Fault Tolerant Control

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Outline

- Definition of problem
- Modelling
- Fault detection filters
- Fault tolerant control systems
- Example

Introduction

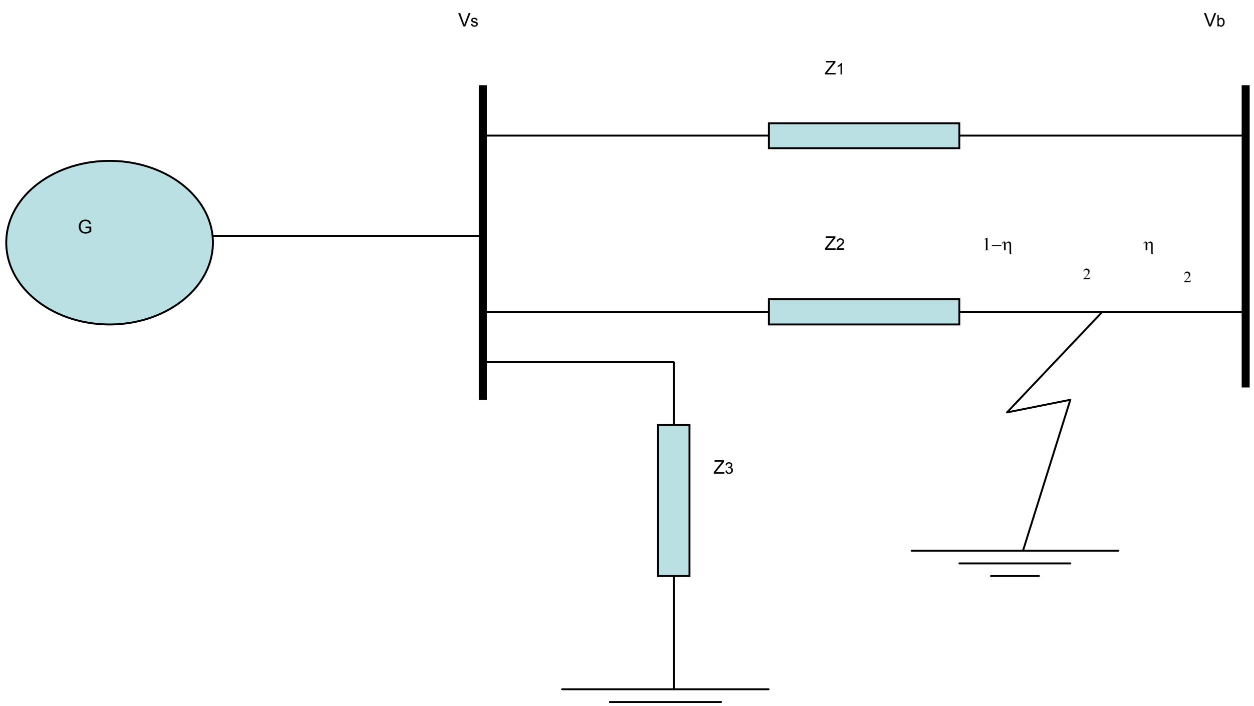
- Used in critical applications where faults cannot be tolerated
- Additional features need to be incorporated into the control system to maintain adequate/safe operation during abnormal conditions

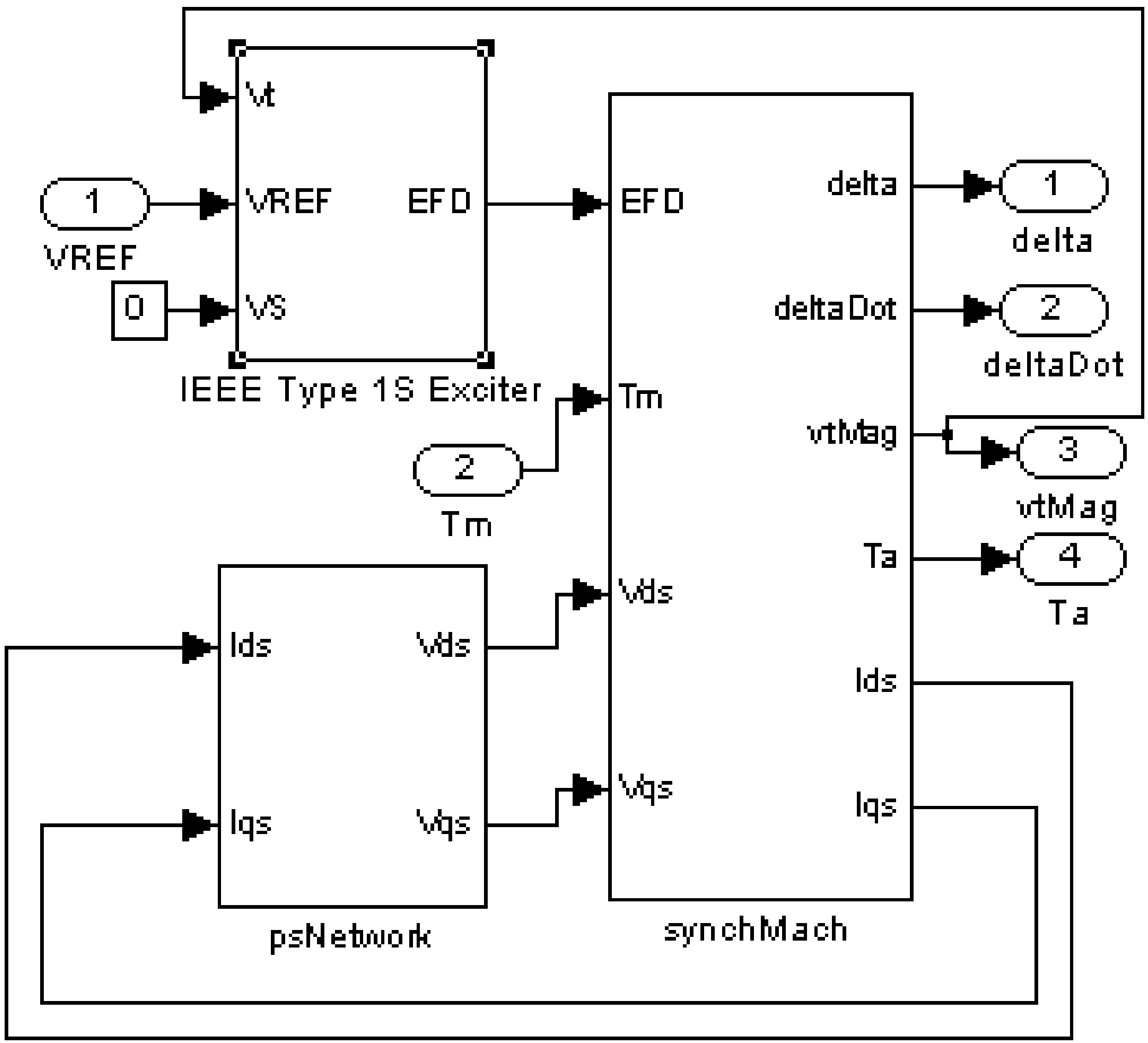
Example 1 – Fighter Aircraft

- Have redundant flight control surfaces, eg 17 instead of traditional 3 (aileron, elevator, rudder).
- Control reconfigurator distributes control effort amongst functioning control surfaces

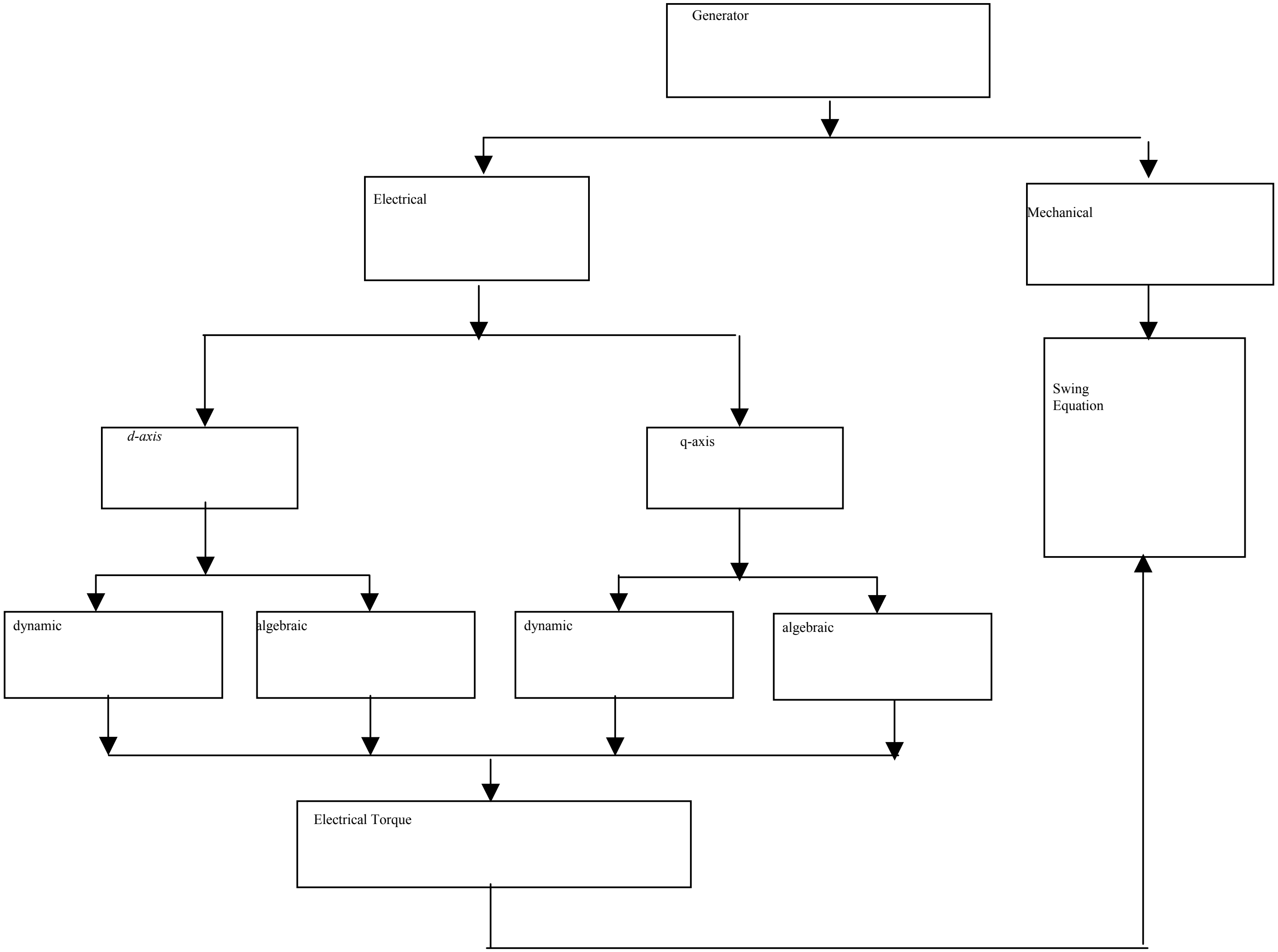
Example 2: Power Systems

- Detect, locate fault + reconfigure generation





Vt
1
VREF
VREF
EFD
0
VS
IEEE Type 1S Exciter
EFD
delta
1
delta
deltaDot
2
deltaDot
Tm
2
Tm
vtMag
3
vtMag
Ta
4
Ta
Ids
Vds
Vds
Iqs
Vqs
Vqs
psNetwork
Ids
Iqs
synchMach


Generator
Electrical
Mechanical
Swing Equation
d-axis
q-axis
dynamic
algebraic
dynamic
algebraic
Electrical Torque

Modelling for FTC

- Nonlinear dynamical system, with state vector x, input vector u, output vector y, and fault signal vector f:

$$\dot{x} = f(x, u, m, t)$$

$$y = g(x, u, m, t)$$

Fault Detection and Isolation

- Requirement: design a filter to unambiguously detect each possible fault {Isidori, differential geometry…}
- Simpler problem: design a bank of filters with each customised toward detecting a specific fault {Mueller, svd}

Design of FTC system

- Start with fault detection filter, then use active control reconfiguration
- Various possibilities:
  - Switched controllers
  - Smoothly-scheduled controllers

Unknown Inp Obs [Hou & Mueller]

- plant

$$\dot{x}(t) = Ax(t) + Bu(t) + \sum_{i=1}^{k} L_i m_i(t)$$

$$y(t) = Cx(t)$$

- filter

$$\dot{w}(t) = H_1 w(t) + H_2 y(t) + H_3 u(t)$$

$$r(t) = H_4 w(t) + H_5 y(t)$$

Plant model

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \end{bmatrix} = \begin{bmatrix} 0 & 3 & 4 \\ 1 & 2 & 3 \\ 0 & 2 & 5 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} 1 \\ -0.5 \\ 0.5 \end{bmatrix} m_1 + \begin{bmatrix} -3 \\ 1 \\ 0 \end{bmatrix} m_2$$

FDI filter #1

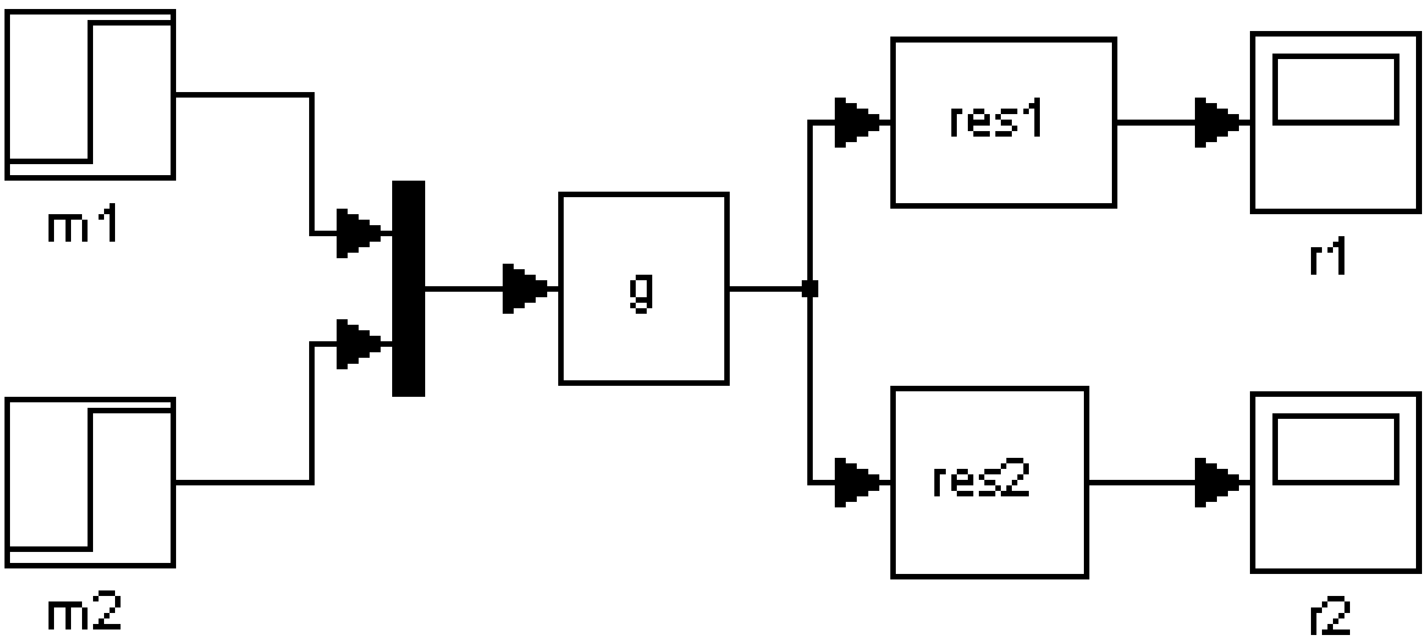
$$\dot{\eta} = (5-\alpha)\eta + \begin{bmatrix} 2 & \alpha \end{bmatrix} y \qquad \alpha > 5$$

$$r_1 = -\eta + \begin{bmatrix} 1 & 0 \end{bmatrix} y$$

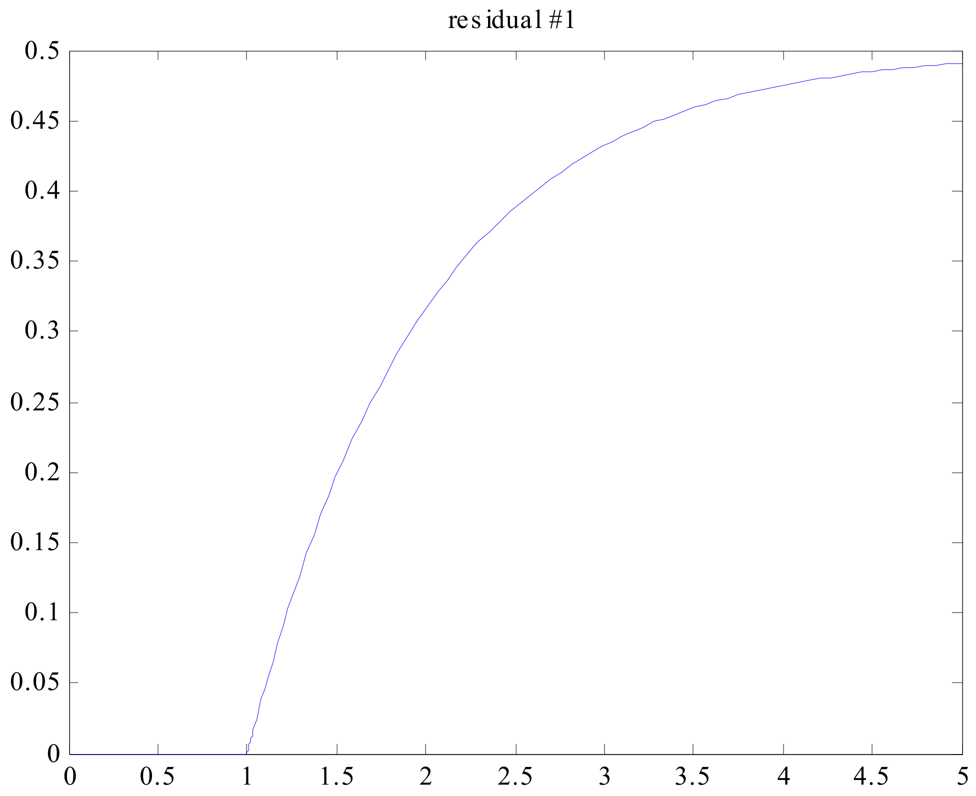
- FDI filter #2

$$\dot{\xi} = \begin{bmatrix} 2 & 3 - l_1 \\ 1 & 2 - l_2 \end{bmatrix} \xi + \begin{bmatrix} l_1 & 7 + l_1 \\ l_2 & 6 + l_2 \end{bmatrix} y$$

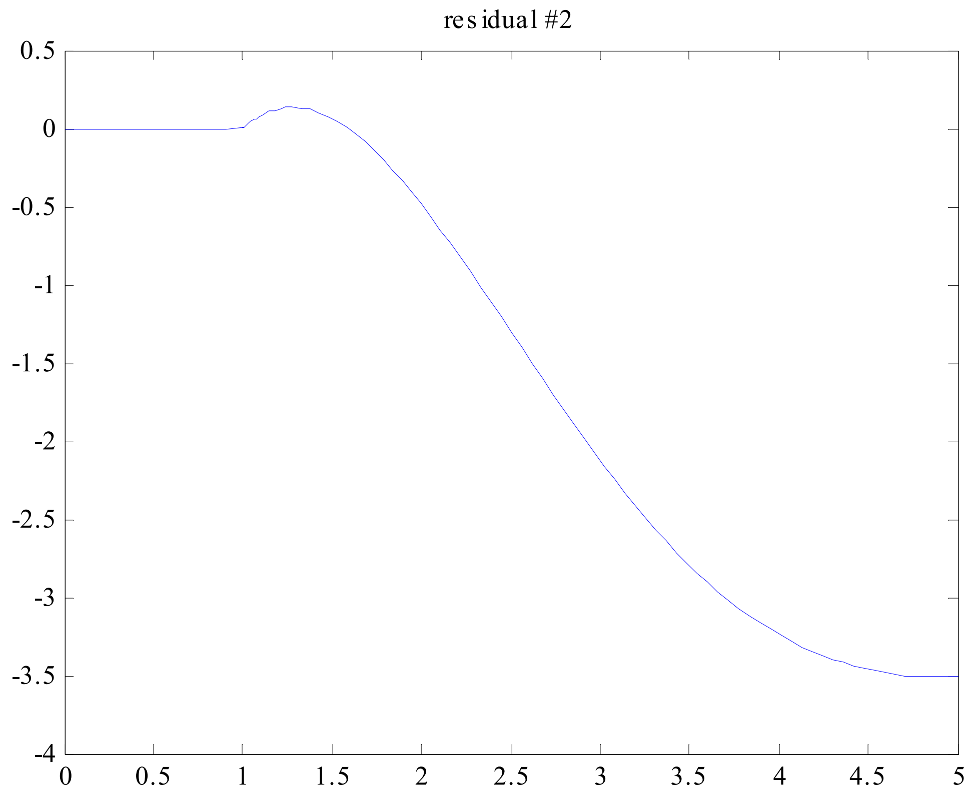
$$r_2 = \begin{bmatrix} 0 & -1 \end{bmatrix} \xi + \begin{bmatrix} 1 & 1 \end{bmatrix} y$$


m1
m2
g
res1
res2
r1
r2

Performance of filter #1



Performance of filter #2



Conclusions

- FTC remains largely an open problem, much research required (present theory only copes with very simple systems and is therefore not of any practical use).