Using a TCSC for Line Power Scheduling and System Oscillation Damping

Small Signal and Transient Stability Studies

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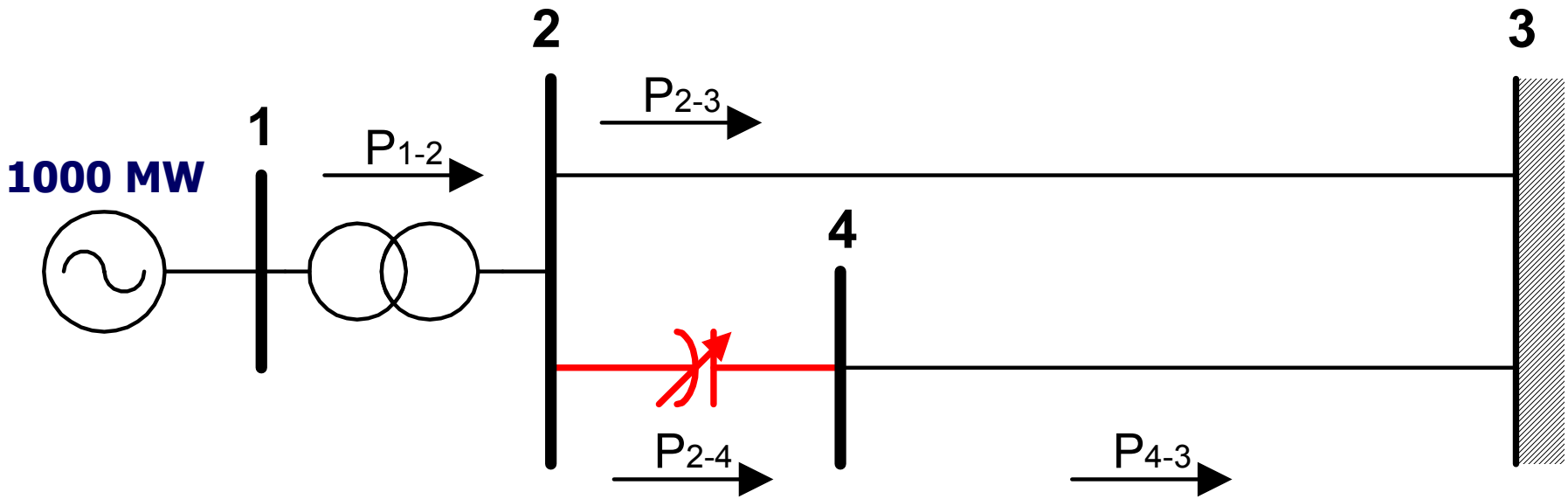
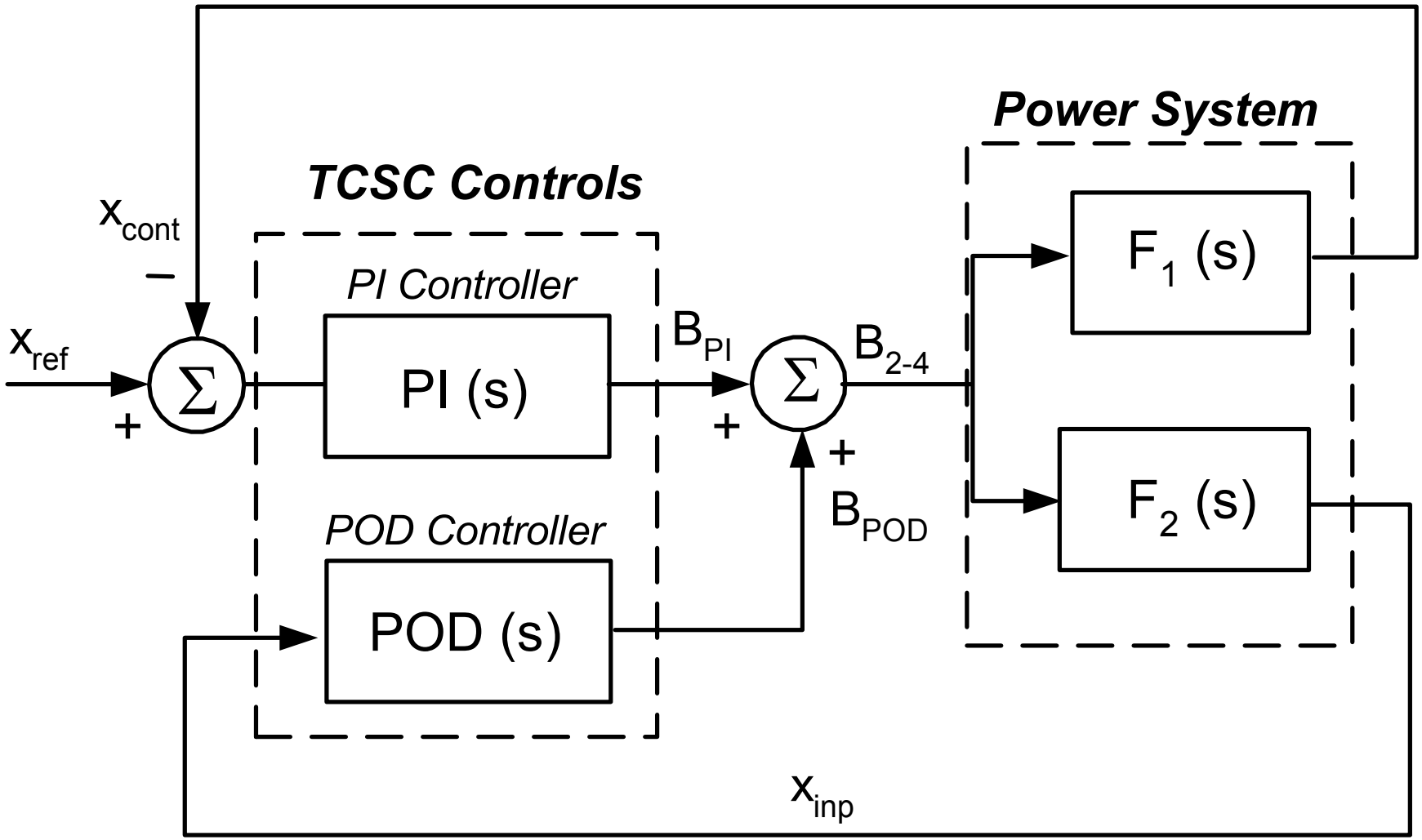
Paper Outline

- TCSC control aspects reviewed
- Tutorial example (Full data provided)
- Two line power scheduling strategies
- Design of power oscillation damping controller
- Potential control problems during line outages
- Transient stability results

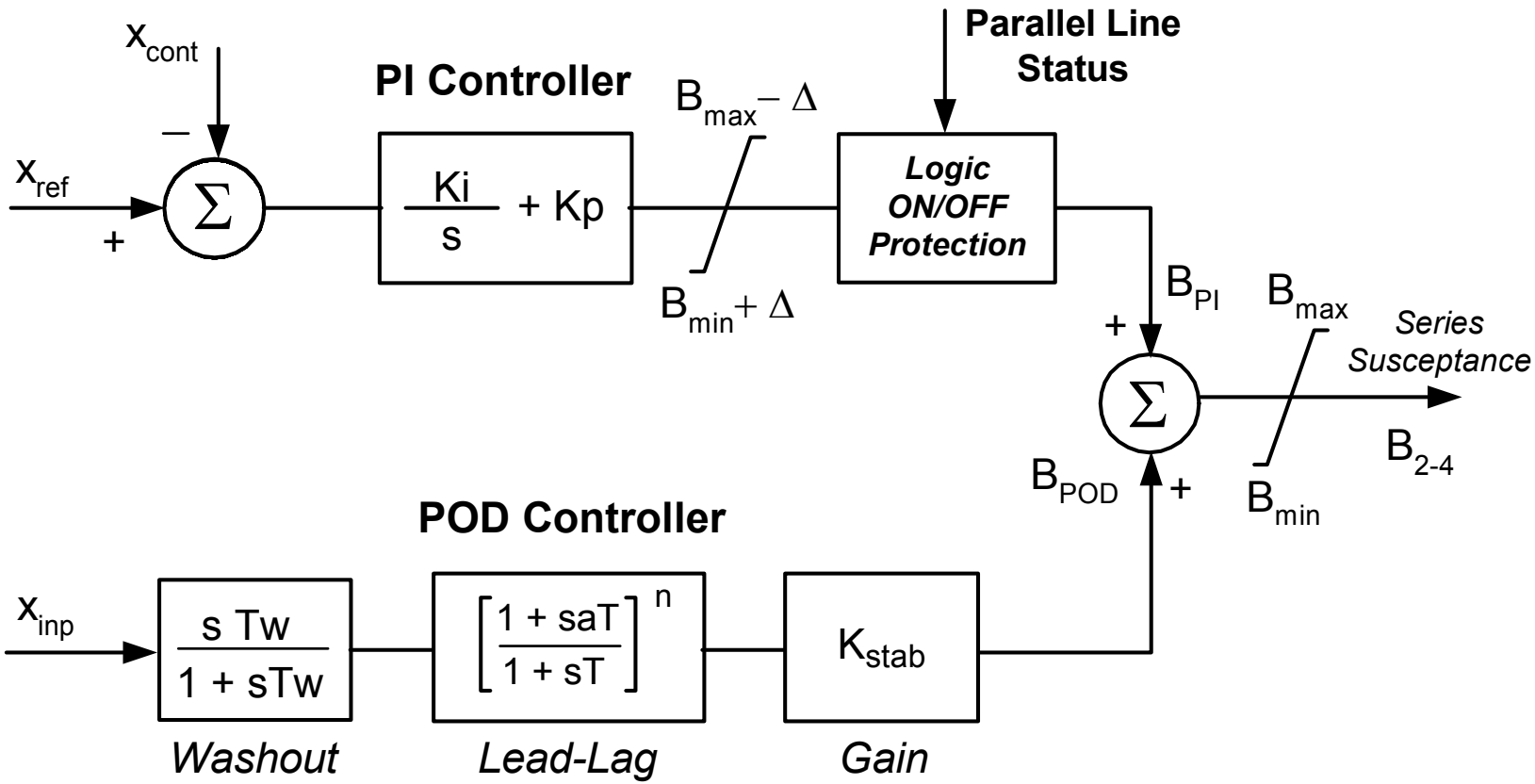
Small Power System with TCSC



TCSC Control System Diagram



TCSC Controls



Ki = 5, Kp = 0.5 in all cases

$x_{cont} = P_{2\text{-}4}$ for Constant Line Power Strategy

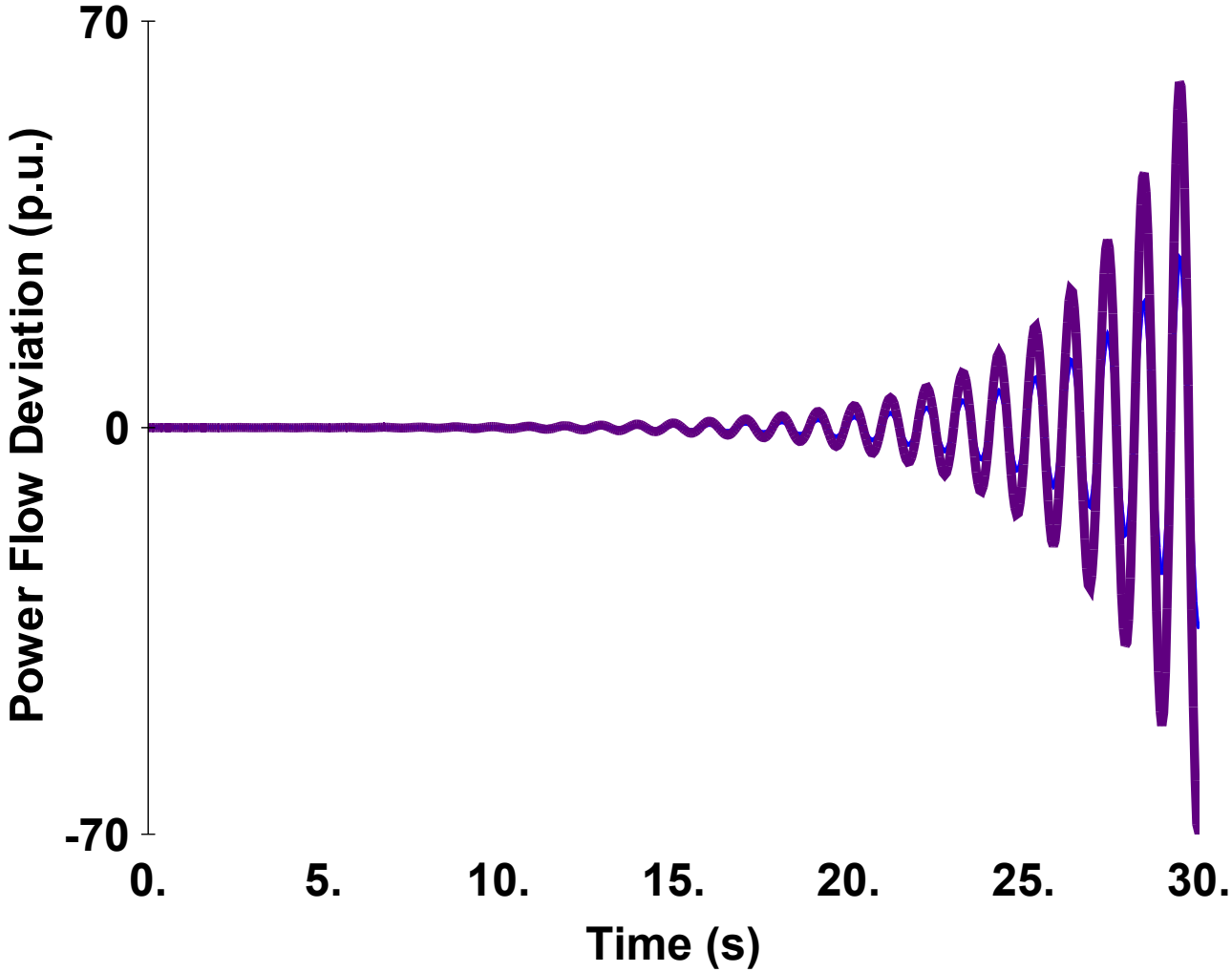
$x_{cont} = P_{2\text{-}4} + P_{2\text{-}1}$ for Constant Angle Strategy

$B_{max} = 5$

$B_{min} = 2.5$

$\Delta = 0.1$

TCSC at Fixed Impedance Mode

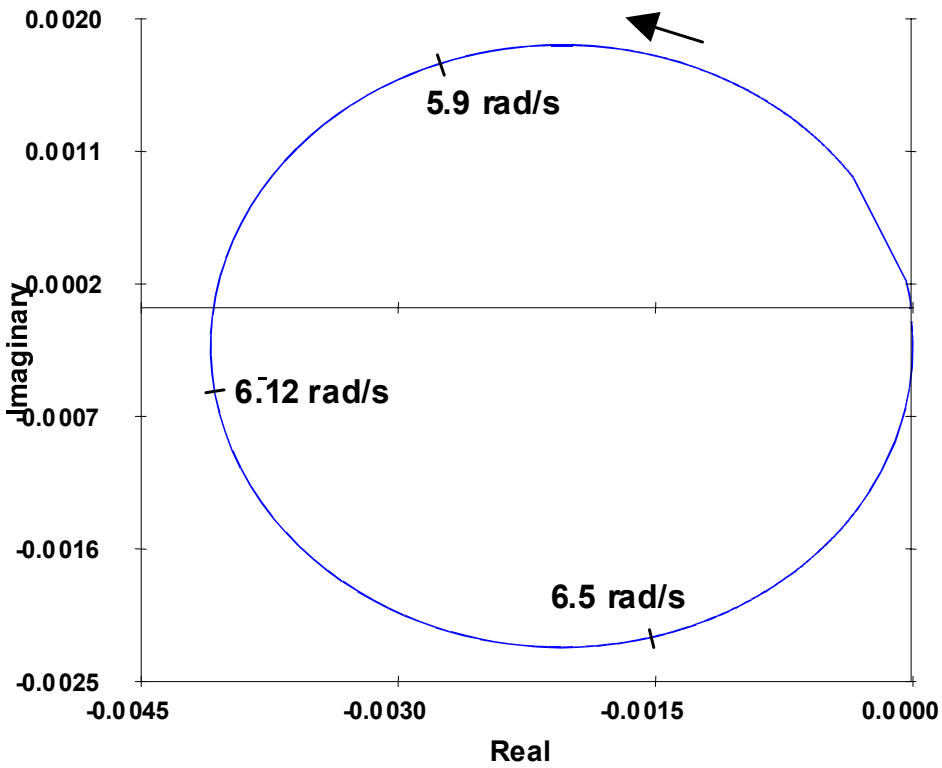


Dominant Mode λ = +0.305 $\pm$j 6.126

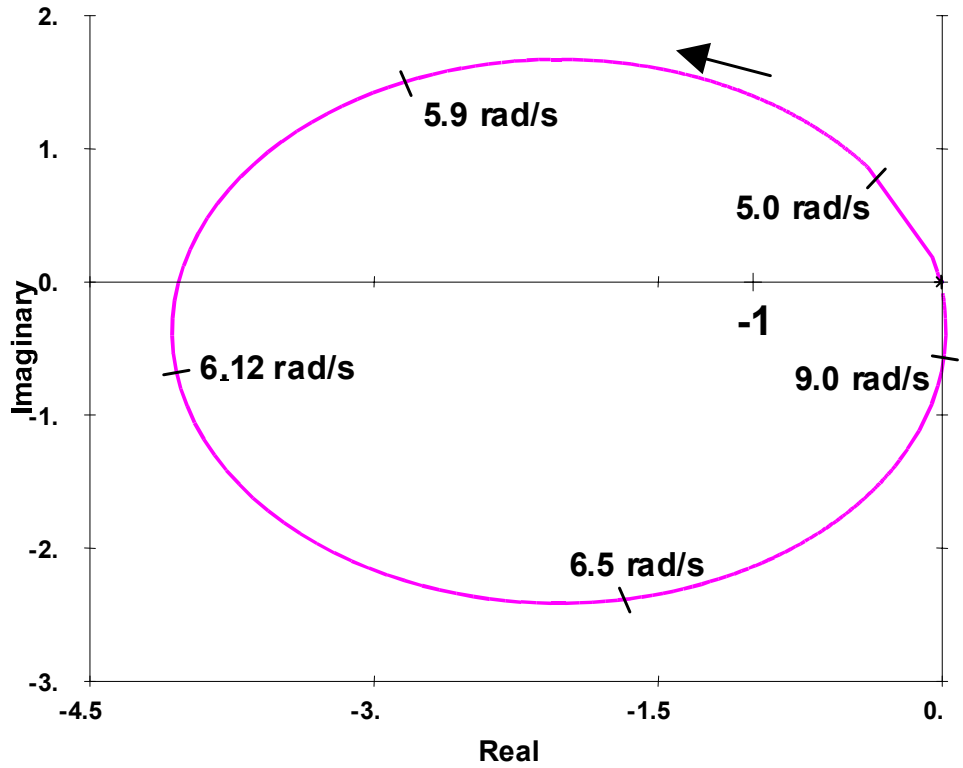
POD Controller Design

- POD Controller design is here based on Nyquist Plots of a chosen Open Loop Transfer Function (OLTF)
- Generator speed (ω) is chosen as the POD controller input
  - Local bus frequency could be used
  - No need for phase compensation

POD Controller Design

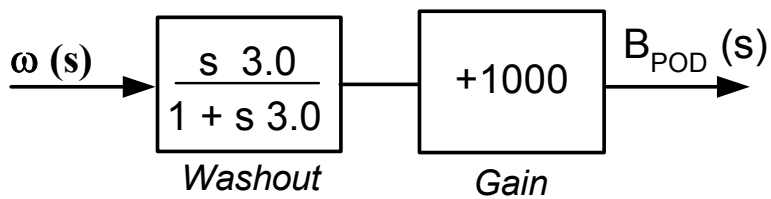


Nyquist Plot of OLTF

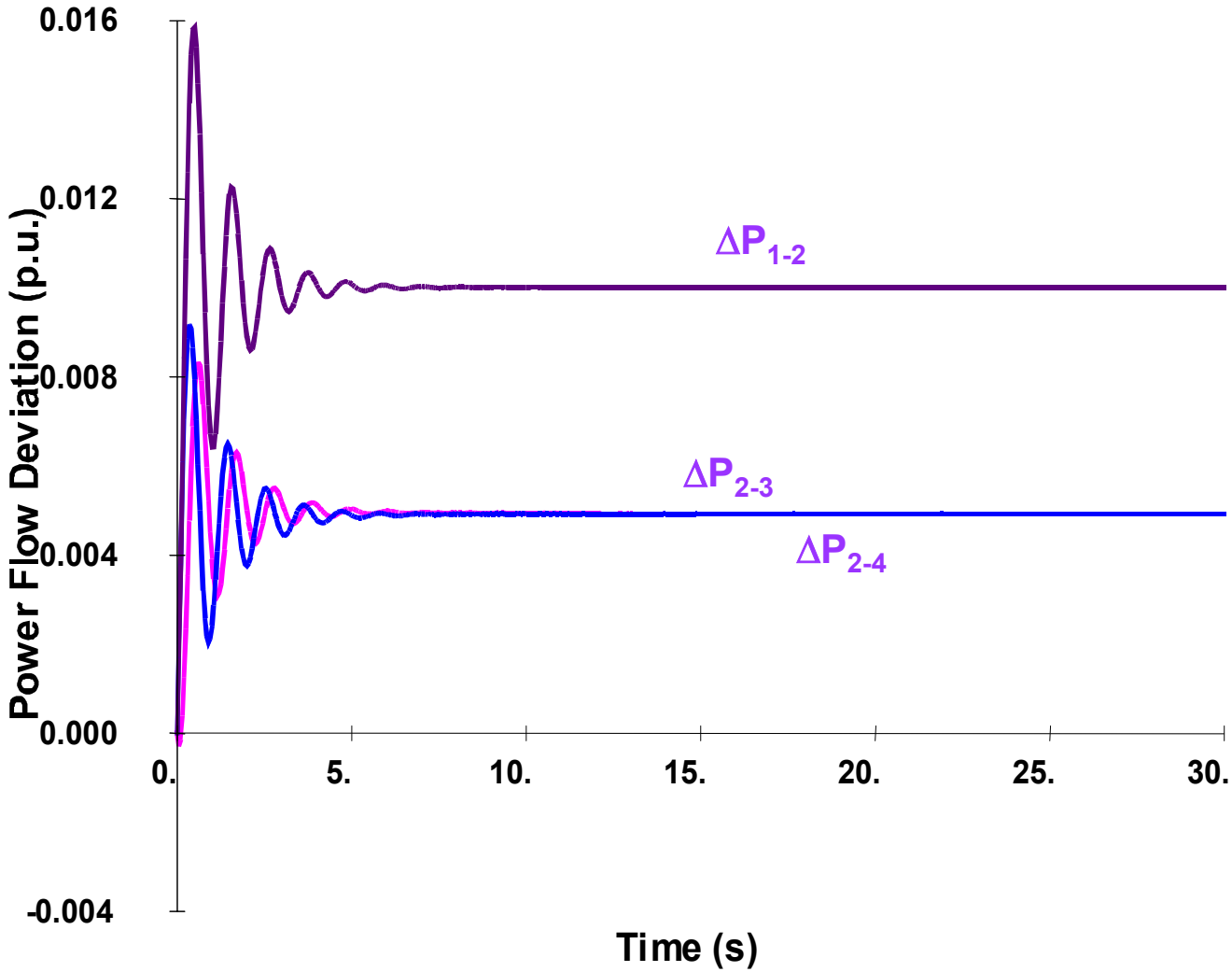


Nyquist Plot of OLTF * POD (s)

POD Controller

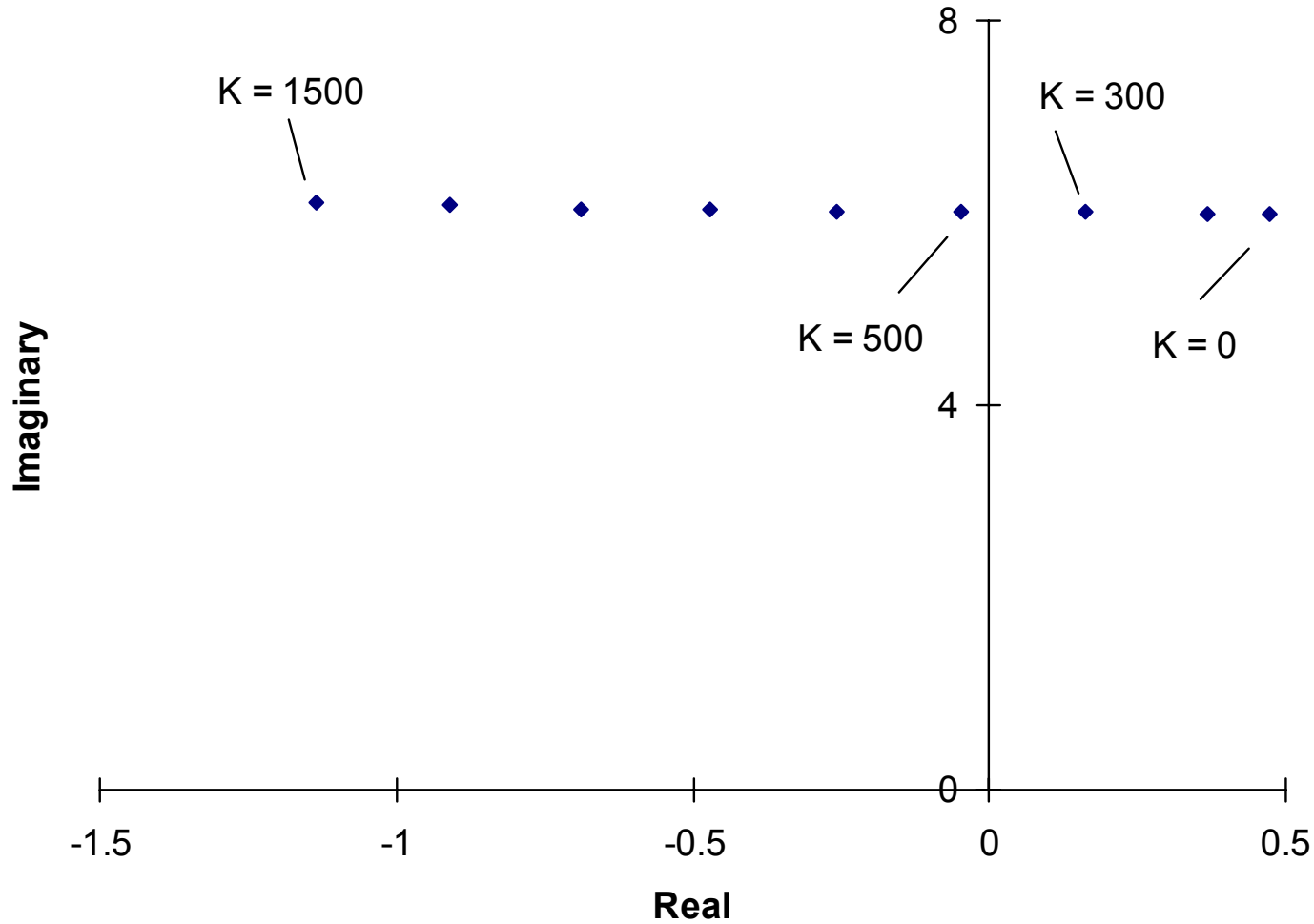


TCSC with POD Controller



Dominant Mode λ = -0.890 $\pm$j 5.822

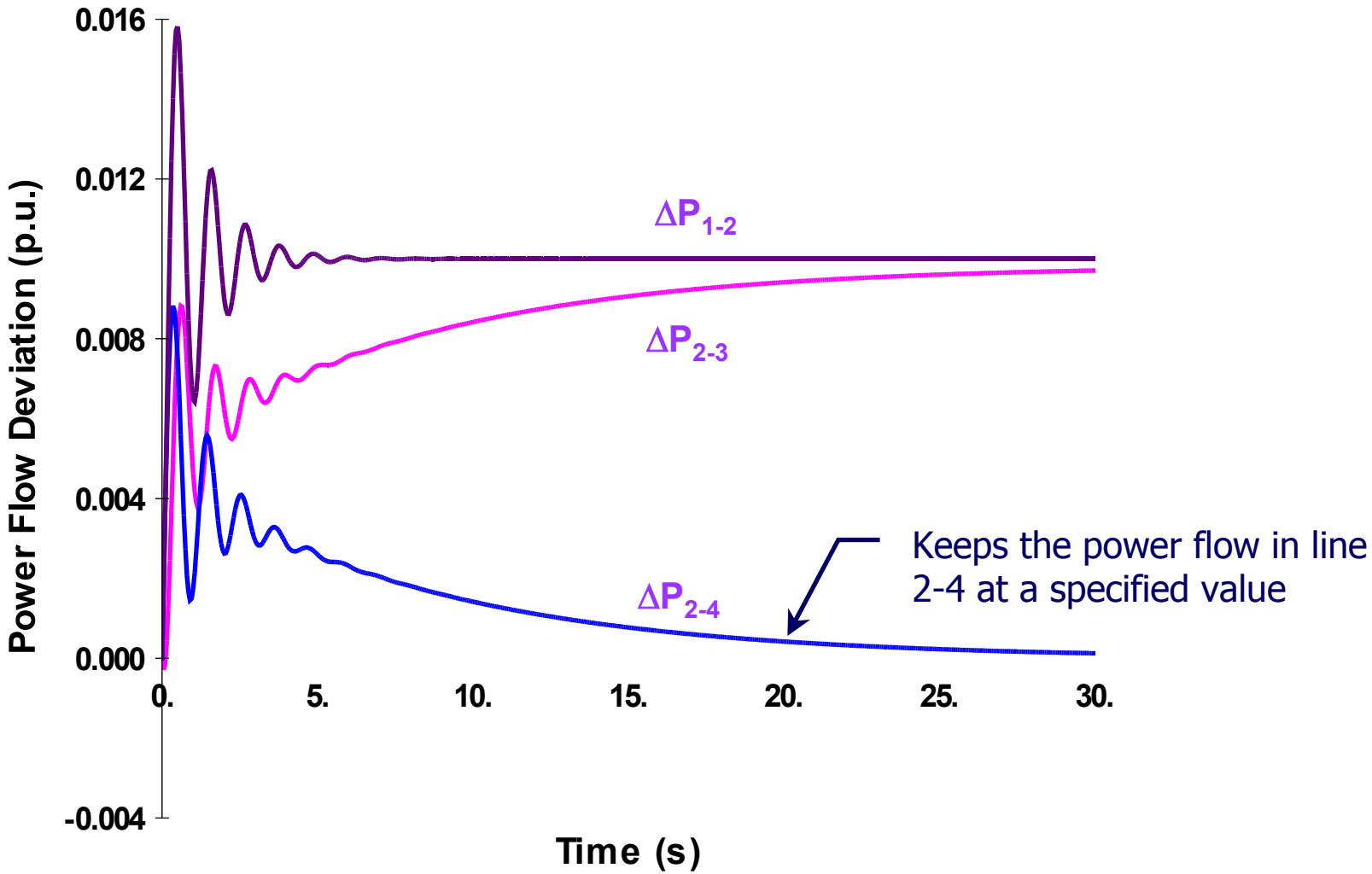
Root Locus for Changes in Gain of POD Controller



TCSC Line Power Scheduling Strategies

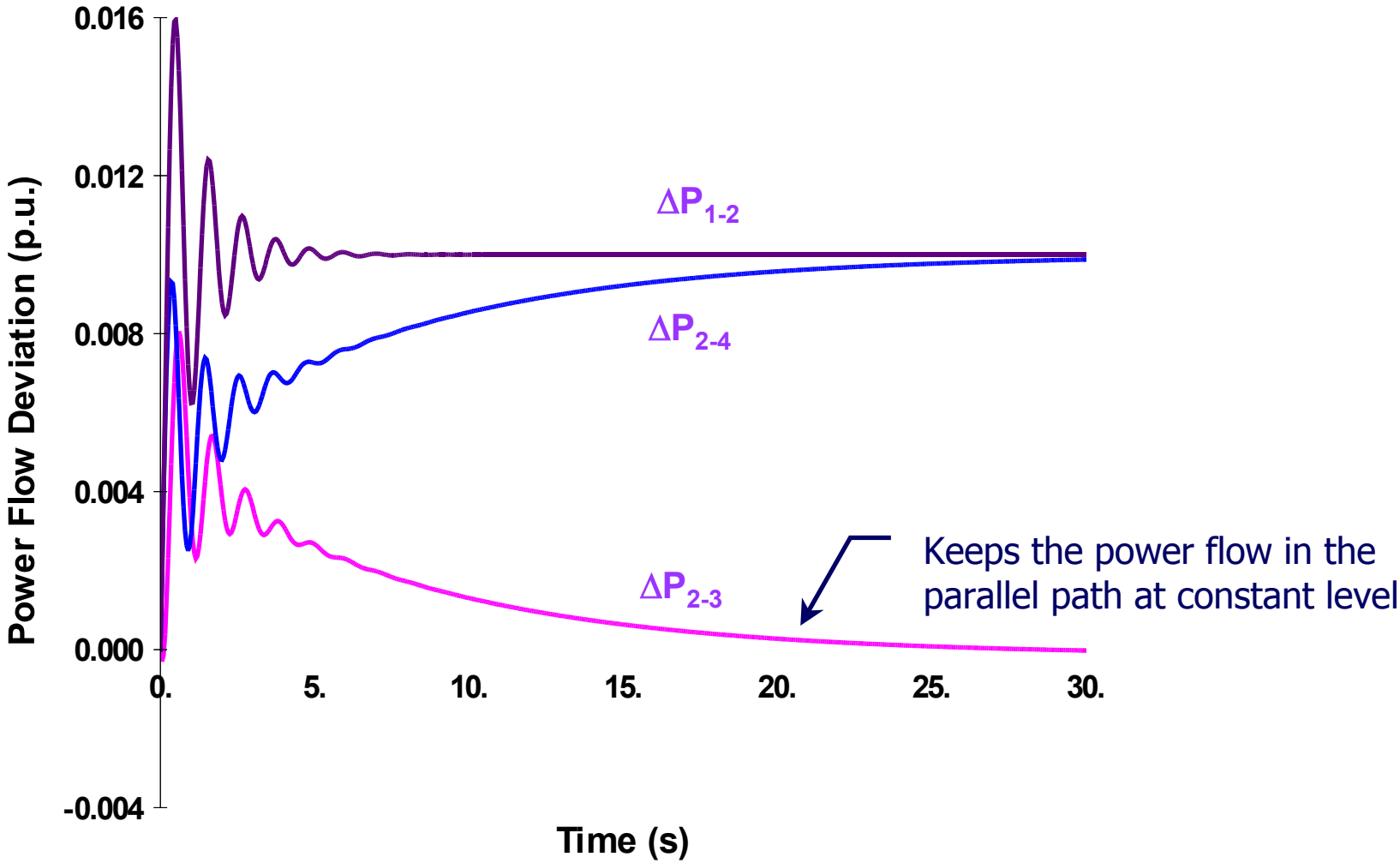
- Constant Line Power
  - Keeps the power flow in line 2-4 at a specified value
- Constant Angle
  - Line 2-4 absorbs any changes in generator power
  - Keeps the steady-state flows at parallel fixed impedance paths at constant level

TCSC with POD and Constant Line Power Controllers



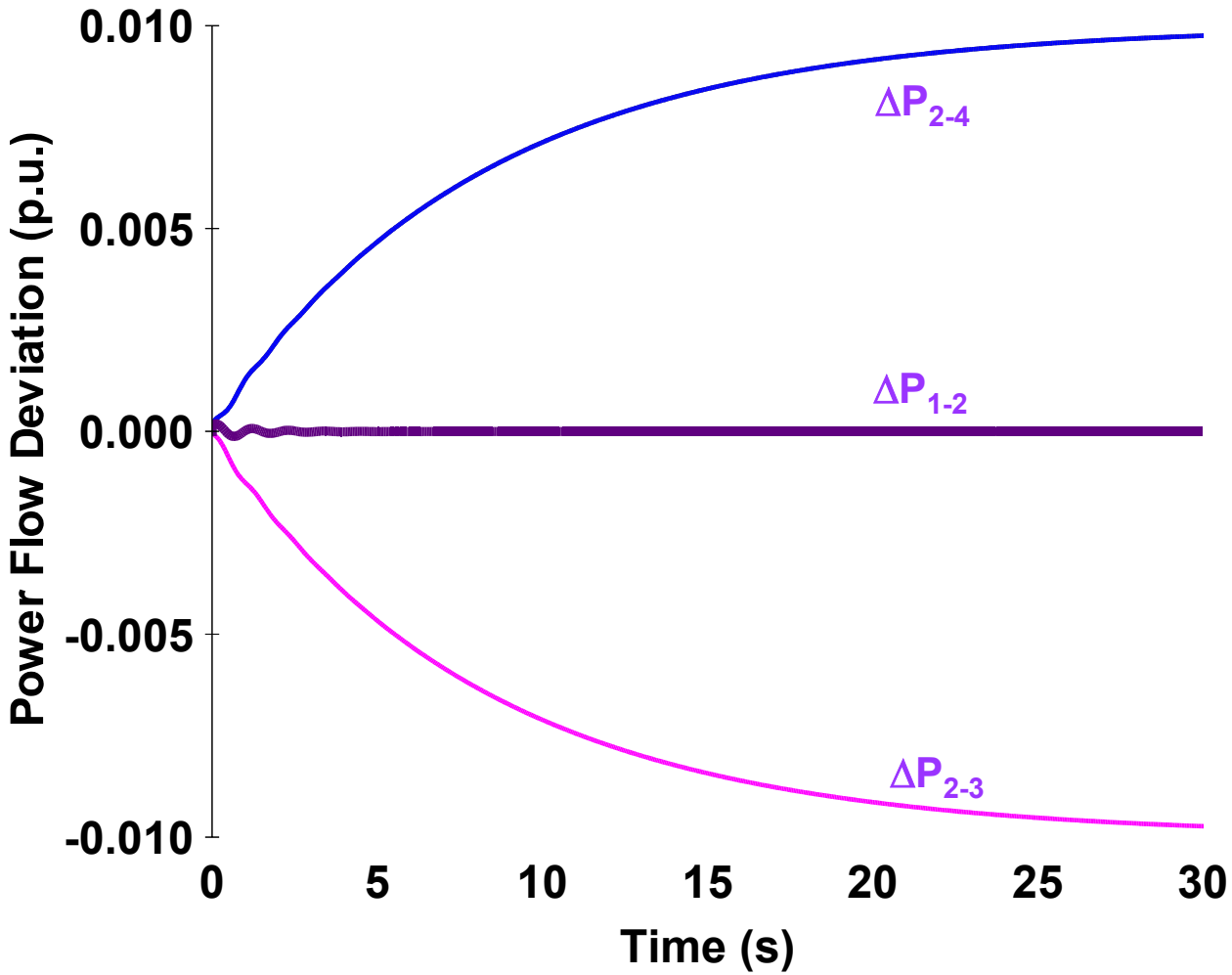
Dominant Modes: $\lambda = -0.889 \pm j\ 5.771$ and $\lambda = -0.123$

TCSC with POD and Constant Angle Controllers



Dominant Modes: $\lambda = -0.849 \pm j\ 5.829$ and $\lambda = -0.123$

Step Disturbance in TCSC Line Power Order



Dominant Mode λ = -0.123

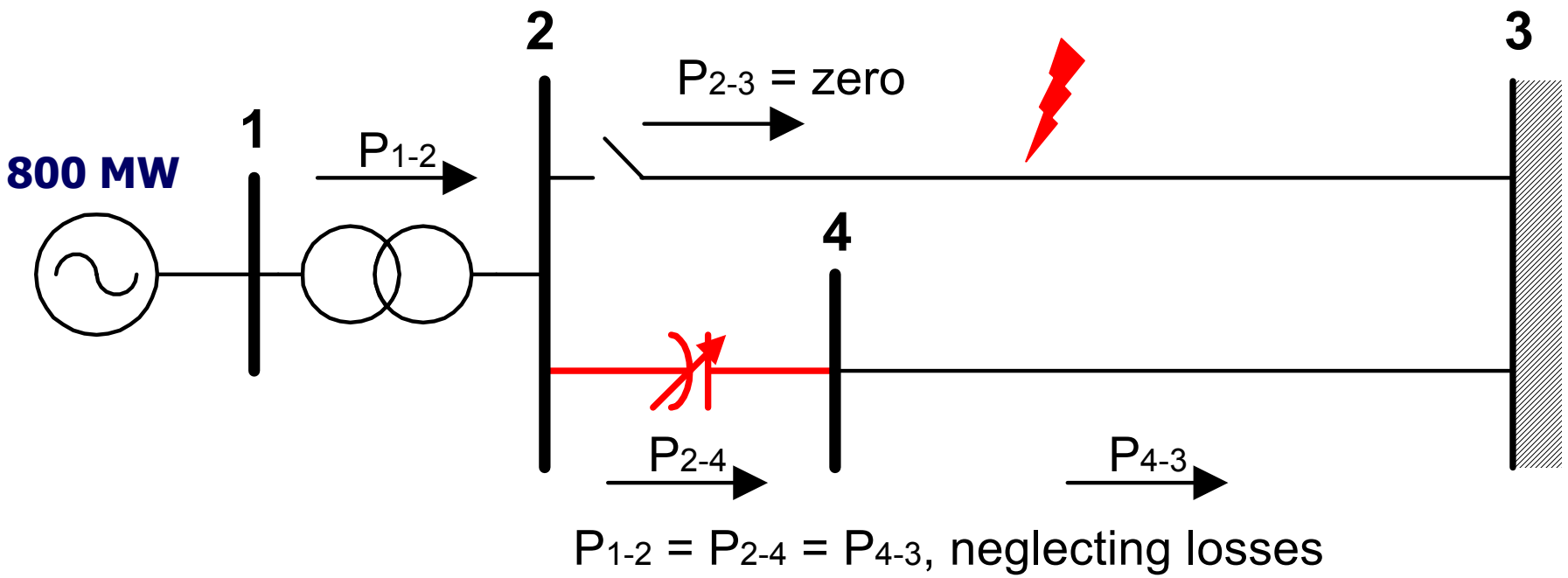
Line Outage Condition (Small Signal and Transient Stability)

For non-linear simulation:

t = 0.5 s -> Short circuit in line 2-3

t = 0.6 s -> Fault clearance by line tripping

t = 0.6 s -> Reject of one gen. unit (200 MW)



$P_{1-2} = P_{2-4} = P_{4-3}$, neglecting losses

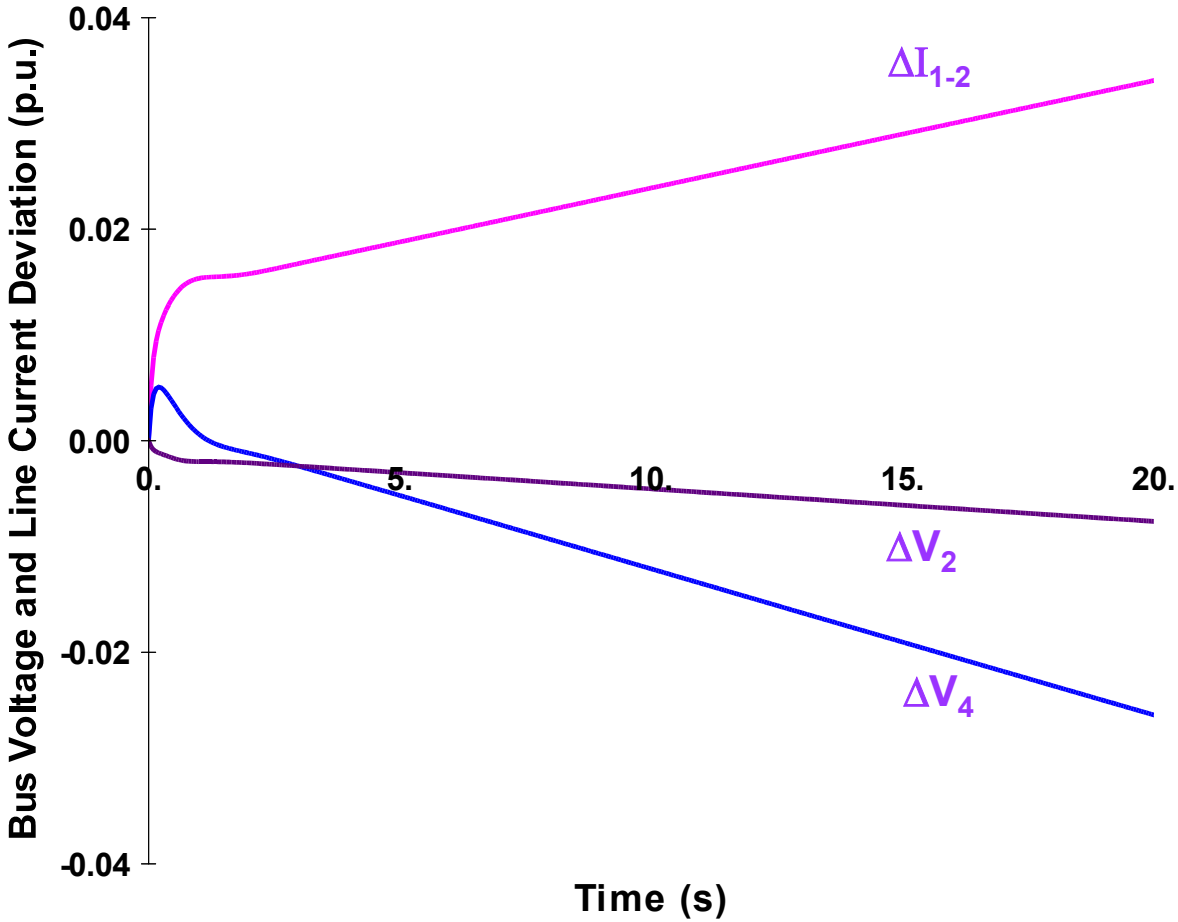
Line Outage Condition (Small Signal Stability Results)

PI-Controller = ON

POD Controller = ON

Serious Control Problem

Dominant Mode: $\lambda = 0$



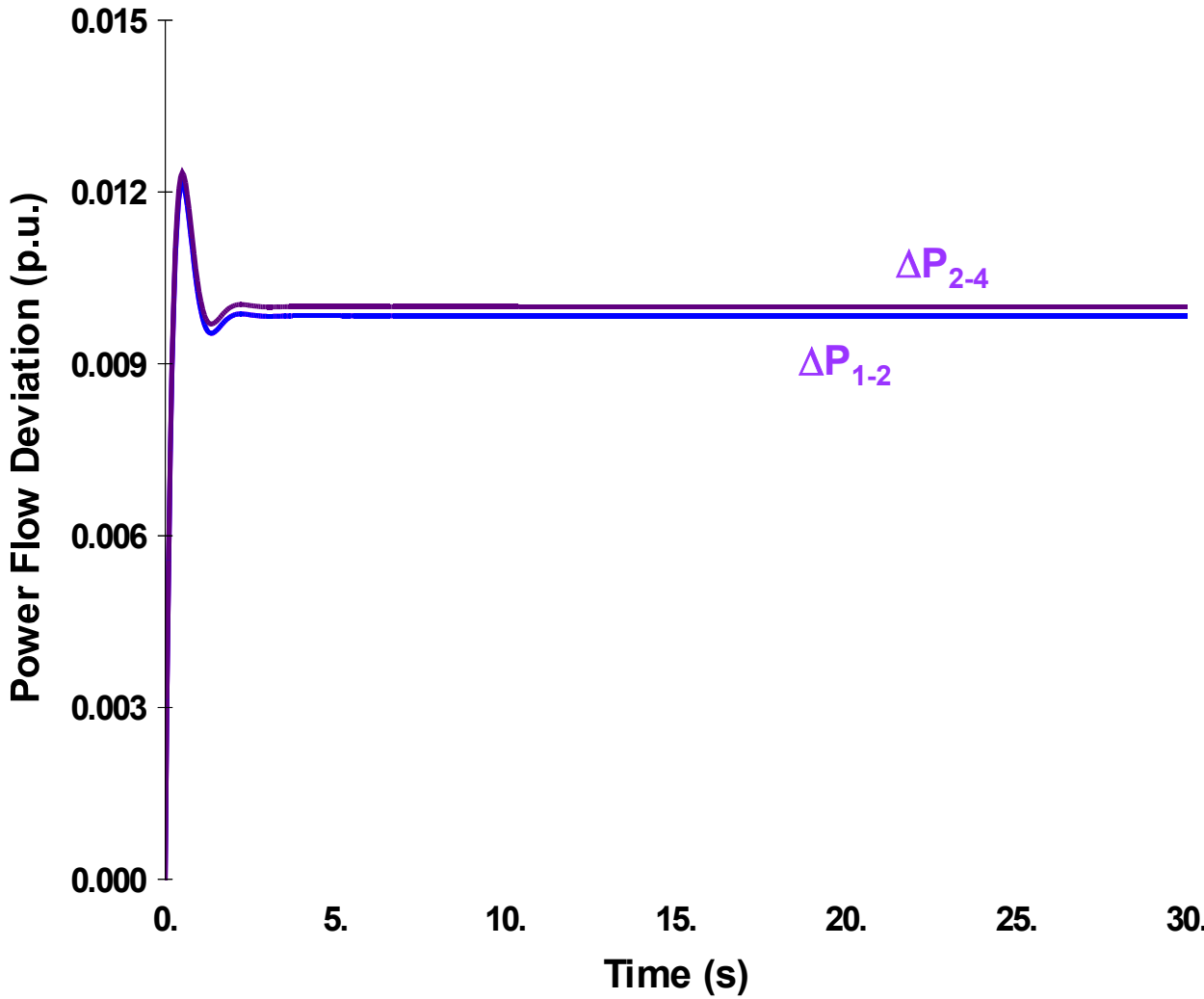
Line Outage Condition (Small Signal Stability Results)

PI-Controller = OFF

POD Controller = ON

System Stable

Dominant Mode: λ = -2.41 ±j 3.64

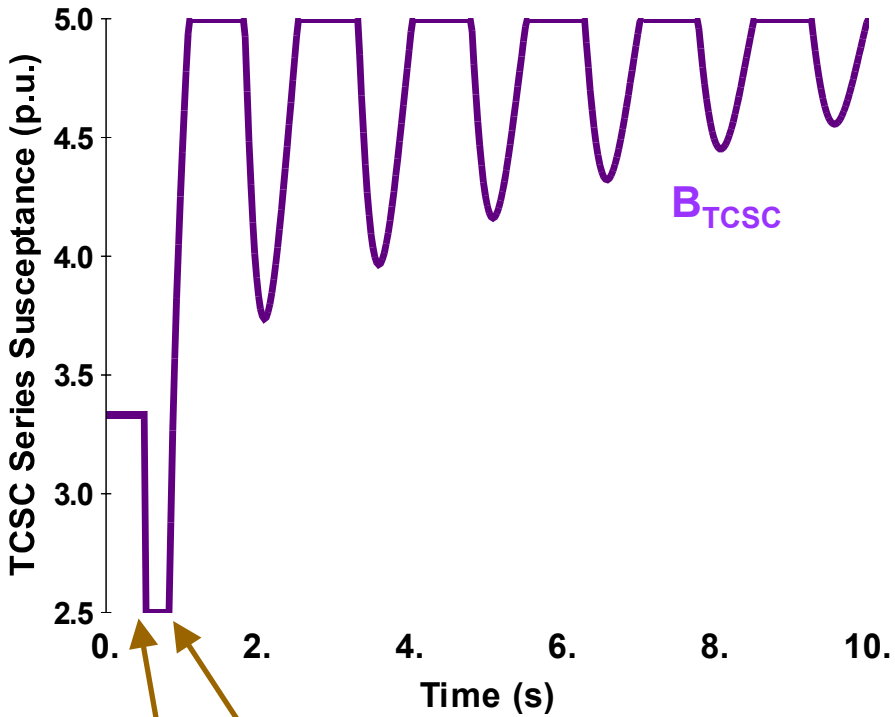


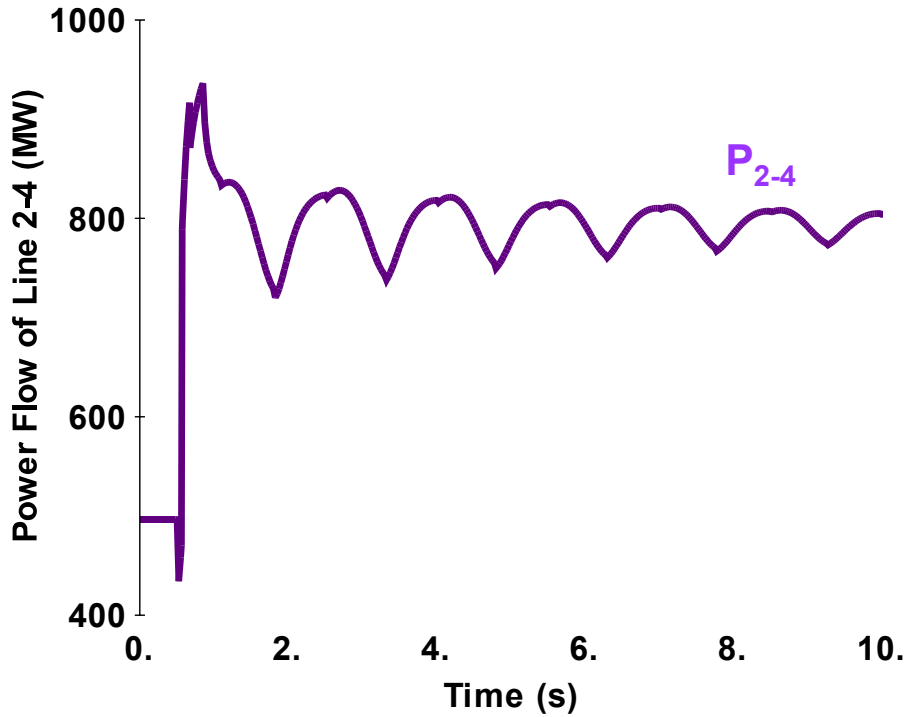
Transient Stability Results

Const. Line Power and POD Controllers are active

TCSC output limiter is active (B_{min} , B_{max})

System Very Poorly Damped





Fault Clearance by line tripping and one generator unit drop (t = 0.6 s)

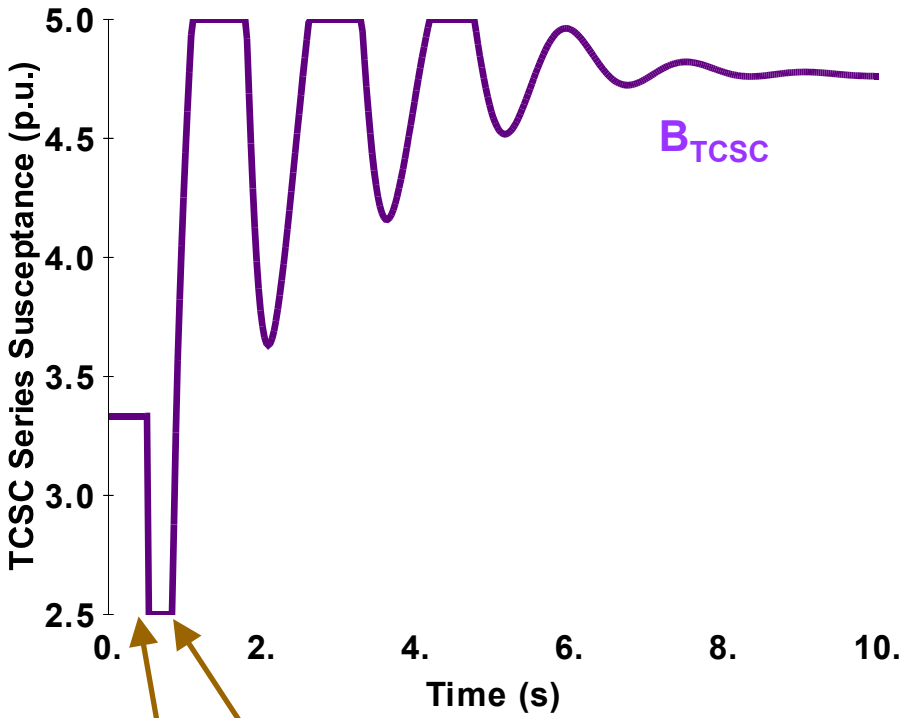
Short circuit in line 2-3 (t = 0.5 s)

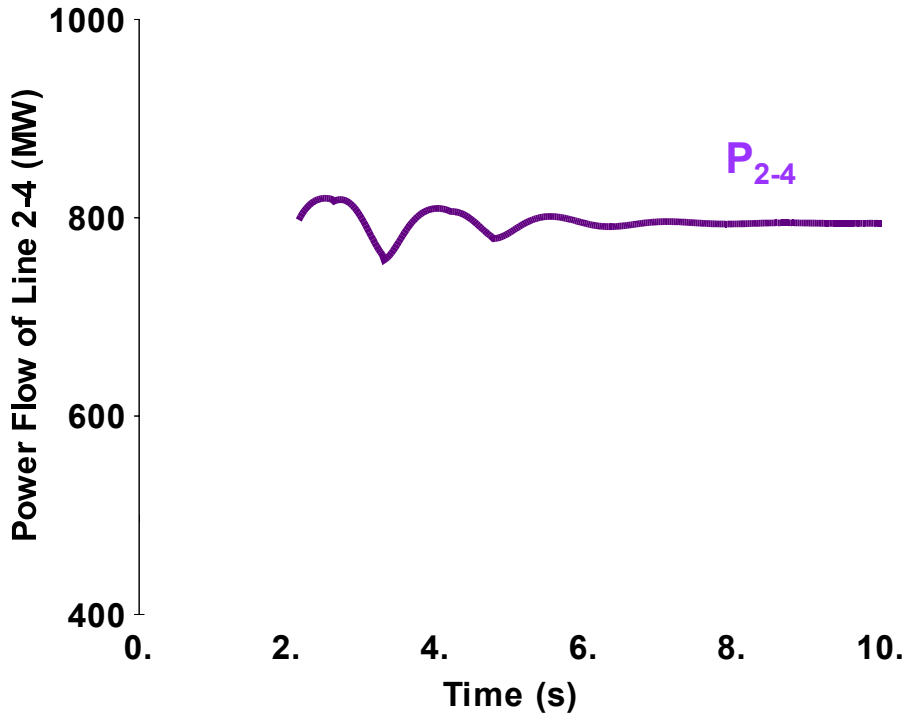
Transient Stability Results

Const. Line Power and POD Controllers are active

Both TCSC limiters are active

System Performance Still Inadequate





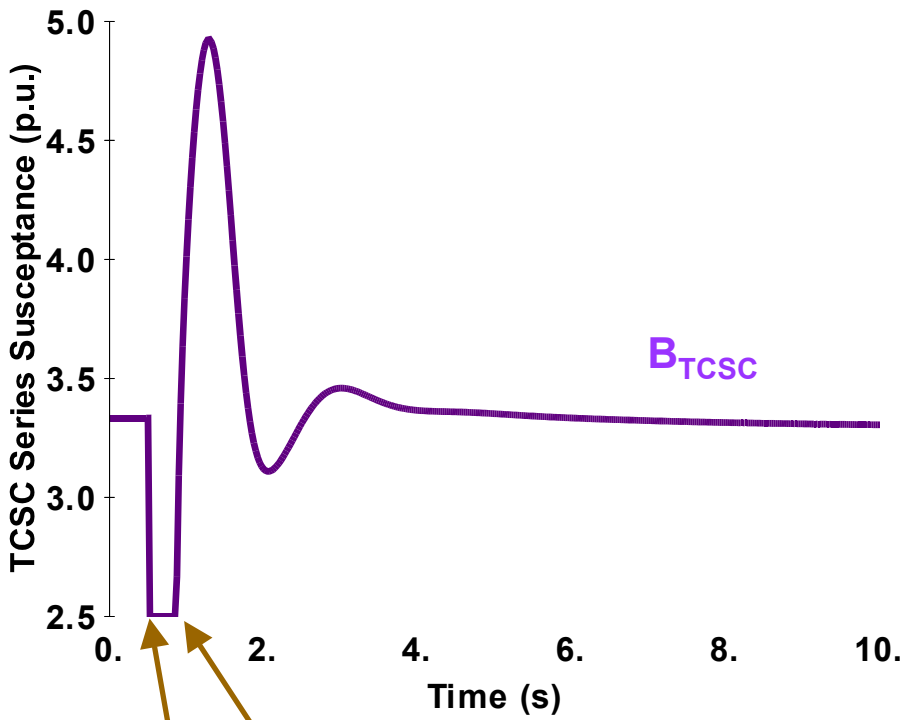
Fault Clearance by line tripping and one generator unit drop (t = 0.6 s)

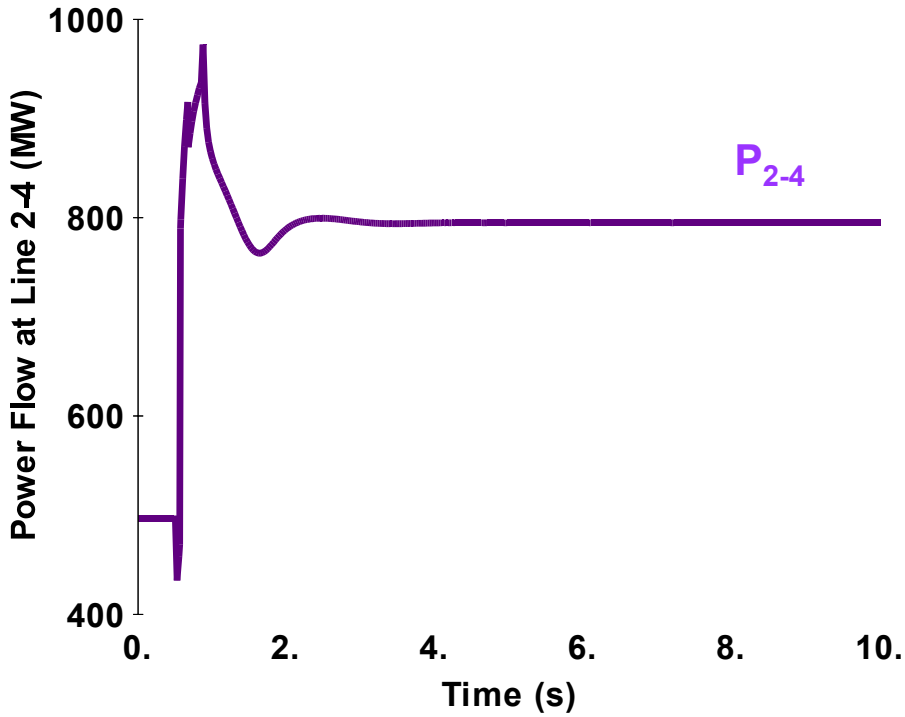
Short circuit in line 2-3 (t = 0.5 s)

Transient Stability Results

PI-Controller channel turned off by protection logics when line 2-3 is tripped

System Highly Damped





Fault Clearance by line tripping and one generator unit drop (t = 0.6 s)

Short circuit in line 2-3 (t = 0.5 s)

Concluding Remarks

- Benefits gained by using modal analysis and frequency response in addition to transient stability
- TCSC effective for line power schedulling and system oscillation damping
- Some additional protection, e.g. power flow controller blocking, may be needed when certain contingencies occur or when the controller is saturating