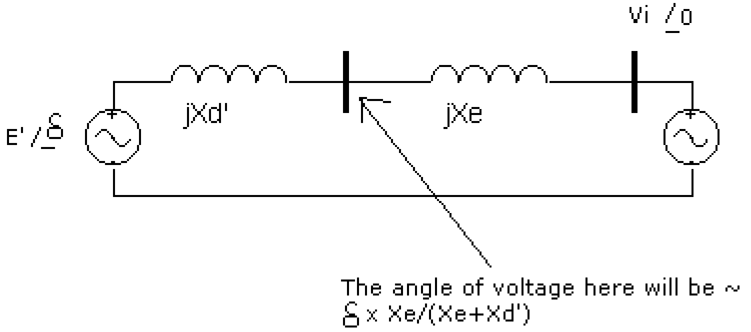
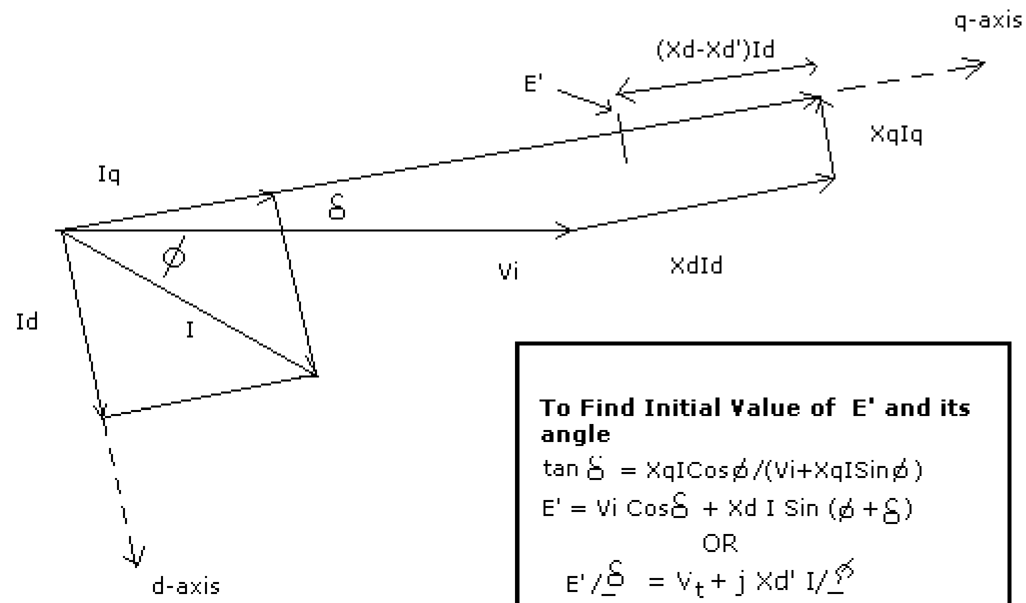
Single Machine - Infinite Bus System
Modelling for Dynamic Stability Analysis



Phasor Diagram Under Steady State



To Find Initial Value of E' and its angle

$\tan\delta = XqI\cos\phi/(Vi+XqI\sin\phi)$

$E' = Vi\cos\delta + Xd\ I\ \sin(\phi+\delta)$

OR

$E'\angle\delta = V_t + j\ Xd'\ I\angle\phi$

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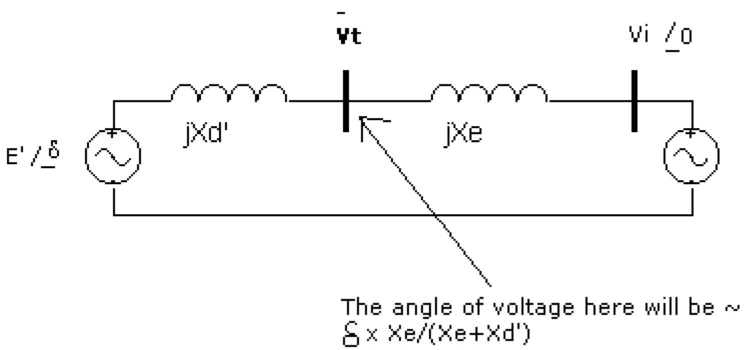

Change in Vt due to changes in E' and its Angle

$$\vec{V_t} = E'\angle\delta \, \frac{X_e}{X_d' + X_e} + V_i \, \frac{X_d'}{X_d' + X_e}$$

$$= E' \cos\delta \, \frac{X_e}{X_d' + X_e} + V_i \, \frac{X_d'}{X_d' + X_e} + j \, E' \sin\delta \, \frac{X_e}{X_d' + X_e}$$

$$V_t^2 = E'^2 \left[\frac{X_e}{X_d'+X_e}\right]^2 + V_i^2 \left[\frac{X_d'}{X_d'+X_e}\right]^2 + 2 V_i E' \, \frac{X_d'//X_e}{X_d'+X_e} \cos\delta$$

$$\therefore \; \Delta V_t = \left(\frac{E'_o}{V_{to}} \left[\frac{X_e}{X_d'+X_e}\right]^2 + \frac{V_i}{V_{to}} \, \frac{X_d'//X_e}{X_d'+X_e} \cos\delta_o \right) \Delta E' - \left(\frac{E'_o V_i}{V_{to}} \, \frac{X_d'//X_e}{X_d'+X_e} \sin\delta_o \right) \Delta\delta$$

$$\text{i.e} \quad \Delta V_t = K_{E'-V} \, \Delta E' - K_{\delta-V} \, \Delta\delta$$

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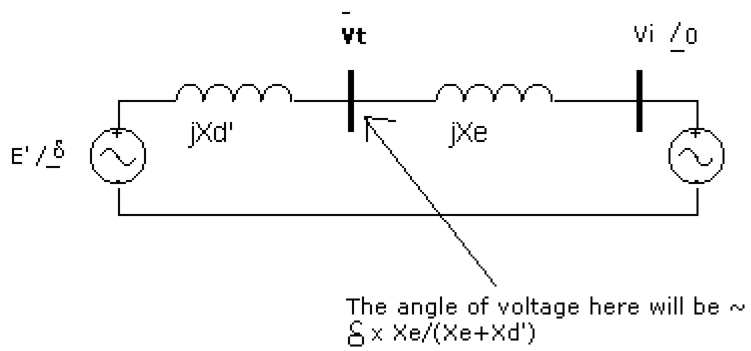


Change in E' due to change in demagnetising component of Current
(This increment has to pass through the field circuit time delay)

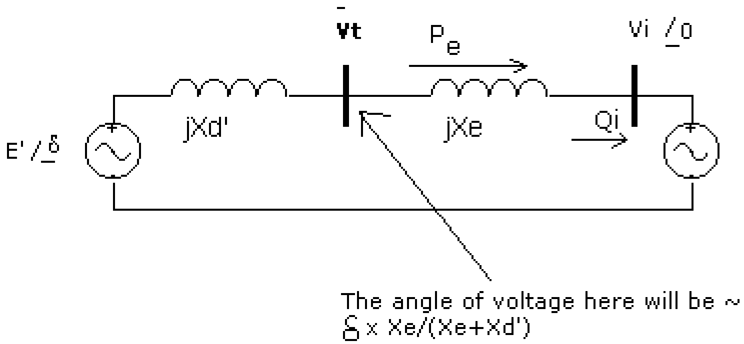
$$I_d = \frac{E' - V_i \cos\delta}{X_d' + X_e}$$

$$\therefore \Delta I_d = \frac{\Delta E'}{X_d' + X_e} + \frac{V_i \sin\delta_0}{X_d' + X_e}\Delta\delta$$

$$\therefore \Delta E' = -\frac{\Delta E'\left(X_d - X_d'\right)}{X_d' + X_e} - \frac{V_i \sin\delta_0\left(X_d - X_d'\right)}{X_d' + X_e}\Delta\delta$$

$$\text{i.e } \Delta E' = -K_{E'-E'}\Delta E' - K_{\delta-E'}\Delta\delta$$

Single Machine - Infinite Bus System Modelling for Dynamic Stability Analysis



Changes in Line Power and Reactive Power at Infinite Bus due to changes in E' and its Angle

$$P_e = \frac{E' \, Vi \, \sin\delta}{Xd' + Xe}$$

$$\therefore \Delta P_e = \frac{E'_0 \, Vi \, \cos\delta_0}{Xd' + Xe} \Delta\delta + Vi \frac{\sin\delta_0}{Xd' + Xe} \Delta E'$$

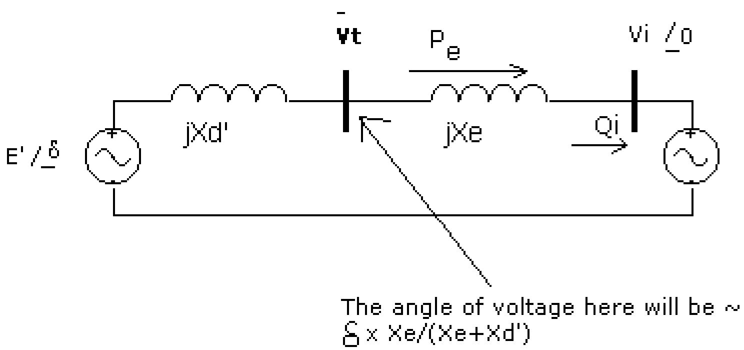
$$\text{i.e } \Delta P_e = + K_{E'\text{-}Pe} \Delta E' + K_{\delta\text{-}Pe} \Delta\delta$$

$$Qi = \frac{Vi \left[E' \cos\delta - Vi \right]}{Xd' + Xe}$$

$$\therefore \Delta Qi = - \frac{E'_0 \, Vi \, \sin\delta_0}{Xd' + Xe} \Delta\delta + Vi \frac{\cos\delta_0}{Xd' + Xe} \Delta E'$$

$$\text{i.e } \Delta Qi = K_{E'\text{-}Qi} \Delta E' - K_{\delta\text{-}Qi} \Delta\delta$$

Single Machine - Infinite Bus System
Modelling for Dynamic Stability Analysis



Effective Damping Constant of the Machine due to Damper Windings

Frequency at Terminal = Xe/(Xe+Xd') times the frequency change at the machine internal voltage.
Therefore frequency differential in the machine is Xd'/(Xe+Xd') times the frequency deviation of the machine with respect to infinite bus.

$$Deff = \frac{D \times Xd'}{Xd' + Xe}$$

where D is the specified damping in pu power per Hz for the machine

Single Machine - Infinite Bus System
Modelling for Dynamic Stability Analysis
— Example —

Generator Rating 500MVA,400MW,
Speed Governor Droop R = 4% ,
Speed Governor Time Constant = 0.4 s ,
Turbine Time Constant = 0.5 s ,
D = 0.04 pu/Hz (due to damper windings)
But this damping coefficient has to be multiplied by Xd'/(Xd'+Xe) to get effective damping coefft.
Inertia Constant = 4 s ,
Nominal Frequency = 50 Hz ,

Line Reactance = 0.2 pu ,
Xd = 1.7 pu , Xd' = 0.27pu , Open Ckt Field Time Constant = 3.8 sec

Excitation System - Rotating Rectifier System - IEEE Type 2
Excitation System Parameters -
Amp Gain - 400 ,
Amp Time Constant - 0.02 s,
Exciter Gain - 1,
Exciter Time Constatnt -0.8s
Derivative Feedback - 0.03
Derivative Feedback Time Constant - 1 s

Initial Operating Point - Infinite Bus at 1<o , Terminal at 1<5.73 deg ,
Delivering 0.5 pu active power at UPF at the terminal.
Therefore E' = Voltage behind transient reactance works out to be 1.022 pu at 13.3 deg.
There is no local load at the terminal.

D_{eff} = 0.04x 0.27/0.47 = 0.023 pu/Hz
Kps = 1/0.023 = 43.5
Power System Time Constant = 7 s , - calculated from H and D_{eff}

E'_0 = 1.022 p.u Vi = 1 p.u
δ_0 = 13.3 deg Xd' = 0.27 p.u
Cos δ_0 = 0.973 Xe = 0.2 p.u
Sin δ_0 = 0.23 Xd = 1.7 p.u

Single Machine - Infinite Bus System
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— Example —

$$\Delta Vt = \left(\frac{E'_o}{Vto} \left[\frac{Xe}{Xd'+Xe} \right]^2 + \frac{Vi}{Vto} \frac{Xd'//Xe}{Xd'+Xe} \cos\delta_o \right) \Delta E' - \left(\frac{E'_o Vi}{Vto} \frac{Xd'//Xe}{Xd'+Xe} \sin\delta_o \right) \Delta\delta$$

$$= \boxed{0.423\,\Delta E' - 0.0575\,\Delta\delta = K_{E'-V}\,\Delta E' - K_{\delta-V}\,\Delta\delta}$$

$$\Delta E' = -\frac{\Delta E' (Xd - Xd')}{Xd' + Xe} - \frac{Vi \sin\delta_o (Xd - Xd')}{Xd' + Xe} \Delta\delta$$

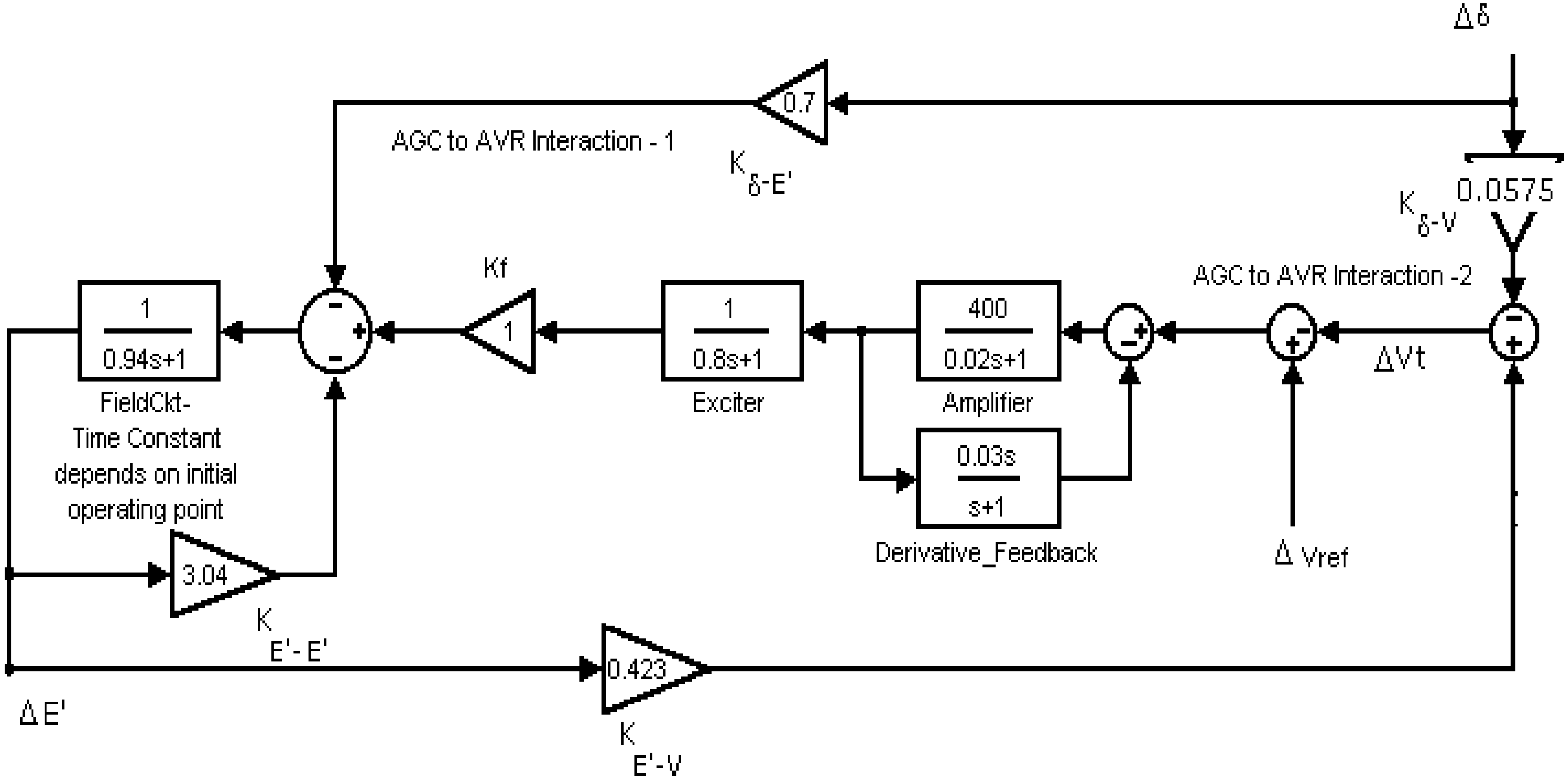
$$= \boxed{-3.04\,\Delta E' - 0.7\,\Delta\delta = -K_{E'-E'}\,\Delta E' - K_{\delta-E'}\,\Delta\delta}$$

$$\Delta P_e = \frac{E'_o\, Vi \cos\delta_o}{Xd' + Xe} \Delta\delta + Vi \frac{\sin\delta_o}{Xd' + Xe} \Delta E'$$

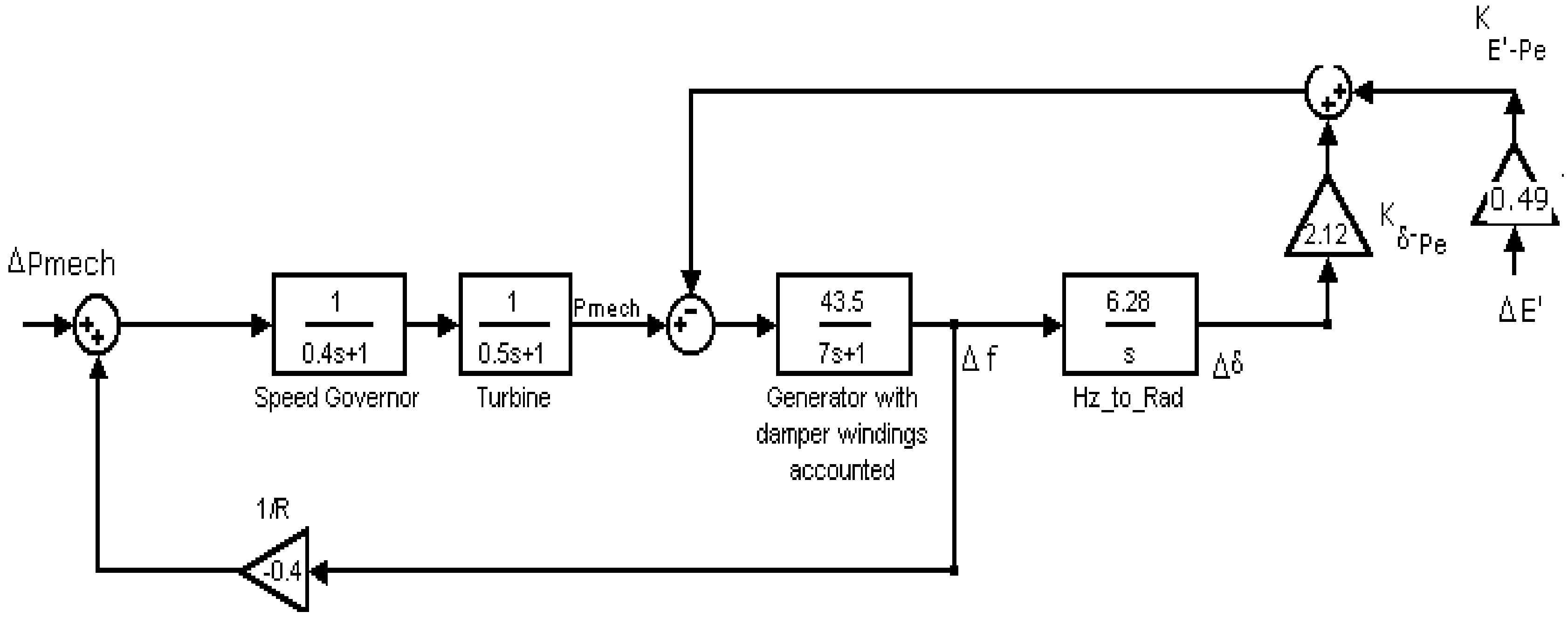
$$= \boxed{2.12\,\Delta\delta + 0.49\,\Delta E' = +K_{\delta-Pe}\,\Delta\delta + K_{E'-Pe}\,\Delta E'}$$

$$\Delta Qi = -\frac{E'_o\, Vi \sin\delta_o}{Xd' + Xe} \Delta\delta + Vi \frac{\cos\delta_o}{Xd' + Xe} \Delta E'$$

$$= \boxed{-0.49\,\Delta\delta + 2.12\,\Delta E' = -K_{\delta-Qi}\,\Delta\delta + K_{E'-Qi}\,\Delta E'}$$


Δδ
0.7
AGC to AVR Interaction - 1
Kδ-E'
0.0575
Kδ-V
AGC to AVR Interaction -2
Kf
1
1
0.94s+1
FieldCkt-
Time Constant
depends on initial
operating point
1
0.8s+1
Exciter
400
0.02s+1
Amplifier
0.03s
s+1
Derivative_Feedback
ΔVt
Δ Vref
3.04
K E'- E'
0.423
K E'-V
ΔE'

AVR Loop



ΔPmech
1
0.4s+1
Speed Governor
1
0.5s+1
Turbine
Pmech
43.5
7s+1
Generator with damper windings accounted
Δ f
6.28
s
Hz_to_Rad
Δδ
2.12
Kδ-Pe
0.49
KE'-Pe
ΔE'
1/R
-0.4

AGC Loop