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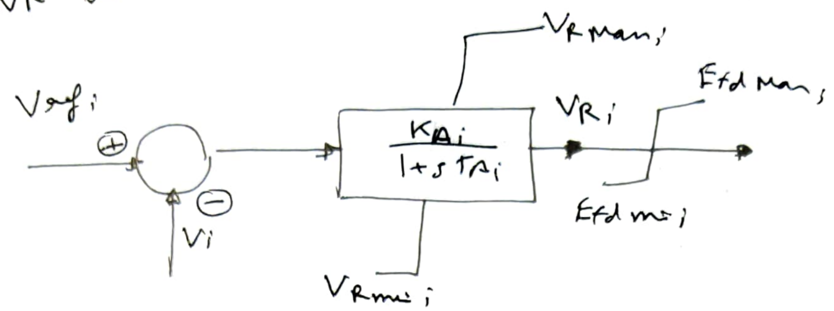
SPRING 2023

1.1

AVR with Static Exciter



$$V_{R\text{-}det_i} = \frac{1}{T_{A_i}} \left\{ -V_{R_i} + (V_{ref_i} - V_i) K_{A_i} \right\}$$

$$\dot{V}_{R_i} = \begin{cases} 0 & \text{if } V_{R_i} \geq V_{R\max_i} \text{ \&\& } V_{R\text{-}det_i} > 0 \\ 0 & \text{if } V_R < V_{R\min_i} \text{ \&\& } V_{R\text{-}det_i} < 0 \\ V_{R\text{-}det_i} & \text{else.} \end{cases}$$

$$E_{fd} = \begin{cases} E_{fd\max_i} & \text{if } E_{fd_i} > E_{fd\max_i} \\ E_{fd\min_i} & \text{if } E_{fd_i} < E_{fd\min_i} \\ V_{R_i} & \text{else.} \end{cases}$$

For Type 1 model, only ~~the~~ one more state variable V_R is added and no other modifications ~~are~~ required for Static Excite AVR.

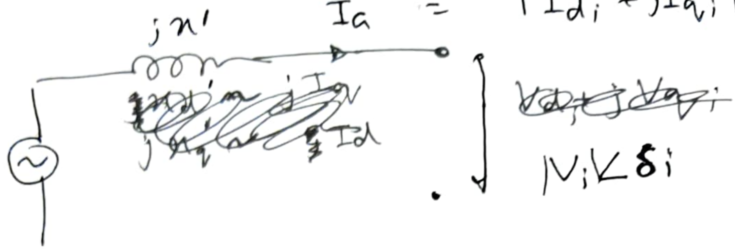
$$\underset{15\times1}{f(x,y)} = \begin{bmatrix} \dot{\theta}_{3\times1} \\ \dot{\omega}_{3\times1} \\ \dot{E}'_{q\,3\times1} \\ \dot{E}'_{d\,3\times1} \\ \dot{V}_{R\,3\times1} \end{bmatrix}_{15\times1} = \underset{15\times1}{f(x,y)} \qquad g(x,y) = 0 = \begin{bmatrix} \begin{bmatrix} P \\ Q \end{bmatrix}_{10\times1} \\ \vdots \end{bmatrix}_{20\times1}$$

For type II model, we need to express the term $|V_i|$ in terms of E'_{q_i}, E'_{d_i}, θ_i.

There are two ways to do the same:

$$\bar{I}_a = |I_{d_i} + jI_{q_i}| \angle \tan^{-1}\left(\frac{I_{q_i}}{I_{d_i}}\right) \angle\left(\theta_i - \frac{\pi}{2}\right)$$

(i)



~~$E'_{d_i} + jE'_{q_i}$~~

$E'_i \angle \gamma_i$

or

$$|E'_{d_i} + jE'_{q_i}| \angle \tan^{-1}\left(\frac{E'_{q_i}}{E'_{d_i}}\right) \cdot \angle\left(\theta_i - \frac{\pi}{2}\right)$$

$$\bar{V}_i = \bar{E}_i - jx'_i I_{a_i}$$

$$\bar{V}_i = \left(\sqrt{E'^2_{d_i} + E'^2_{q_i}}\right) \angle \left\{ \tan^{-1}\left(\frac{E'_{q_i}}{E'_{d_i}}\right) + \theta_i - \frac{\pi}{2} \right\}$$

or

$$\bar{V}_i = \left(\sqrt{E'^2_{d_i} + E'^2_{q_i}}\right) \angle \left\{ \tan^{-1}\left(\frac{E'_{q_i}}{E'_{d_i}}\right) + \theta_i - \frac{\pi}{2} \right\} - x'_i \angle\left(\frac{\pi}{2}\right) |I^2_{d_i} + I^2_{q_i}| \cdot \angle \left\{ \tan^{-1}\left(\frac{I_{q_i}}{I_{d_i}}\right) + \theta_i - \frac{\pi}{2} \right\}$$

or

$$\boxed{\bar{V}_i = \left(\sqrt{E'^2_{d_i} + E'^2_{q_i}}\right) \angle \left\{ \tan^{-1}\left(\frac{E'_{q_i}}{E'_{d_i}}\right) + \theta_i - \frac{\pi}{2} \right\} - x'_i \, |I^2_{d_i} + I^2_{q_i}| \angle \left\{ \tan^{-1}\left(\frac{\sum_{k=1}^{N_{PV}+1} Y_{gen_{ik}} \sqrt{E'^2_{dk} + E'^2_{qk}} \cdot \cos(\gamma_{ik} + \gamma_k - \theta_i)}{\sum_{k=1}^{N_{PV}+1} Y_{gen_{ik}} \sqrt{E'^2_{dk} + E'^2_{qk}} \cdot \sin(\gamma_{ik} + \gamma_k - \theta_i)} \right) + \theta_i - \frac{\pi}{2} \right\}}$$

This is a bit tedious to write.

Instead, we can use:

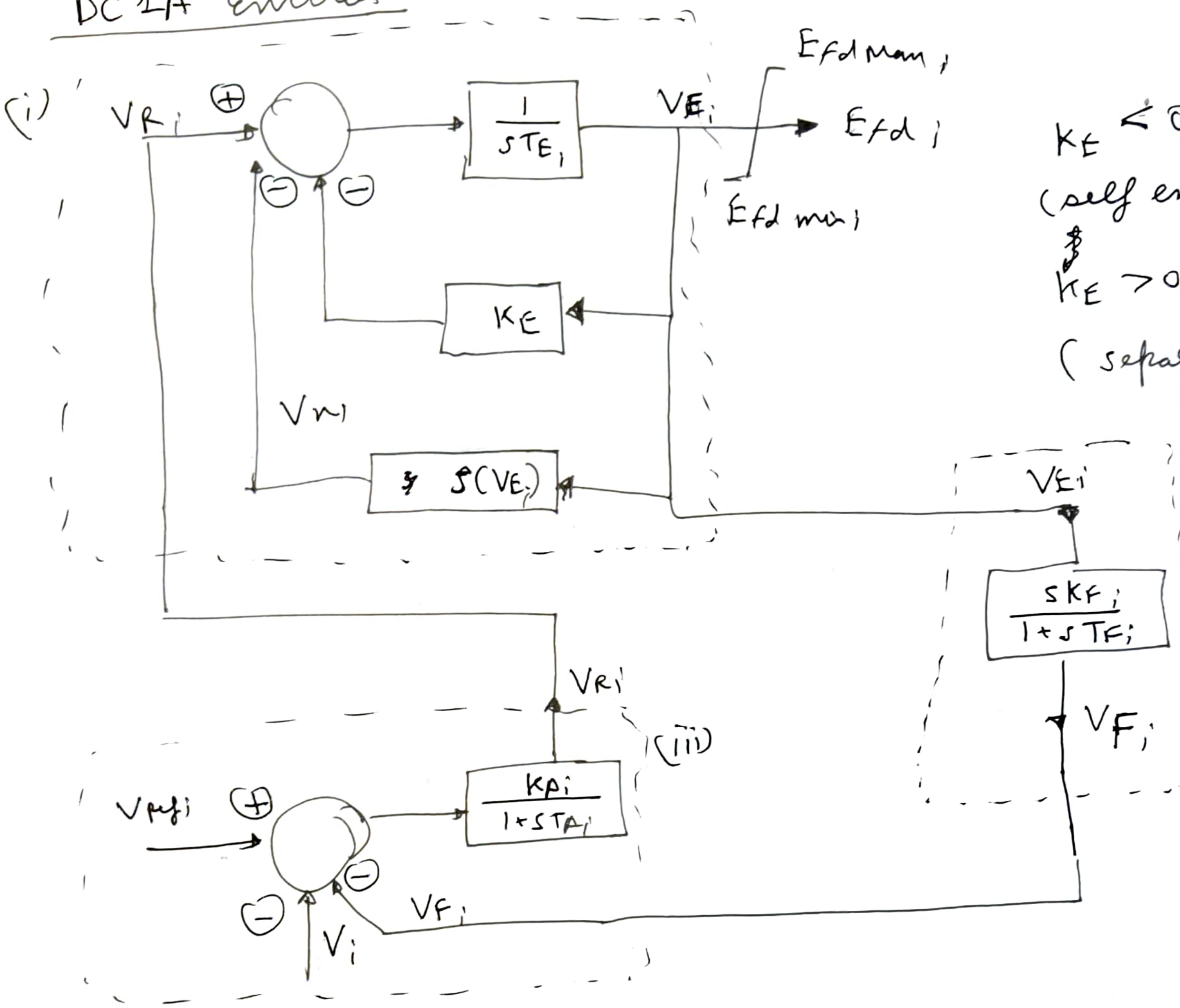
(ii) $\underset{}{V_{rest}} = \underset{(N-1)\times(N-1)}{Y_{rr}^{-1}} \; \underset{(N-1)\times(N_{PV}+1)}{Y_{rg}} \; \underset{(N_{PV}+1)\times 1}{V_{gen}}$

and take ~~vals~~ rows $i = 1$ to N_{PV} of V_{rest}. :)

~~Once again~~ we'll have three equations each for $\dot{\theta}_i, \dot{\omega}_i, \dot{E}'_{q_i}, \dot{E}'_{d_i}$, & V_{R_i}, with the other equations being the same.

DC 1A Exciter

2.1



$K_E < 0$ (+ve fb) (self excited)

&

$K_E > 0$ (−ve fb) (separately excited).

Washout filter: Rejects steady state I/P(s). Only allows high frequency transient I/P(s).

Saturation fn. block.

(i) $$\left(V_R - \left(K_E + S(V_E)\right)V_E\right)\frac{1}{sT_E} = V_E$$

or $$\boxed{\dot{V}_{E_i} = \frac{1}{T_{E_i}}\left\{-\left(K_{E_i} + S(V_{E_i})\right)V_{E_i} + V_{R_i}\right\}} \quad (1)$$

$$E_{fd_i} = \begin{cases} E_{fd\,max_i} & V_{E_i} > E_{fd\,max_i} \\ E_{fd\,min_i} & V_{E_i} < E_{fd\,min_i} \\ V_{E_i} & \text{else} \end{cases} \quad (1a)$$

(ii) $\cancel{\dot{V}_{F_i} = \frac{1}{T_{F_i}}\{} - V_{F_i}$ =

$$sK_{F_i}V_{E_i} = (1+sT_{F_i})V_{F_i}$$

or $$K_{F_i}\dot{V}_{E_i} = V_{F_i} + T_{F_i}\dot{V}_{F_i}$$

or $$\boxed{\dot{V}_{F_i} = \frac{1}{T_{F_i}}\left\{-V_{F_i} + K_{F_i}\dot{V}_{E_i}\right\}} \quad (2)$$

(iii). $$\boxed{V_{R\text{-}det_i} = \frac{1}{T_{A_i}}\left\{-V_{R_i} + K_{A_i}(V_{ref_i} - V_i - V_{F_i})\right\}} \quad (3a)$$

$$\boxed{\dot{V}_{R_i} = \begin{cases} 0 & V_{R_i} > V_{R\max_i} \text{ \& } V_{R\text{-}det_i} > 0 \\ 0 & V_{R_i} < V_{R\min_i} \text{ \& } V_{R\text{-}det_i} < 0 \\ V_{R\text{-}det_i} & \text{else} \end{cases}} \quad (3)$$

For both Type I and Type II models, equations (1) (for $\dot{V}_E$) will remain unchanged and and (2) (~~for $\dot{V}_R$~~) (for $\dot{V}_F$) will be appended to the set of state variable derivatives. will be appended too, For Type I, equation (3) will directly be appended too, whereas in Type II, in order to accommodate the V_i term, we need to perform the same maneuver as we did for ~~static-based~~ exciter-based AVR in Type II.

where $\boxed{V_i = Y_{mm}^{-1} Y_{mg} V_{gen} \text{ (} i^{th} \text{ row)} \quad i = 1 \text{ to } N_{PV}}$.

Thus, overall for ~~Both~~ Type I ~~and Type II~~ models DC1A enabled AVR model:

$$\cancel{f(x)} \quad \underset{21\times1}{\dot{x}} = \underset{21\times1}{f(x,y)} = \begin{bmatrix} \dot{\Theta}_{3\times1} \\ \dot{\omega}_{3\times1} \\ \dot{E}'_{q\,3\times1} \\ \dot{E}'_{d\,3\times1} \\ \dot{V}_{E\,3\times1} \\ \dot{V}_{F\,3\times1} \\ \dot{V}_{R\,3\times1} \end{bmatrix}_{21\times1}$$

$$\underset{20\times1}{g(x,y)} = \begin{bmatrix} \begin{bmatrix} P \\ Q \end{bmatrix}_{12\times1} \\ \\ \\ \end{bmatrix}_{20\times1}$$

For Type II, DC1A enabled AVR model:

$$\underset{21\times1}{\dot{x}} = \underset{21\times1}{f(x)} = \begin{bmatrix} \dot{\Theta}_{3\times1} \\ \dot{\omega}_{3\times1} \\ \dot{E}'_{q\,3\times1} \\ \dot{E}'_{d\,3\times1} \\ \dot{V}_{E\,3\times1} \\ \dot{V}_{F\,3\times1} \\ \dot{V}_{R\,3\times1} \end{bmatrix}_{21\times1}$$

$\dot{V}_R$ → has a V_i term, which can be computed using

$V_i = Y_{rr}^{-2} Y_{rg} V_{gen}$ (i^{th} row).

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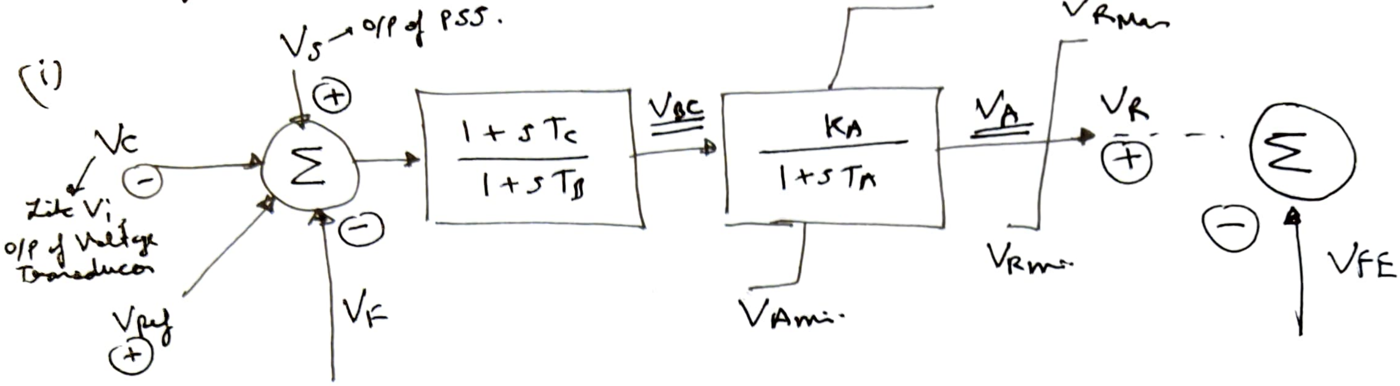
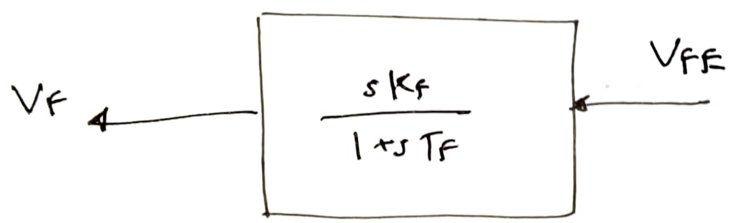
3.1

Type AC1A model:

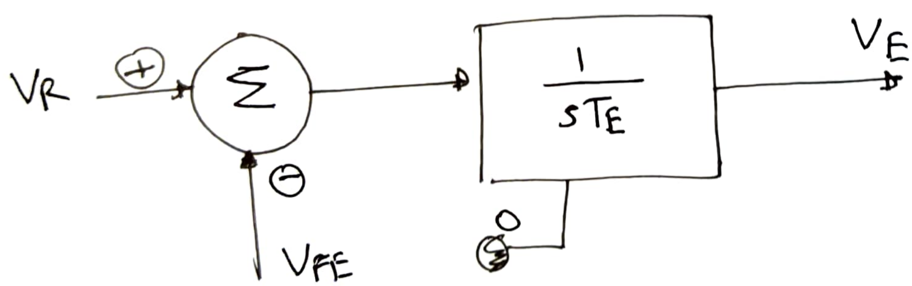
(i)



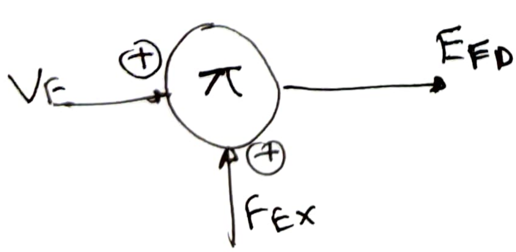
(ii)



(iii)

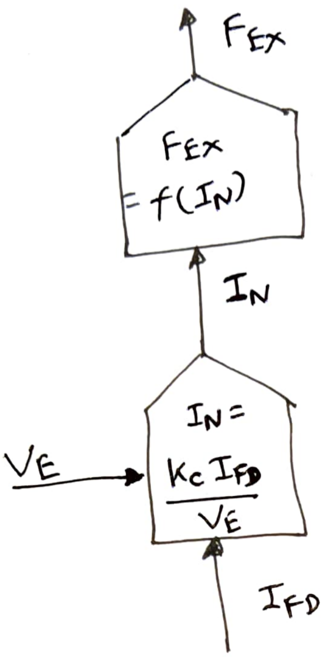


(iv)



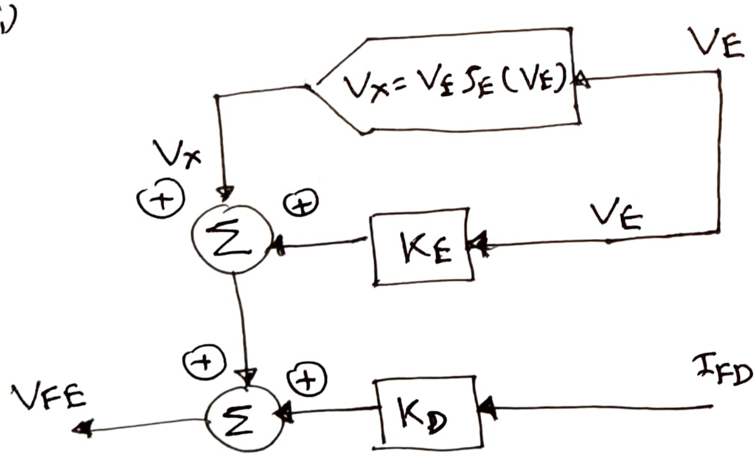
3.2

(v)



F_{EX}
$F_{EX} = f(I_N)$
I_N
$I_N = \frac{K_C I_{FD}}{V_E}$
V_E
I_{FD}

(vi)



V_E
$V_X = V_E S_E(V_E)$
V_X
+
+
Σ
K_E
V_E
+
+
V_{FE}
Σ
K_D
I_{FD}

$$\cancel{\ } (V_S + V_{ref} - V_C - V_F) \cdot (1 + sT_C) = V_{BC} \cdot (1 + sT_B)$$

(i) Assuming that V_S, V_{ref} are constant here:

or $(V_S + V_{ref} - V_C - V_F) - T_C(\dot{V}_C + \dot{V}_F) = V_{BC} + T_B \dot{V}_{BC}$

or (a)
$$\boxed{\dot{V}_{BC} = \frac{1}{T_B}\left\{ -V_{BC} + (V_S + V_{ref} - V_C - V_F) - T_C(\dot{V}_C + \dot{V}_F)\right\}}$$

~~$V_{BC}(1 + sT_A) = K_A V_A$~~

$$V_{BC} K_A = V_A (1 + sT_A)$$

or
$$\boxed{V_{A\text{-}dot} = \frac{1}{T_A}\left\{ -V_A + K_A V_{BC}\right\}}$$

(b)
$$\boxed{\dot{V}_A = \begin{cases} 0 & V_A > V_{Amax} \ \&\ V_{A\text{-}dot} > 0 \\ 0 & V_A < V_{Amin} \ \&\ V_{A\text{-}dot} < 0 \\ V_{A\text{-}dot} & \text{else} \end{cases}}$$

$$\boxed{V_R = \begin{cases} V_{Rmax} & V_A > V_{Rmax} \\ V_{Rmin} & V_A < V_{Rmin} \\ V_A & \text{else} \end{cases}}$$

We could also call V_A as some V_{RO}. (Like we did introduce $V_{A\text{-}dot}$).

(ii) ~~$\dot{V}_F = \frac{1}{T_F}\{-V_F$~~

(ii) $V_F \cdot (1 + sT_F) = sK_F V_{FE}$

or $sV_F = \frac{1}{T_F}(-V_F + sK_F V_{FE})$

or (c)
$$\boxed{\dot{V}_F = \frac{1}{T_F}\left\{ -V_F + K_F \dot{V}_{FE}\right\}}$$

3.4

(iii) $(V_R - V_{FE}) \cdot 1 = s T_E V_E$

or $\boxed{V_{E\text{-}dot} = \frac{1}{T_E}\{V_R - V_{FE}\}}$

(d) $$\boxed{\dot{V_E} = \begin{cases} 0 & V_E < 0 \text{ and } V_{E\text{-}dot} < 0 \\ V_{E\text{-}dot} & \text{else} \end{cases}}$$

(iv) $\boxed{E_{FD} = F_{EX} \cdot V_E}$

(v) $\boxed{I_N = \frac{K_C I_{FD}}{V_E}}$

$$\boxed{F_{EX} = f(I_N) = f\left(\frac{K_C I_{FD}}{V_E}\right)}$$

(vi) $\boxed{V_x = V_E S_E(V_E)}$

$$\boxed{V_{FE} = K_D I_{FD} + K_E V_E + \cancel{V_E S_E(V_E)}\ V_x}$$

State Variables: (Four state variables)

- V_C (it is V_i }, basically } → Here since it is an I/P, ~~since~~ we do not have an equation for its derivative and so we'll assume it to be a constant.
- (1) (a) V_{BC}
- (2) (b) V_R (with $V_{RO} \to V_A$ and $V_{RO\text{-}dot} \to V_{A\text{-}dot}$)
- (3) (c) V_F
- (4) (d) V_E