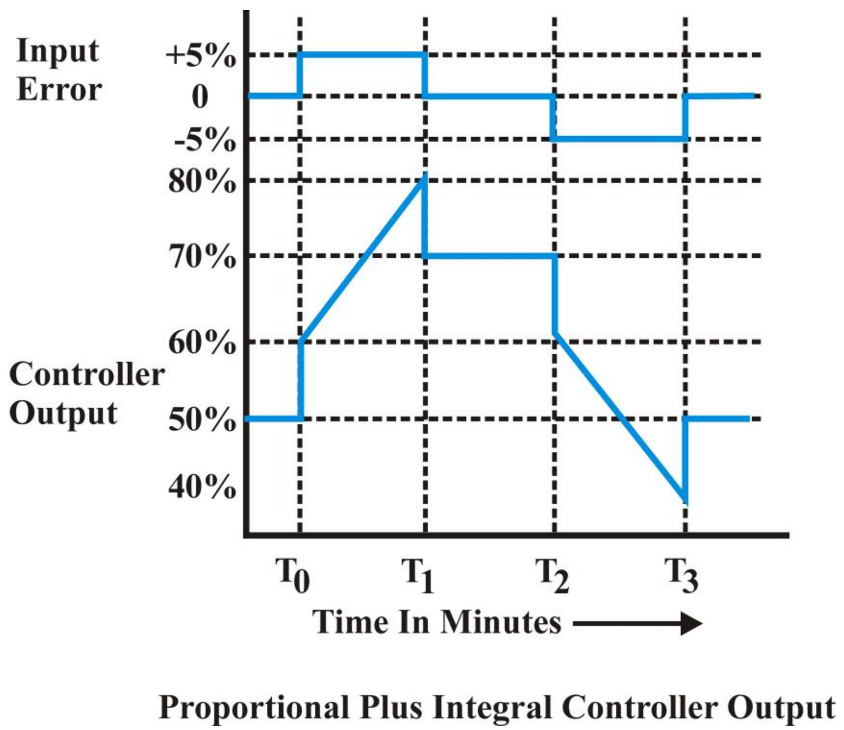
R1 = R2/Kp = 300KΩ/2 = 150KΩ

KI = 1/(R2C1)

C1 = 1/KIR2C1 = 1/[(2/min) x (1 min/60 sec) x 300K]

C1 = 100 µf

e) Signal analysis



Picture 6, Proportional Plus Integral Controller Output

(1) Prior to To error signal

= 0 volts, output of OA1

= -5 VDC, output of QA2

= + 5VDC by charge on C1

(2) At To, input steps to +

0.5VDC and I in through

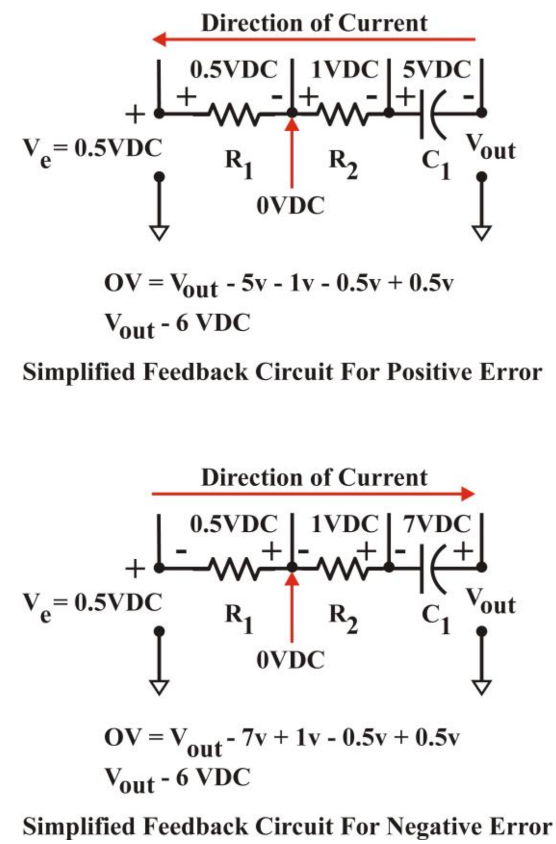
R1 is 3.33 µADC

$$Iin = \frac{Ve}{R1} = \frac{0.5VDC}{150K} = 3.33\mu ADC$$

(3) Voltage drop across R2 = 1VDC

VR2 = 3.33µADC

(4) Voltage drop across C1 across C1 cannot change instantly - output of OA1 will be sum of volt-age drops across R2 and C1 which will be (-)6VDC.



Picture 7, Simplified Feedback Circuits

(5) Theoretically, direct-acting controller with Kp = 2 and KI = 2 repeats per minute has these output characteristics.

(6) Assume input error signal and output signal have 0 - 10VDC ranges.

(7) Between To and T1 - change on C1, 4 and output ☐ in order to maintain constant Ifb

(8) Instant before T[1], charge on C1 = 7VDC and ER2 = 1VDC resulting in (-) 8 VDC output from OA1

(9) At T1, error → 0VDC and Iin and Ifb → 0 and so ER2 → 0VDC and output drops to (-) 7VDC

(10) From T1 to T2 output stable at 70% - notice that unlike the proportional only controller, output of the PI controller can be stable at any level with zero error signal.

(11) At T2, input error drops to (-) 0.5 VDC and Iin and Ifb are again = 3.33μADC but now in opposite direction.

(12) Again, C1 charge cannot change instantly and remains 7VDC initially resulting in (-) 6VDC output from OA1.

(13) T2 to T3 - C1 discharges at constant current (Ifb) - so voltage drop across C1 decreases linearly

(14) At T3, charge on C1 5VDC and controller output is difference between ER2 and Ec1 = (-) 4VDC

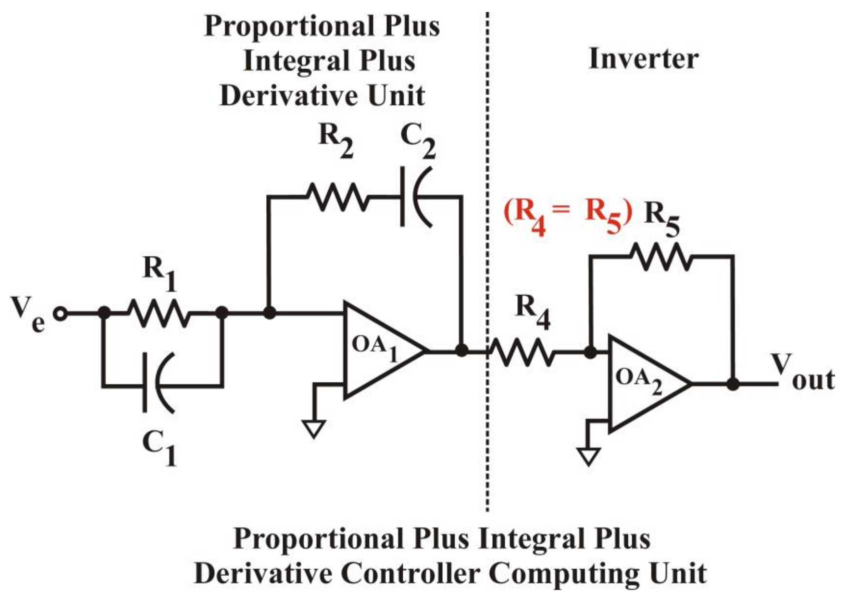
(15) At T3, error returns to zero and output stabilizes at 5VDC (the voltage drop across C1)

(16) If, value of C1 ↑, number repeats/minute ↑

(17) If R1 ↓, proportional gain ↑

f. Proportional plus integral plus derivative

Construction and Circuit Operation



Picture 8, Proportional Plus Integral Plus Derivative Circuit

1) Designed to solve equation

   a) P = Kp Ep + Kp KI ☐Epdt + Kp Kd (dEp/dt)+Po

      Kd = derivative gain

      dEp/dt = rate of change of error signal

2) Circuit that solves the equation

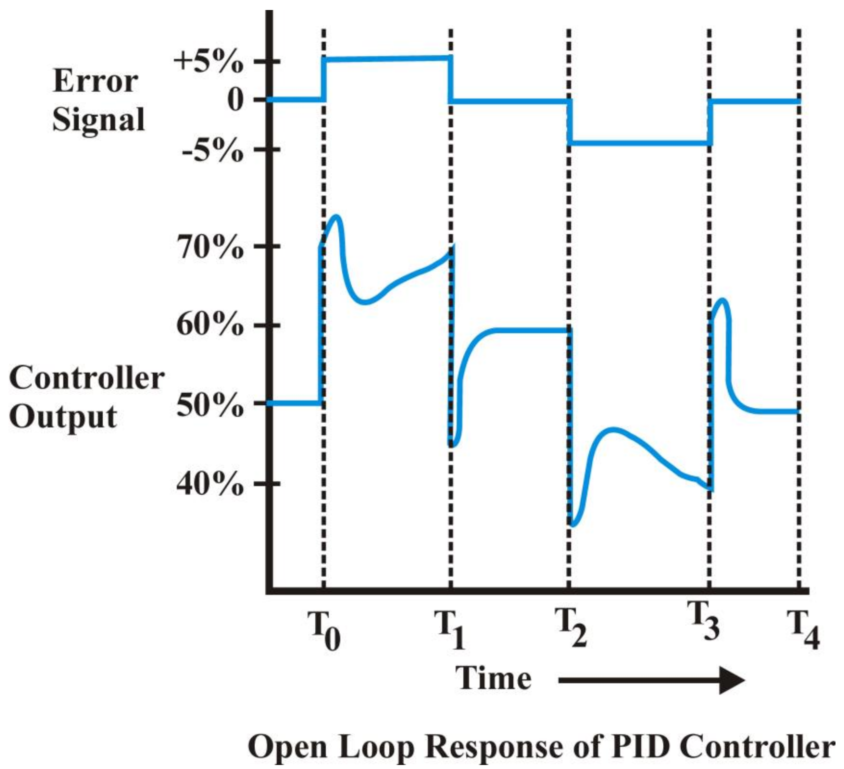
   a) Signal analysis

      (1) Initially at steady state and 50% output

      (2) C1 discharged, C2 at (+) 5VDC for 0 to 10VDC span

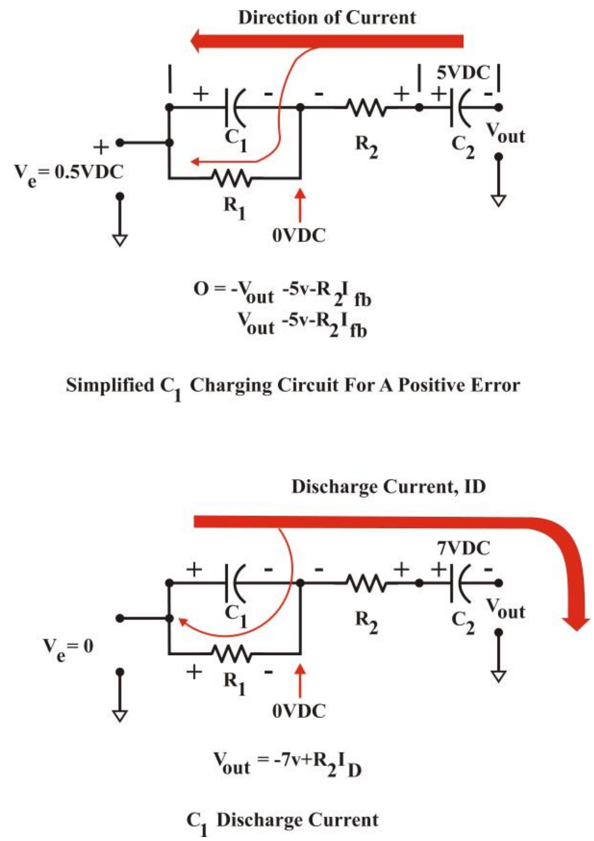
      (3) Assume proportional gain = 2 and integral gain of 2 repeats/minute (each time increment = 30 sec)

      (4) Higher KD is - the peak on the curve



Picture 9, Open Loop Response of PID Controller

(5) At To - C1 is short circuit, Ifb is large, large voltage drop across R2 which adds to charge of C2 - producing large peak.



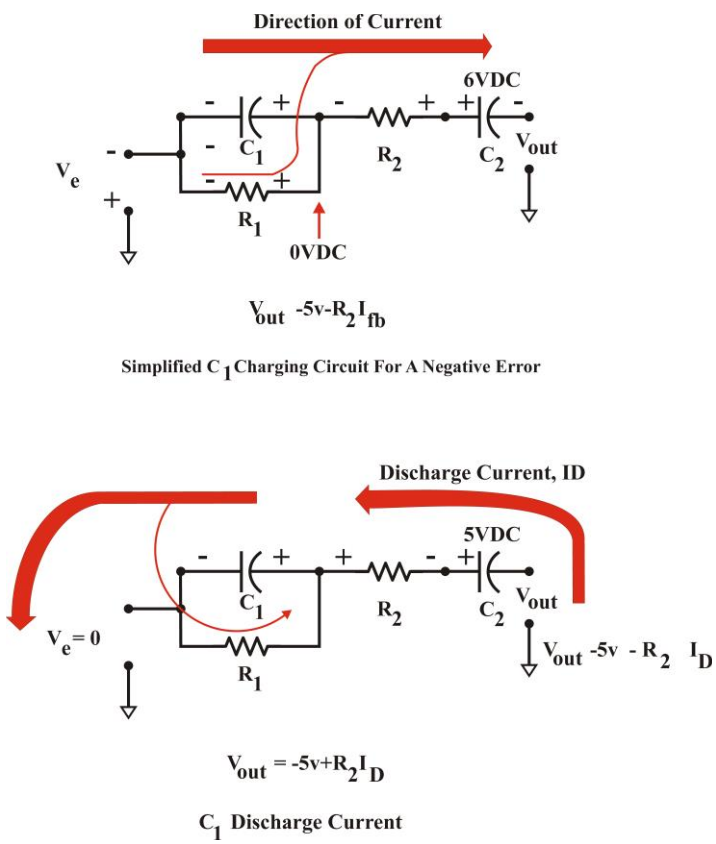
Picture 10, Capacitive Charge-Discharge

(6) As C1 charges to Ve current ☐ exponentially occurs during decay of peak.

(7) When C1 fully charged, I in and Ifb determined by value of R1 - notice that after 30 seconds the output has the same value as a purely PI controller has.

(8) At T1 - input error to zero, C1 discharges, major path through R2 and C2 direction of current reversed, voltage drop of R2 opposes C2 and output voltage is difference of them - this discharge produces the peaked output shortly after T1.

(9) At T2 - input steps negative, C1 is short, Iin & Ifb are high, R2 voltage drop opposes C2 charge and output peaks low at T2.

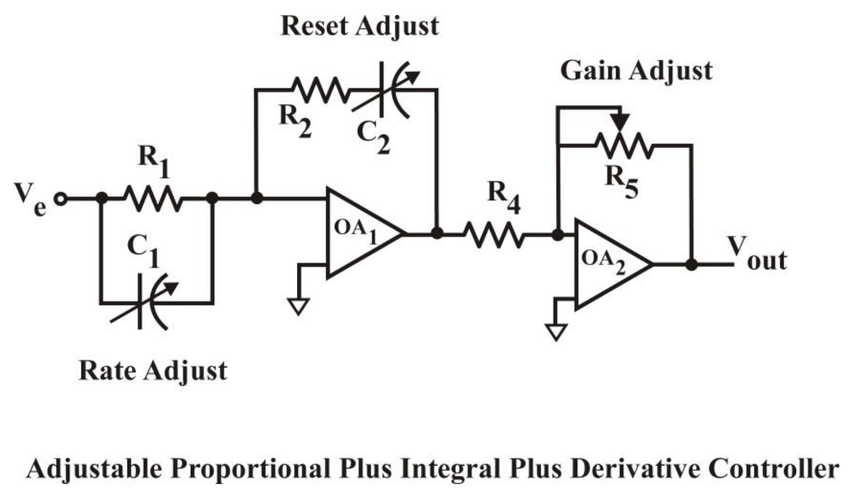


Picture 11, Capacitive Charge - Discharge

(10) (x) As C1 charges its current decays to zero, and output decreases between T2 and T3 as C2 discharges.

(11) At T3 - error returns to zero - C discharges, R2 voltage drop adds to charge of C2 producing peak at T3

3) Adjustments



Picture 12, Adjustable PID Controller

a) Kp = R2/R1

KI = 1/(R2C2)

KD = R1 C1

b) KI and KD adjusted by C2 and C1

c) Kp adjusted by R5

PRACTICE:

1 What basic component is added to a proportional only electronic controller to make it a proportional plus integral controller?

2. What basic component is added to a proportional only electronic controller to make it a proportional plus derivative controller?