Heffron-Phillips Model

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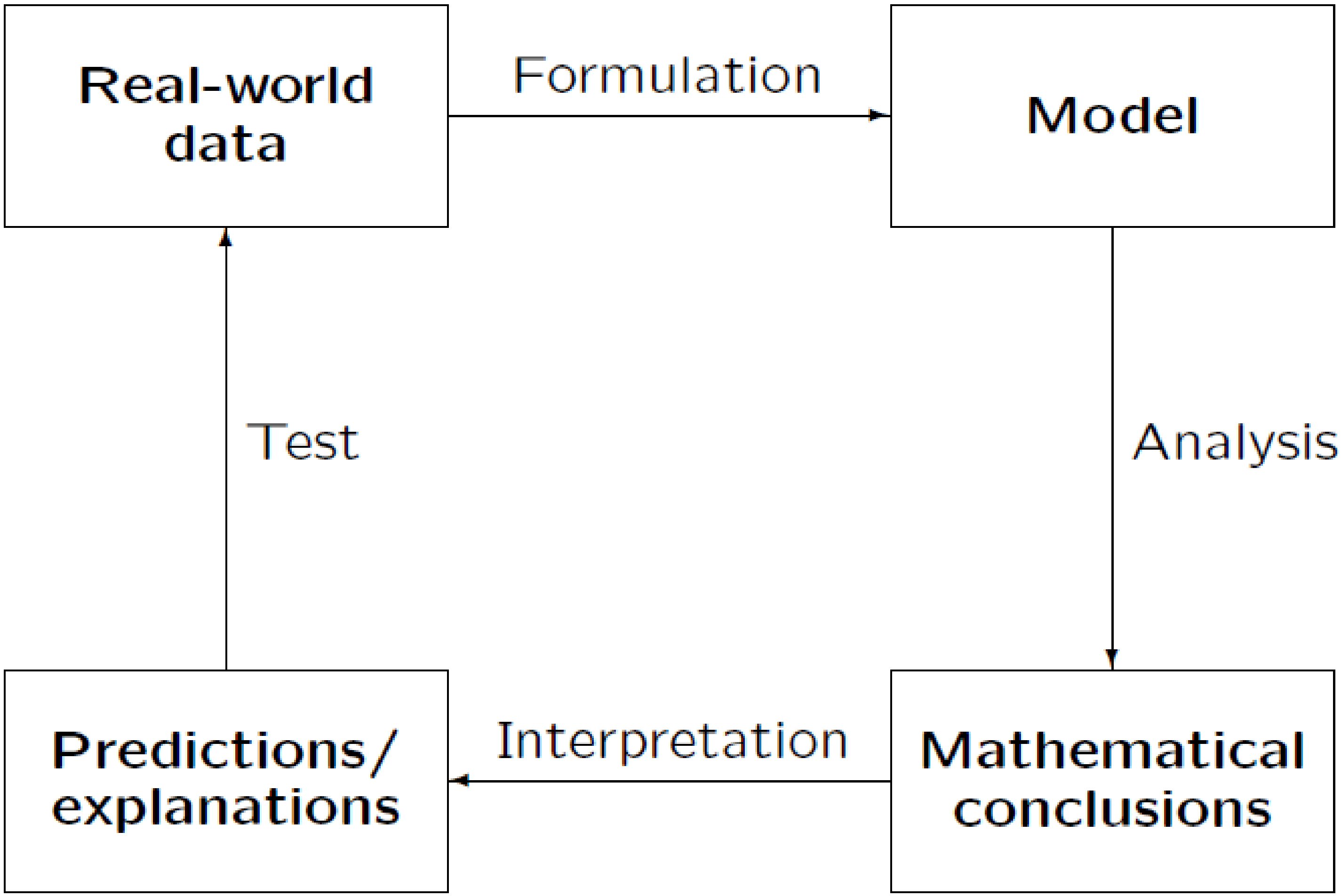
WHAT IS MODELLING



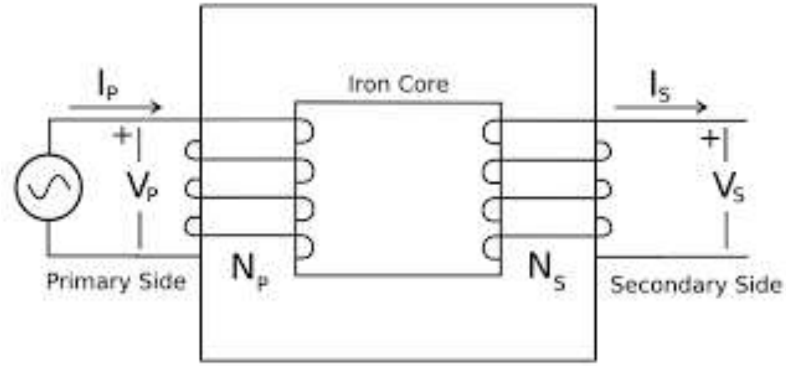
A mathematical model is an abstract model that uses mathematical language to describe the behaviour of a system

- Mathematical models are used particularly in the natural sciences and engineering disciplines but also in the social sciences (such as economics, sociology and political science); physicists, engineers, computer scientists, and economists use mathematical models most extensively.
- Eykhoff (1974) defined a mathematical model as 'a representation of the essential aspects of an existing system (or a system to be constructed) which presents knowledge of that system in usable form'.

Mathematical modelling is the use of mathematics to

- describe real-world phenomena
- investigate important questions about the observed world
- explain real-world phenomena
- test ideas
- make predictions about the real world

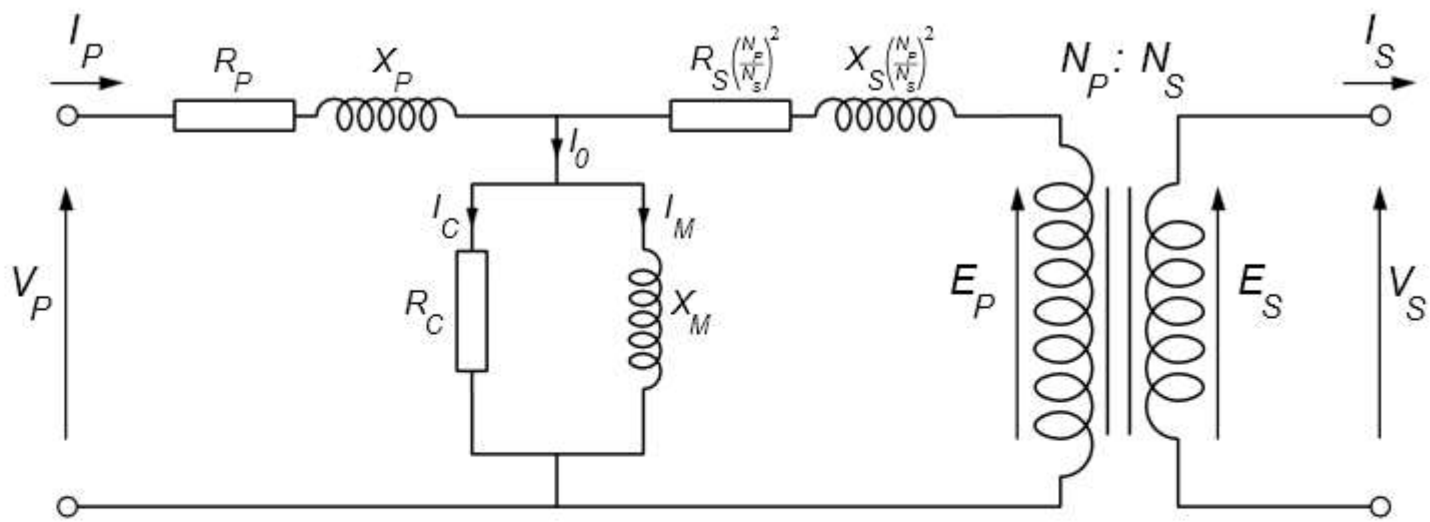
PHYSICAL MODELLING



$$\frac{V_P}{V_S} = \frac{N_P}{N_S} = \frac{I_S}{I_P}$$

Real World , Physical, graphical and Mathematical Modeling

$$E = 4.44 \cdot f \cdot N \cdot a \cdot B$$



Heffron-phillip’s Model

- Heffron-phillip’s Model of a synchronous machine is commonly used for the small signal stability analysis.
- Heffron-Phillips model has been used extensively and many analytical conclusions and design methods have been developed on the basis of Phillips-Heffron model.
- The Heffron-Phillips model of a synchronous machine has successfully been used for investigating the low frequency oscillations and designing power system stabilisers.
- The parameters of the model are usually calculated using the synchronous generator parameters and some system variables at steady-state conditions.
- Heffron-Phillips model of a synchronous machine is commonly used in small signal stability analysis and for off-line design of power system stabilisers.

Purpose:

- Simplified representation of synchronous machine, suitable for stability studies:

  "Small Signal Stability" → linearized model

Basis:

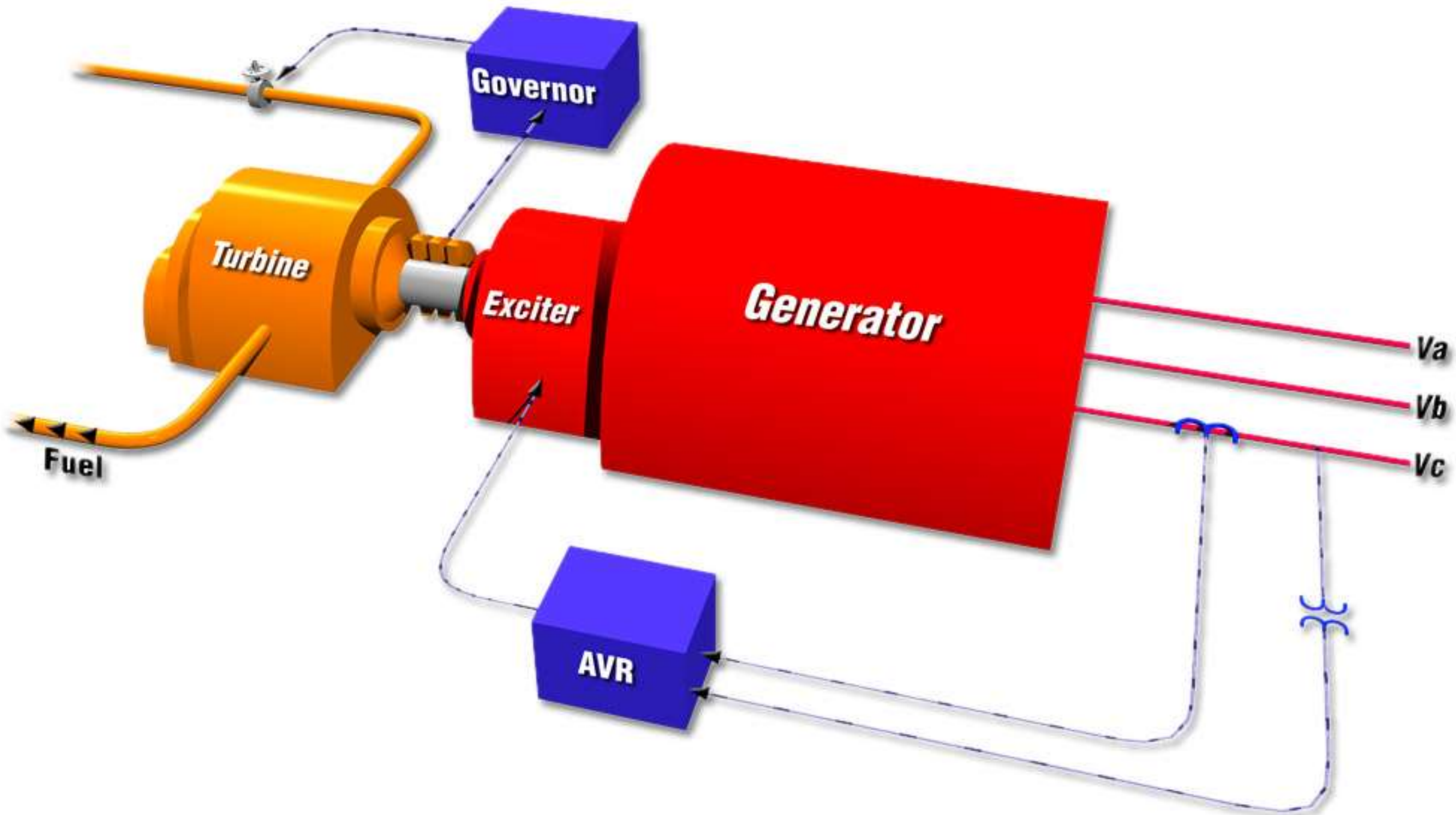
- Third-order Model of synchronous machine

Starting point for derivation:

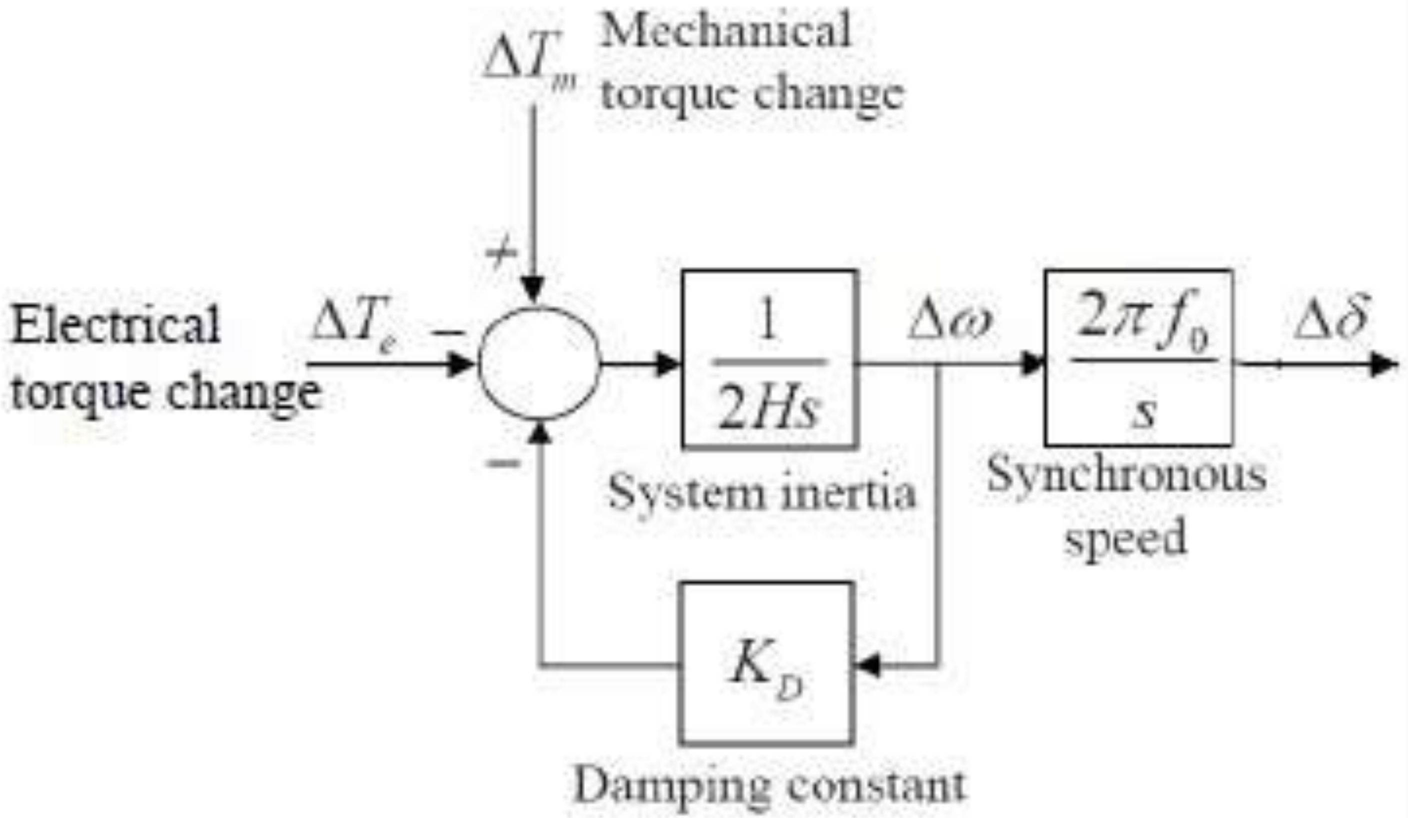
- Single-Machine Infinite-Bus (SMIB) System
- Linearized generator swing equation:

$$\Delta\omega = \frac{1}{2Hs + K_D}(\Delta T_m - \Delta T_e)$$

$$\Delta\delta = \frac{2\pi f_0}{s}\Delta\omega$$

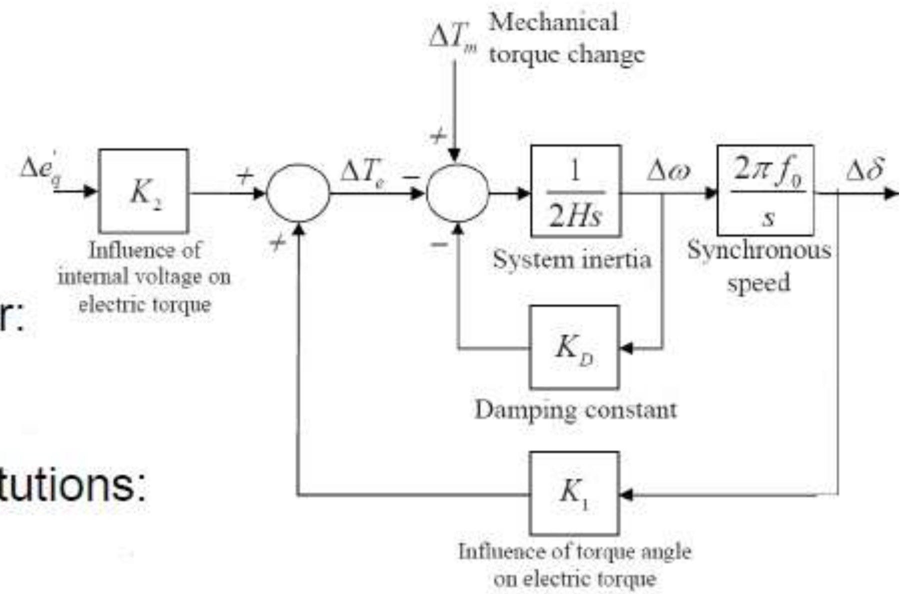

Governor
Turbine
Exciter
Generator
Va
Vb
Vc
Fuel
AVR

BASIC MODEL


ΔT_m
Mechanical
torque change
+
Electrical
torque change
ΔT_e
−
−
$\frac{1}{2Hs}$
System inertia
$\Delta\omega$
$\frac{2\pi f_0}{s}$
Synchronous
speed
$\Delta\delta$
K_D
Damping constant

Heffron-Phillips Model

… including the composition of the electric torque:



Approximation of torque with power:

$$T_e \approx P_e = i_d u_d + i_q u_q$$

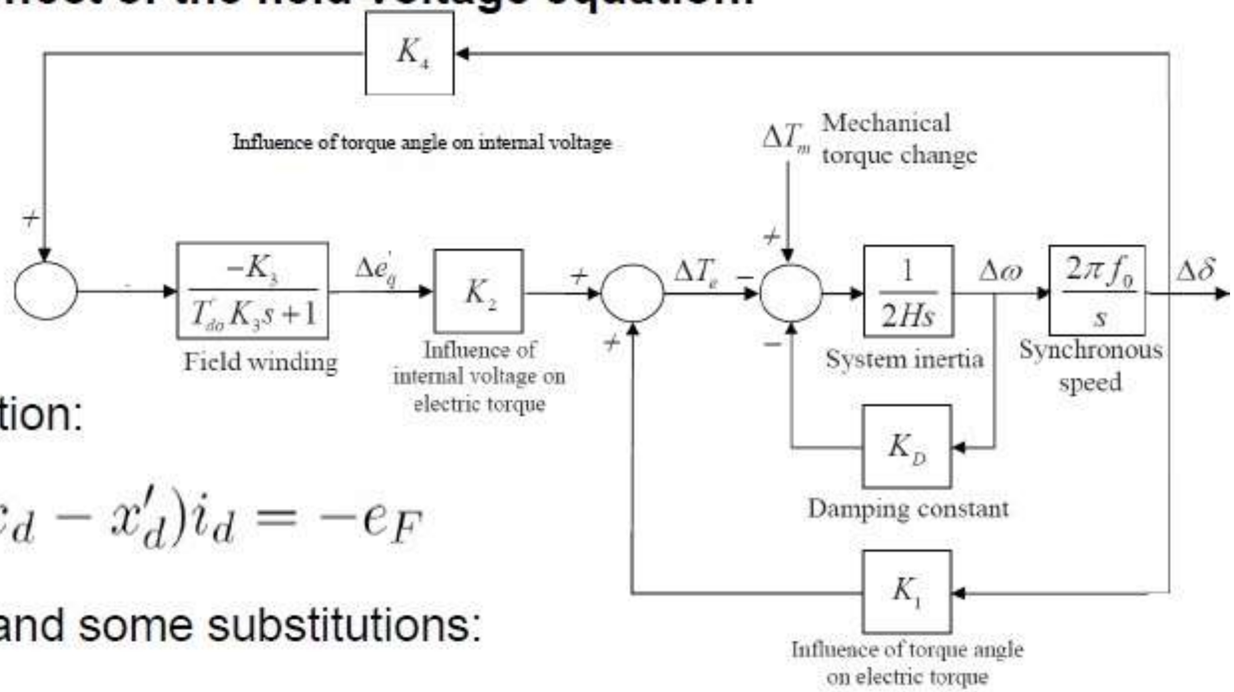
After linearization and some substitutions:

$$\Delta T_e = K_1 \Delta\delta + K_2 \Delta e_q'$$

$$\begin{bmatrix} K_1 \\ K_2 \end{bmatrix} = \begin{bmatrix} 0 \\ i_{q0} \end{bmatrix} + \begin{bmatrix} F_d & F_q \\ Y_d & Y_q \end{bmatrix} \begin{bmatrix} (x_q - x_d')i_{q0} \\ e_{q0}' + (x_q - x_d')i_{d0} \end{bmatrix}$$

Heffron-Phillips Model

… including the effect of the field voltage equation:



Field voltage equation:

$$T'_{do}\dot{e}'_q + e'_q + (x_d - x'_d)i_d = -e_F$$

After linearization and some substitutions:

$$(1 + s\,T'_{do}K_3)\Delta e'_q = -K_3(\Delta e_F + K_4\Delta\delta)$$

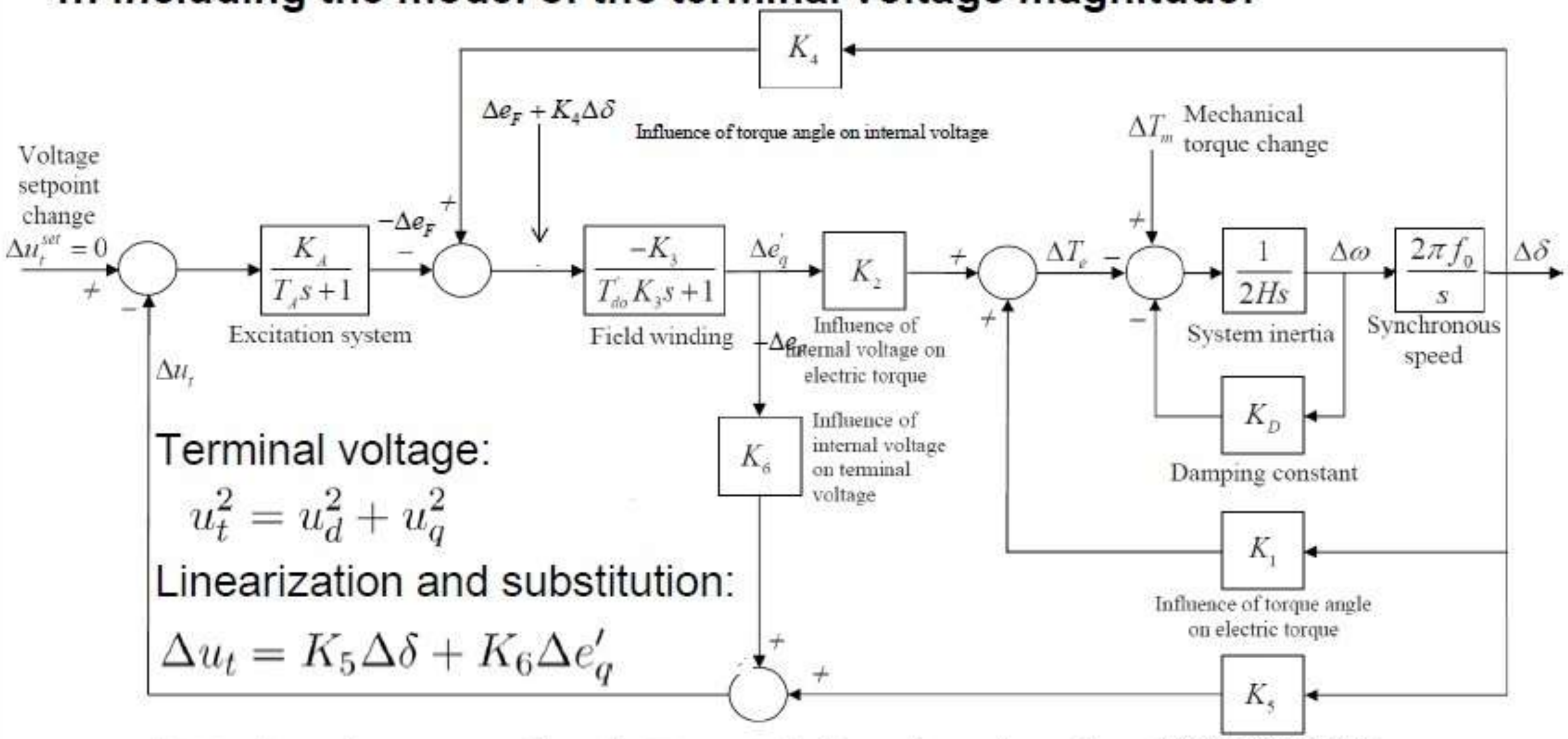
with:

$$K_3 = 1/(1 + (x_d - x'_d)Y_d)$$

$$K_4 = (x_d - x'_d)F_d$$

Heffron-Phillips Model

… including the model of the terminal voltage magnitude:



Terminal voltage:

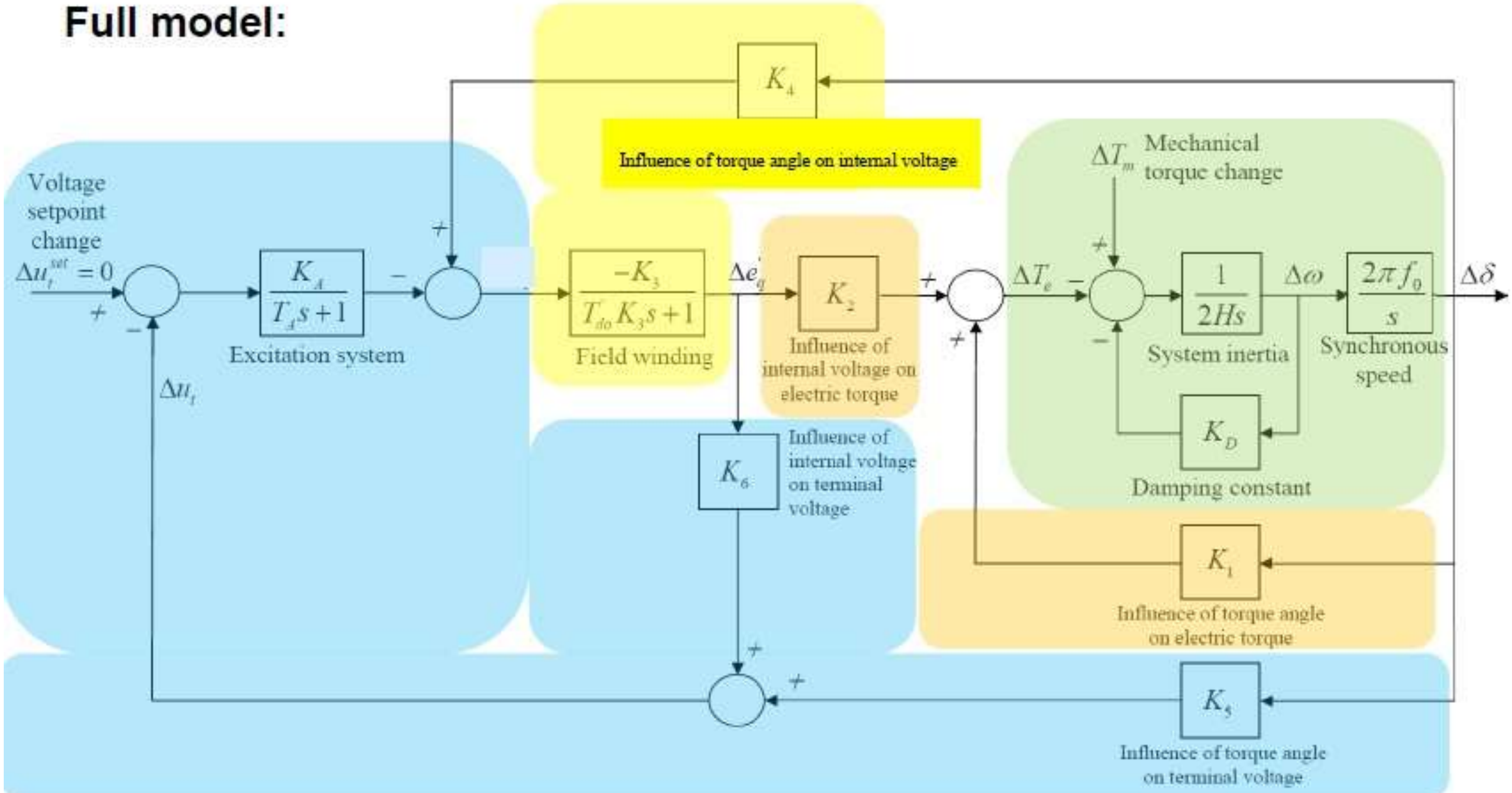
$$u_t^2 = u_d^2 + u_q^2$$

Linearization and substitution:

$$\Delta u_t = K_5\Delta\delta + K_6\Delta e'_q$$

with $\begin{bmatrix} K_5 \\ K_6 \end{bmatrix} = \begin{bmatrix} 0 \\ u_{q0}/u_{t0} \end{bmatrix} + \begin{bmatrix} F_d & F_q \\ Y_d & Y_q \end{bmatrix} \begin{bmatrix} -x'_d u_{q0}/u_{t0} \\ x_q u_{d0}/u_{t0} \end{bmatrix}$

Full model:



K_4
Influence of torque angle on internal voltage
Voltage setpoint change
$\Delta u_t^{set} = 0$
+
−
$\frac{K_A}{T_A s + 1}$
Excitation system
−
+
Δu_t
$\frac{-K_3}{T_{do} K_3 s + 1}$
Field winding
$\Delta e_q'$
K_2
Influence of internal voltage on electric torque
K_6
Influence of internal voltage on terminal voltage
+
+
ΔT_e
ΔT_m
Mechanical torque change
+
−
−
$\frac{1}{2Hs}$
System inertia
$\Delta \omega$
$\frac{2\pi f_0}{s}$
Synchronous speed
$\Delta \delta$
K_D
Damping constant
K_1
Influence of torque angle on electric torque
+
+
K_5
Influence of torque angle on terminal voltage