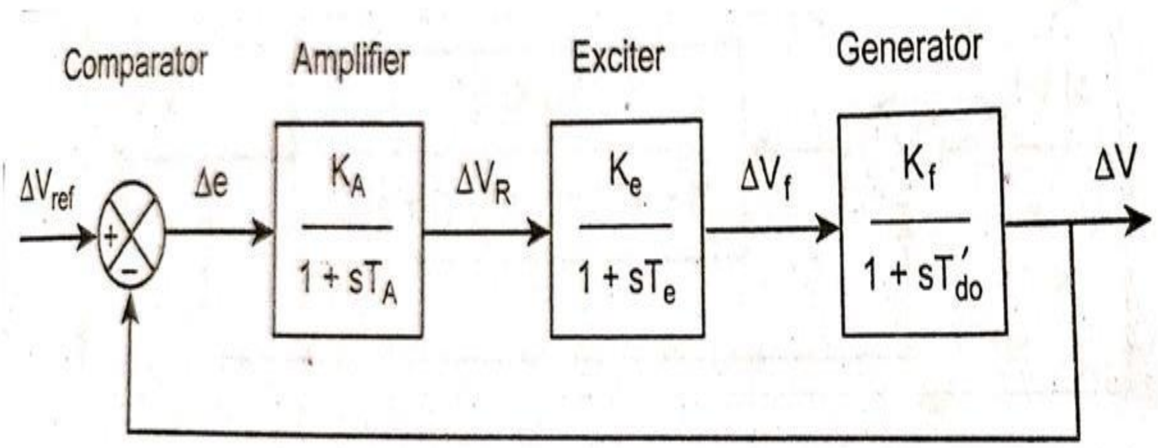
STATIC ANALYSIS OF AUTOMATIC VOLTAGE REGULATOR LOOP

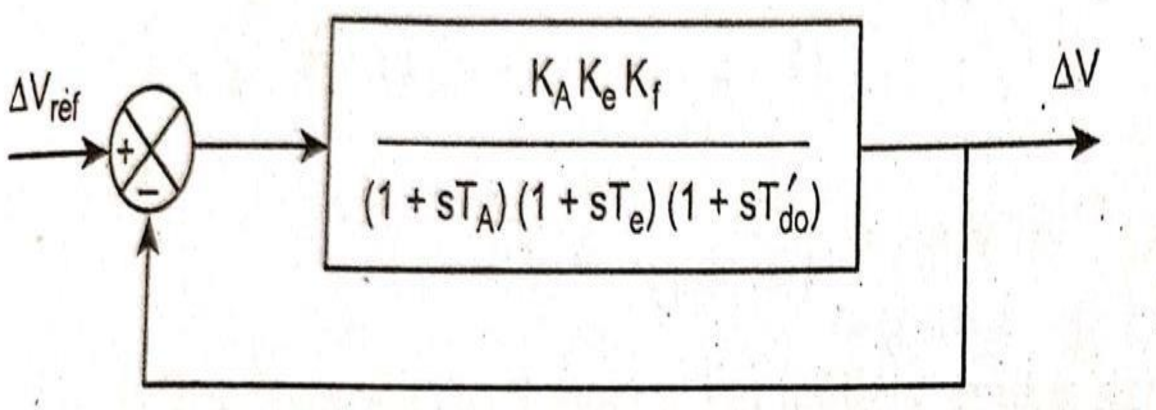
- The automatic voltage regulator must regulate the terminal voltage |V| within the required static accuracy limit.
- It must have sufficient speed response.
- It must be stable.

The block diagram of AVR is as shown in Fig.



Initial error, $\Delta e_0 = \Delta|V|ref_0 - \Delta|V|_0$

Open loop T.F, $G(s) = \frac{K_A \quad K_e \quad K_f}{(1 + sT_A)\ (1 + sT_e)|\ (1 + sT^{F}_{d0})}$



At initial condition, $\Delta |V|_0 = \frac{G(s)}{1 + G(s)} \Delta|V|_{ref0}$ ....(1)

Δe_0 must be less than some specified percentage P of reference voltage $\Delta|V|_{ref0}$. The static accuracy specification is :

$\therefore \Delta e_0 < \frac{P}{100} \Delta|V|_{ref0}$ ....(2)

For a constant input, the transfer function is obtained by setting s=0

Substituting equation (1) in (2) we get,

$$\Delta e_0 = (\Delta|V|_{ref0}) - (\frac{G(s)}{1 + G(s)} \Delta|V|_{ref0})$$

$$\Delta e_0 = \Delta|V|_{ref0} [\frac{1}{1 + G(s)}]$$

Putting S = 0,

$$\Delta e_0 = (\Delta|V|_{ref0}) [\frac{1}{1 + \lim_{s\to 0} G(s)}] = \frac{\Delta|V|_{ref0}}{1 + k_p}$$

Position error constant, $K_p = \lim_{s\to 0} G(S)$

$$K_p = \lim_{s\to 0} G(S)$$

$$= \lim_{s\to 0} G(S) = \lim_{s\to 0} \frac{K_A \quad K_e \quad K_f}{(1 + sT_A) \quad (1 + sT_e) \quad (1 + sT'_{do})}$$

$$K_p = K_A \quad K_e \quad K_f$$

$$\Delta e_0 = \frac{\Delta|V|_{ref0}}{1 + K}$$

If K increases, Δe_0 decreases, so static error decreases with an increased loop gain.

To find the value of K;

$\therefore \Delta e_0 < \frac{P}{100} \Delta|V|_{ref0}$

$\frac{\Delta|V|_{ref0}}{1 + K} < \frac{P}{100} \Delta|V|_{ref0} \quad = \frac{1}{1 + K} < \frac{P}{100}$

$1 + K > \frac{100}{P}$

$K > \frac{100}{P} - 1$

If Δe_0 is less than 1%, K must exceed 99%.

Steady state response for a closed loop Transfer Function

$$\text{Closed loop T.F} = \frac{\Delta V(s)}{\Delta V_{ref}(s)} = \frac{\frac{K_A \ K_e \ K_f}{(1 + sT_A)\ (1 + sT_e)\ (1 + sT'_{d0})}}{1 + \frac{K_A \ K_e \ K_f}{(1 + sT_A)\ (1 + sT_e)\ (1 + sT'_{d0})}}$$

$$\Delta V(s) = \frac{K_A \ K_e \ K_f \, \Delta V_{ref}(s)}{(1 + sT_A)\ (1 + sT_e)\ (1 + sT'_{d0}) + K_A \ K_e \ K_f}$$

For a step input $\Delta V_{ref}(s) = \frac{1}{s}$

Applying final value theorem,

$\Delta V_{stat} = \lim_{s \to 0} s\, \Delta V(S)$

$$\Delta V_{stat} = \lim_{s \to 0} \frac{s\, x\, K_A \ K_e \ K_f \, \Delta V_{ref}(s) x \frac{1}{s}}{(1 + sT_A)\ (1 + sT_e)\ (1 + sT'_{d0}) + K_A \ K_e \ K_f}$$

$$\Delta V_{stat} = \frac{K_A \ K_e \ K_f}{1 + K_A \ K_e \ K_f}$$

$$\Delta V_{stat} = \frac{K}{1 + K}$$

Dynamic Analysis of AVR Loop

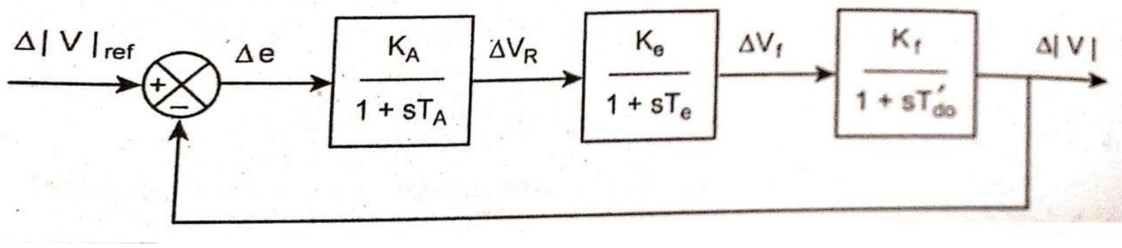


Fig Block diagram of AVR

Open loop T.F $G(s) = \frac{K_A \quad K_e \quad K_f}{(1 + sT_A)\ (1 + sT_e)\ (1 + sT'_{d0})}$

$\Delta V(s) = \frac{G(s)}{1 + G(s)} \Delta V_{ref}(s)$

Taking inverse Laplace transform

$\Delta V(s) = L^{-1}[\Delta V(s)]$

The response depends upon the eigen values or closed loop poles, which are obtained from the characteristic equation
1+ G(s) = 0.

Find roots of characteristic equation [Eigen values] s_1, s_2, s_3 .

Case I : Roots are real and distinct

The open loop transfer function G(s) is of 3rd order. There are three eigen values s_1, s_2, s_3.

$\Delta V(t) = L^{-1}\left[\frac{k_1}{s - s_1} + \frac{k_2}{s - s_2} + \frac{k_3}{s - s_3}\right]$

Transient response $= k_1 e^{s_1 t} + k_2 e^{s_2 t} + k_3\, e^{s_3 t}$

Case II : Two roots (Eigen values) are complex conjugate ($\sigma \pm j\omega$)

The transient response is $Ae^{\sigma t}\sin(\omega t + \beta)$

For AVR loop to be stable, the transient components must vanish with time.

All the eigen values are located in left half of s-plane. Then the loop possesses good tracking ability i.e the system is stable.

For high speed response, the loop possesses eigen values located far away to the left from origin in s-plane.

The closer the eigen value is located to the $j\omega$ axis, the more dominant it becomes.