# Methods to Improve Transient Stability of Low Inertia Synchronous Machines

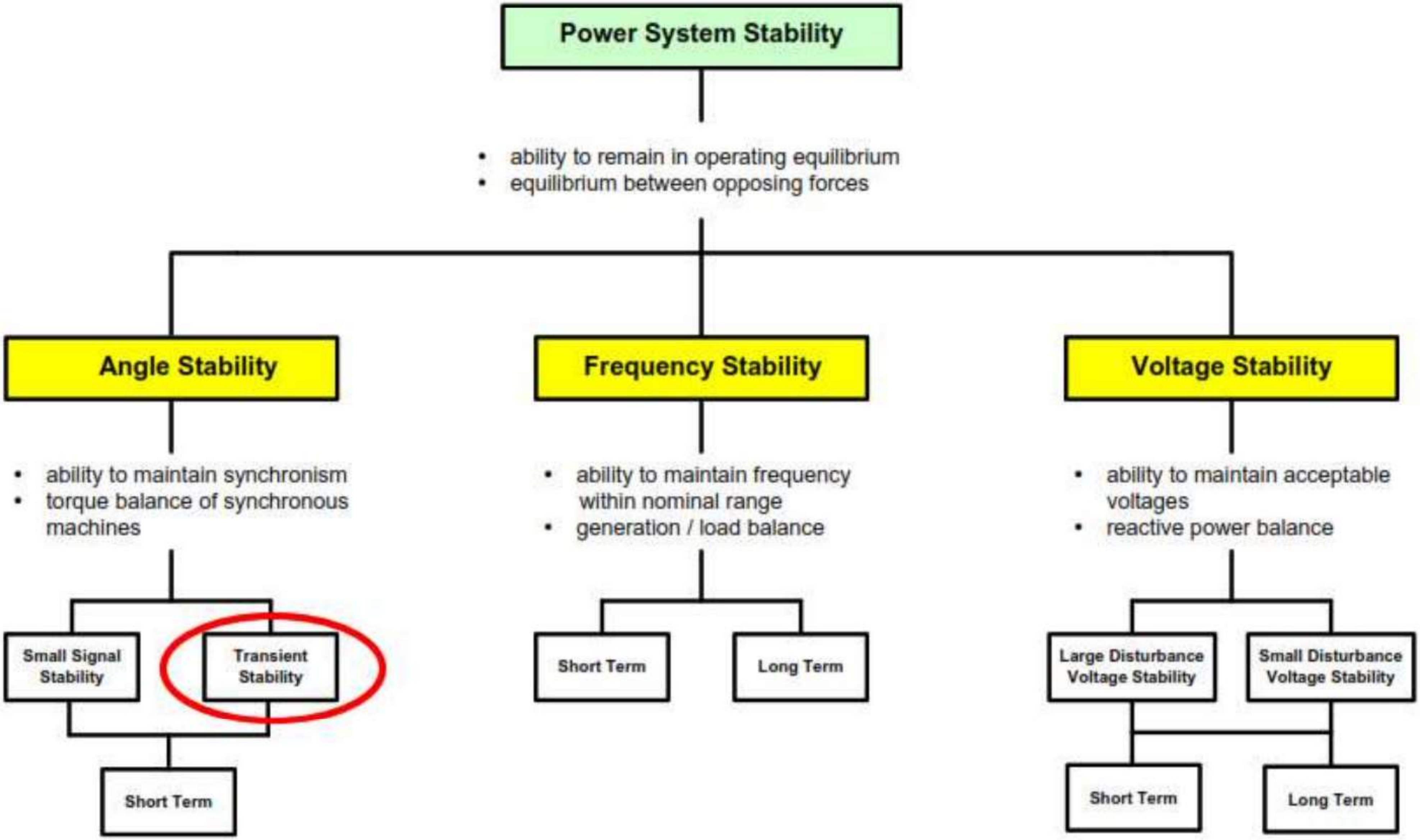
Muhammed Rahim, PE

# Agenda

- What is Transient Stability?
- Why is it important?
- Factors influencing Transient Stability
- Role of the Excitation System
- Test System & Study Methodology
- Simulation Results
- Recommendations

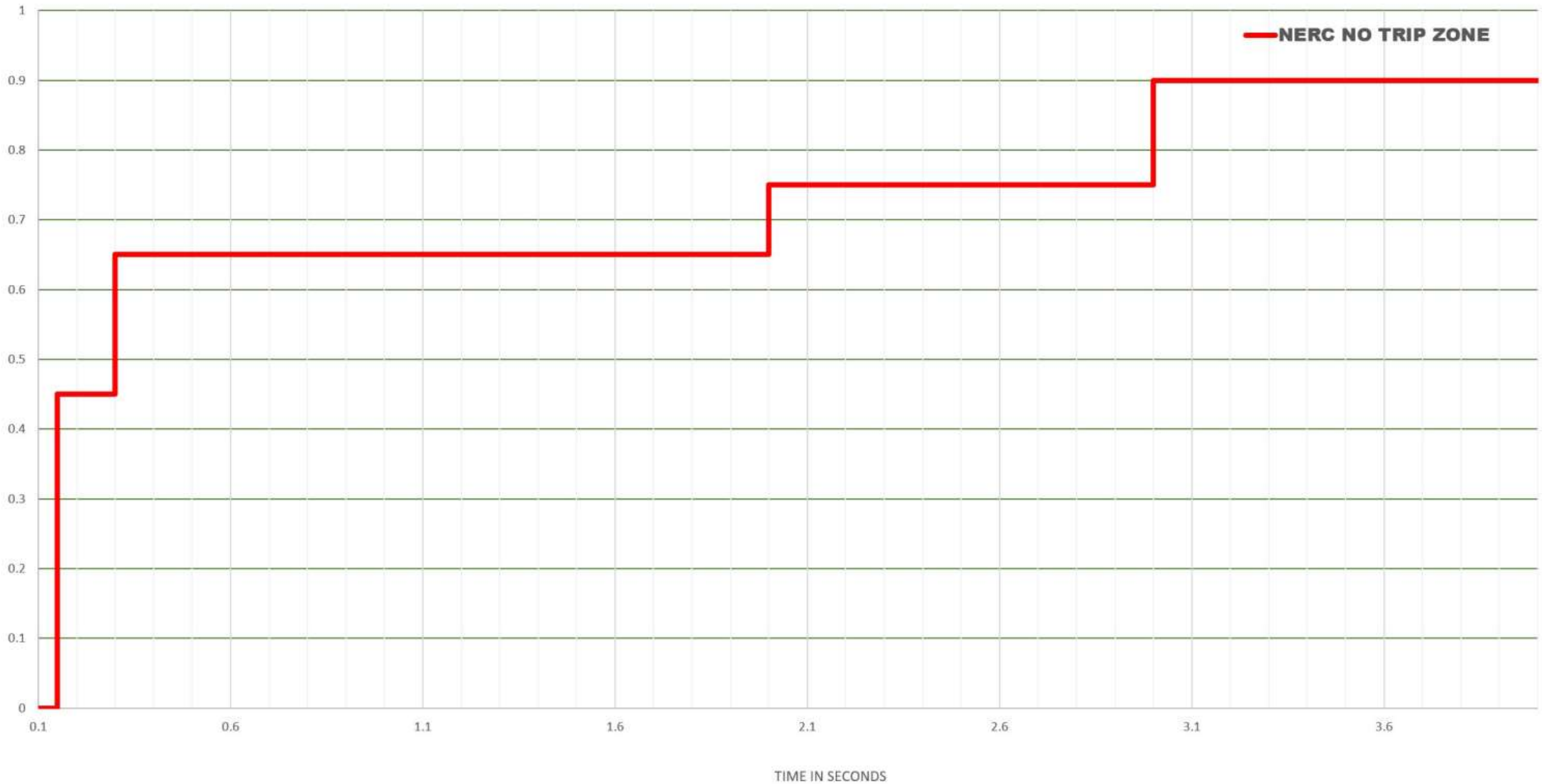
# What is Transient Stability?

- Ability of synchronous machines of an interconnected power system to maintain synchronism after being subjected to large/severe disturbances.
- Depends on the ability to maintain/restore equilibrium between electromagnetic torque and mechanical torque of each synchronous machine in the system
- System considered transiently stable if it can survive the most onerous initial disturbance
- Often referred to as first swing stability


Power System Stability
ability to remain in operating equilibrium
equilibrium between opposing forces
Angle Stability
ability to maintain synchronism
torque balance of synchronous machines
Small Signal Stability
Transient Stability
Short Term
Frequency Stability
ability to maintain frequency within nominal range
generation / load balance
Short Term
Long Term
Voltage Stability
ability to maintain acceptable voltages
reactive power balance
Large Disturbance Voltage Stability
Small Disturbance Voltage Stability
Short Term
Long Term

# Why is it important?

- Improves system reliability
- System Operators are diligently enforcing grid codes
- Clear definition of fault-ride-through (FRT) requirements
- FRT requirements have direct correlation with transient stability phenomenon
- NERC PRC-024-2



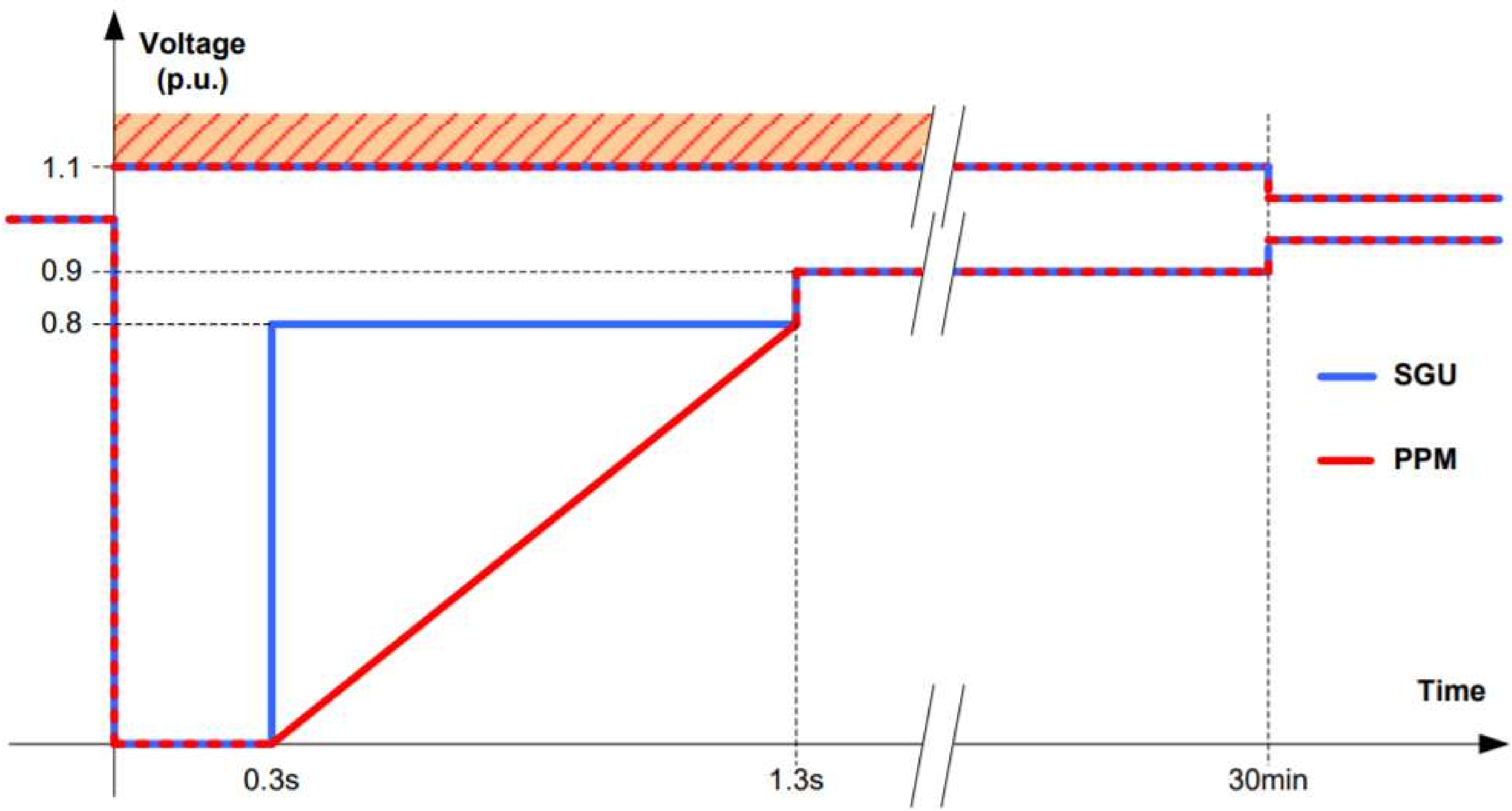
NERC NO TRIP ZONE
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.1
0.6
1.1
1.6
2.1
2.6
3.1
3.6
TIME IN SECONDS

# Australian Grid Code…

| Nominal voltage at fault location(kV) | Time(milliseconds) | | |
|---|---|---|---|
| **Column 1** | **Column 2** | **Column 3** | **Column 4** |
| **400kV and above** | 80 | 100 | 175 |

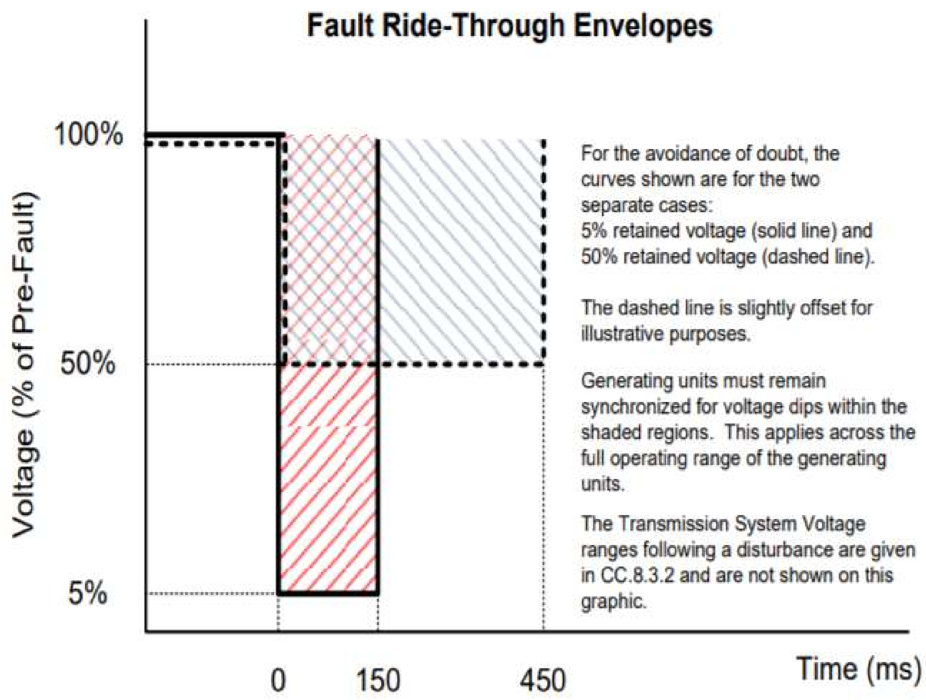
| Nominal voltage at fault location(kV) | Time(milliseconds) | | |
|---|---|---|---|
| **Column 1** | **Column 2** | **Column 3** | **Column 4** |
| **at least 250kV but less than 400kV** | 100 | 120 | 250 |
| **more than 100kV but less than 250kV** | 120 | 220 | 430 |
| **less than or equal 100 kV** | As necessary to prevent *plant* damage and meet stability requirements | | |

# Saudi Arabian Grid Code…



# Ireland Grid Code…

| VOLTAGE DIP MAGNITUDE | Fault Ride-Through Times | | |
|---|---|---|---|
| | 400 kV System | 220 kV System | 110 kV System |
| 95% (5% retained) | 150 ms | 150 ms | 150 ms |
| 50% (50% retained) | 450 ms | 450 ms | 450 ms |



# Influencing Factors

- System transfer reactance
- Grid strength
- Synchronizing power
- Moment of inertia
- Damping
- System Protection
- MW loading/de-loading
- Excitation system & PSS

$$M\frac{d^2\delta}{dt^2} + D\frac{d\delta}{dt} = P_{mech} - P_{elec} \text{ (Eq. 2)}$$

Where,

$M$ = Inertia constant

$D$ = Damping constant

$P_{mech}$ = Input mechanical power

$P_{elec}$ = Output electrical power

$$P_T = \frac{V_1 V_2}{X}\sin\delta \text{ (Eq. 3)}$$

Where,

$P_T$ = Power transferred between Bus 1 and 2

$V_1$ = Voltage phasor at Bus 1

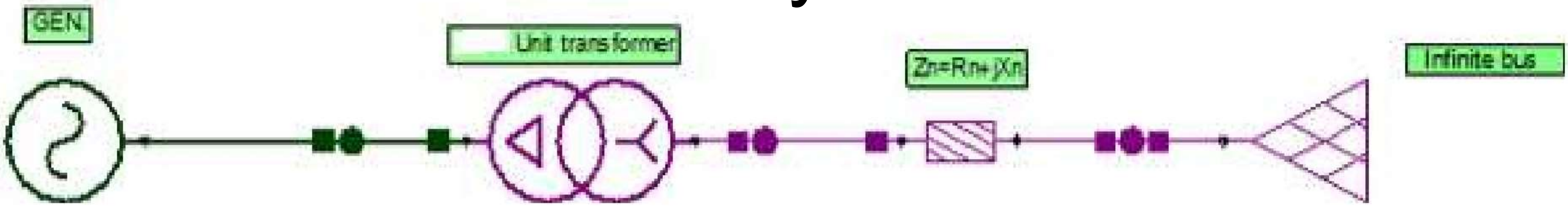
$V_2$ = Voltage phasor at Bus 2

$\delta$ = Relative rotor angle between Bus 1 and 2

# Role of the Excitation System

- Modern fast excitation systems are usually beneficial to transient stability by driving the field to ceiling without delay.
- Electrical power output of the machine may be increased during the first swing, which reduces the accelerating power.
- Effect of the excitation system on the severity of the first swing is relatively small, except for cases involving faults with long clearing times (or stuck breaker)
- Improvement of first swing by only a few degrees; increases the generator transient stability power limit only by a few percent.

# Test System



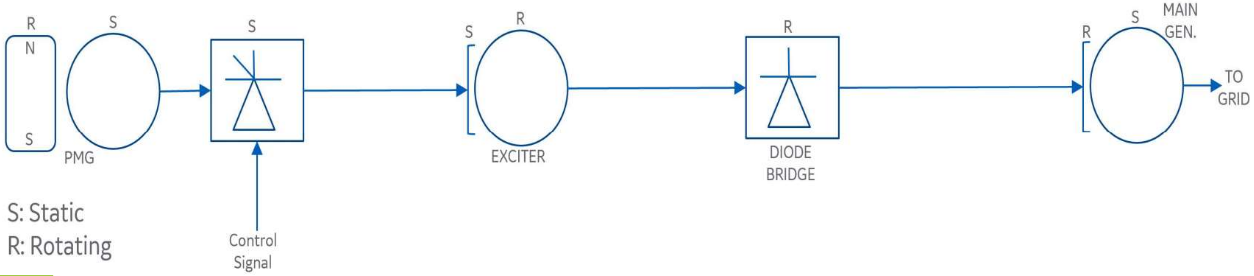

- H = 1.375
- 47.8 MVA, 0.85 Lagging PF, 13.8kV, 60Hz, 2-pole, round-rotor
- Grid short-circuit strength: 30kA at 138kV
- GSU Transformer: YNd1, 13.8kV/138kV, Z = 15% at 80 MVA
- Governor action: Fixed (No action)

# Test System (Cont'd)

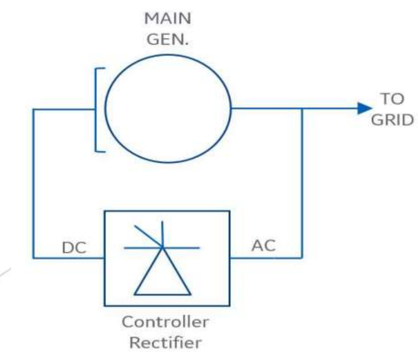
- Generator in Voltage Control mode
- Initial MW load setpoint: 35 MW (1.0 per unit Voltage)
- Bolted 3-phase fault at the POI (138kV HV bus)
- Target: FRT of 150 milliseconds (per NERC PRC-024-2)
- Simulations performed at 0.95 leading PF at POI

# Study Methodology

- Excitation systems considered
  - ✓ Fixed
  - ✓ Brushless - IEEE 421.5 AC7B (simulations performed with 3 different data sets)
  - ✓ Static - IEEE 421.5 ST1A and ST2A
  - ✓ Power System Stabilizer – IEEE 421.5 PSS2A (used with AC7B-3)




Brushless




Static

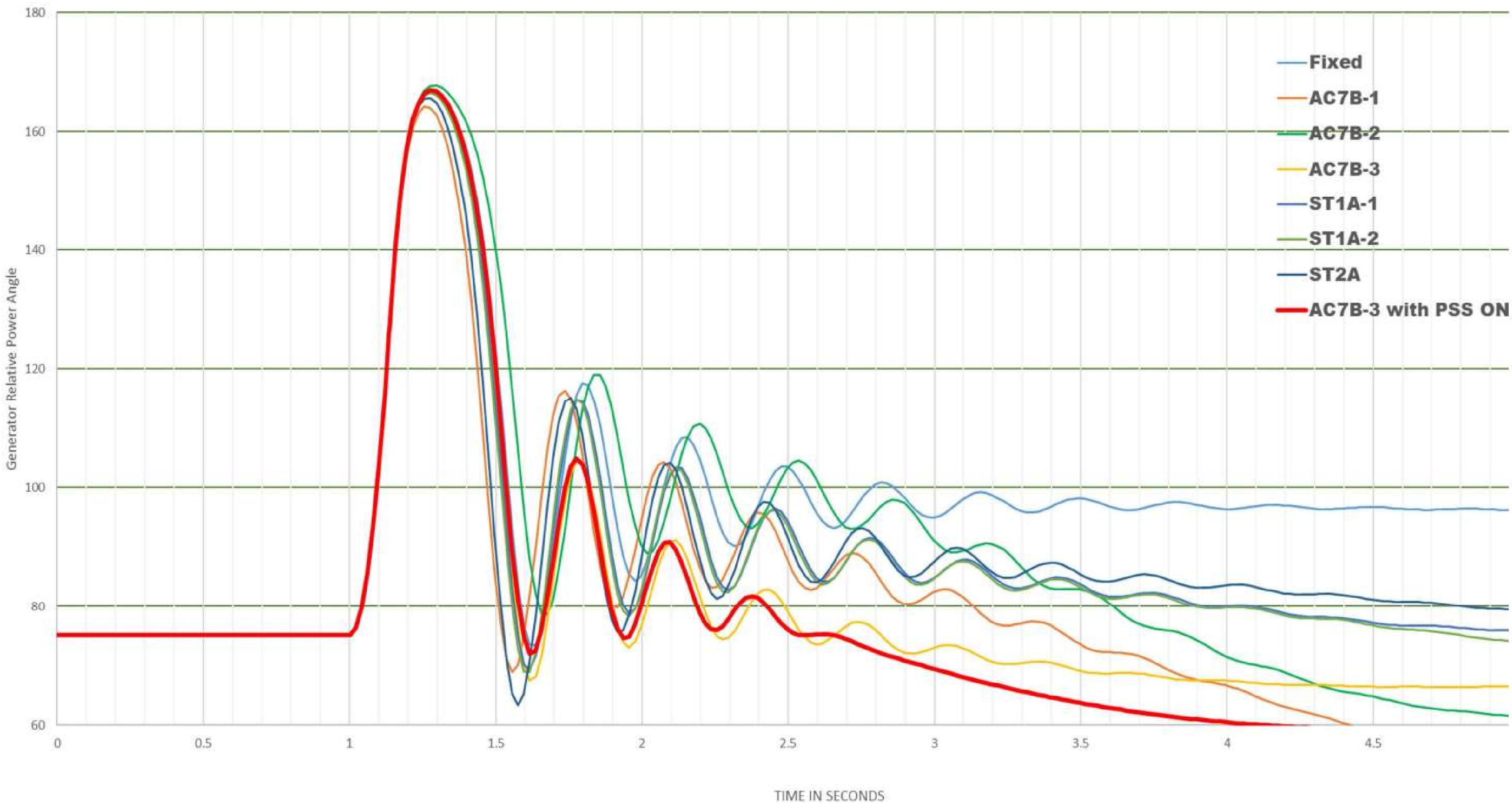
# Simulation Results

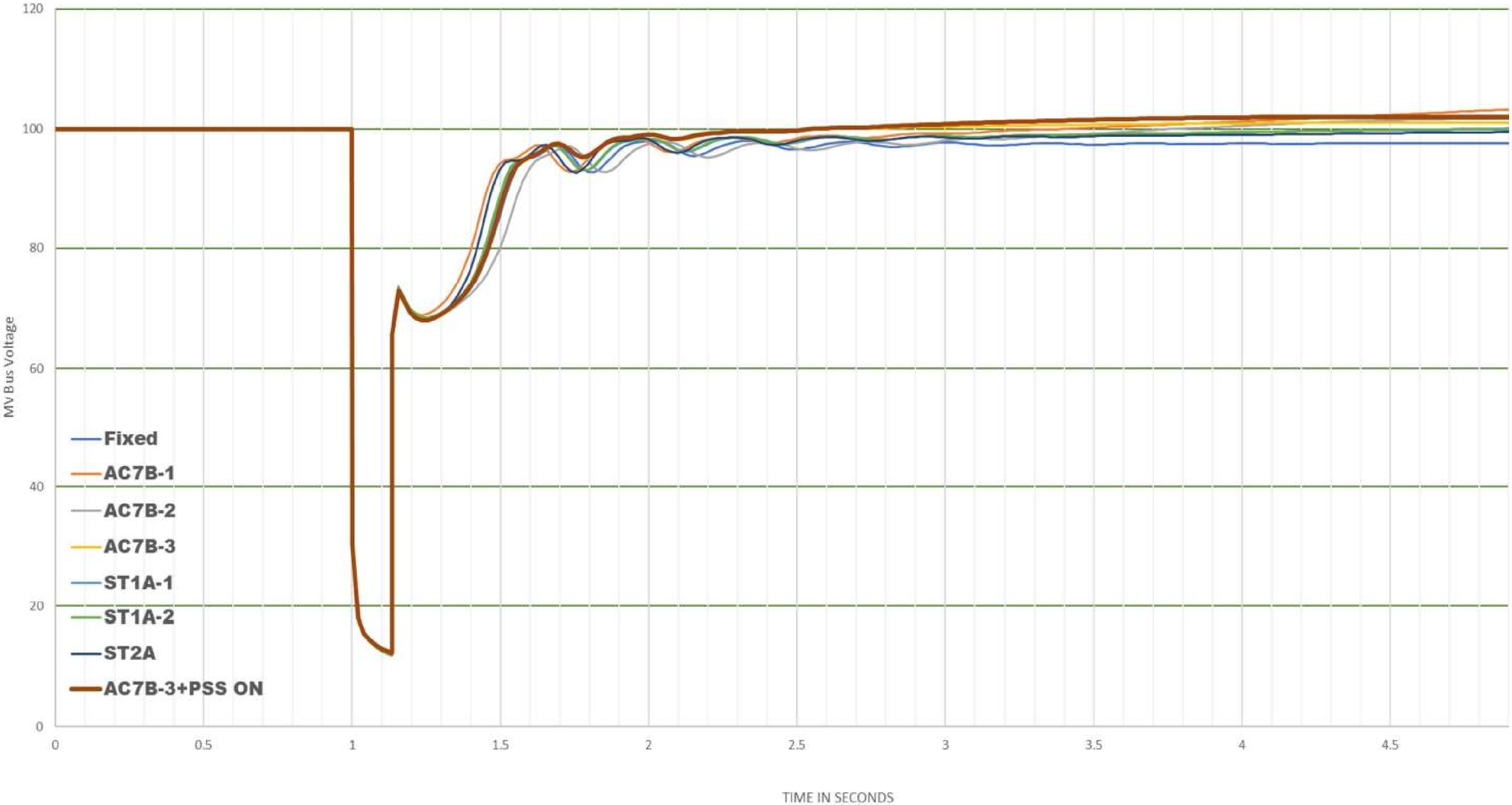
- Excitation systems and PSS had no meaningful impact on the first swing stability

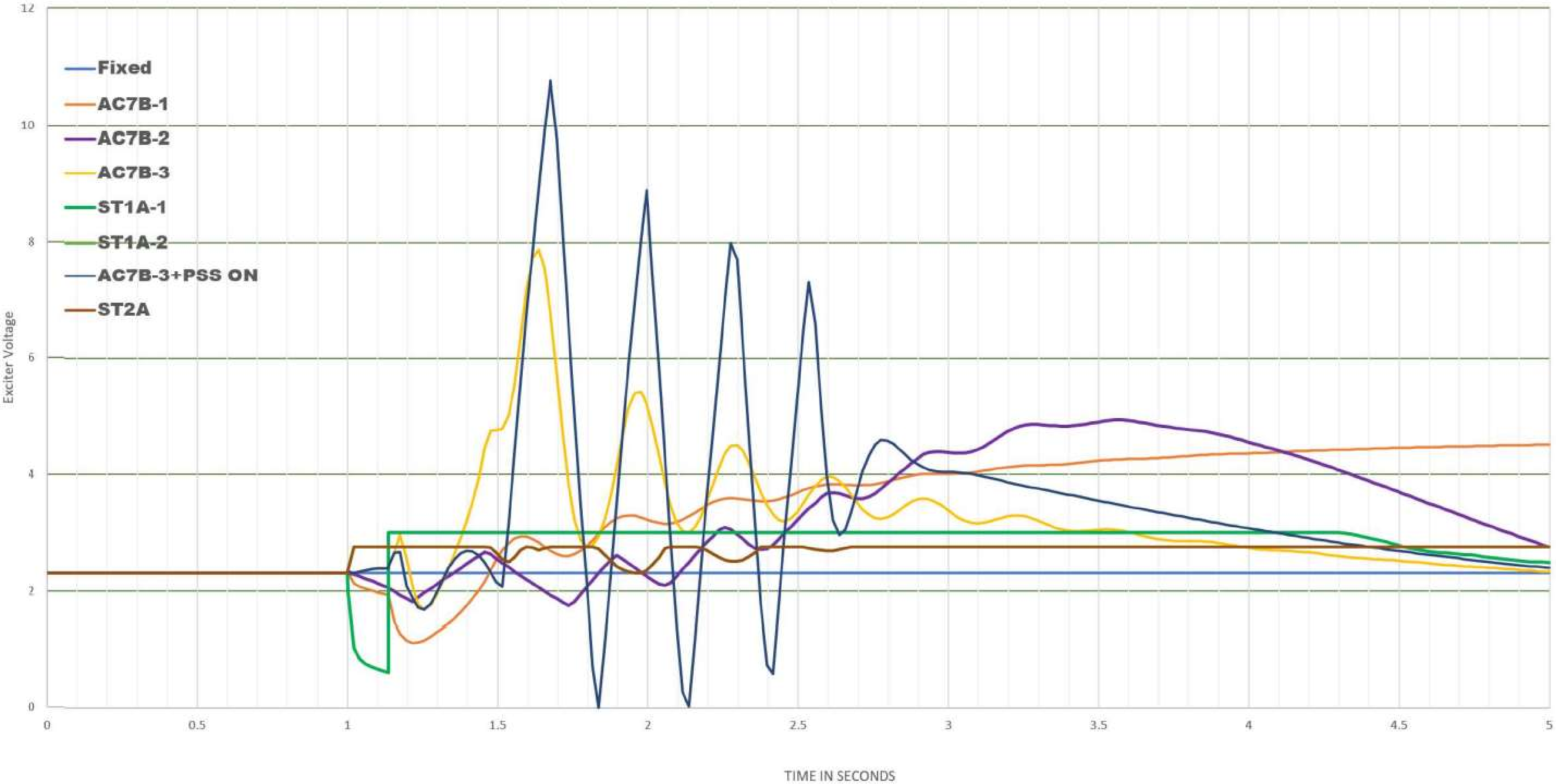
- In all cases the maximum clearing time achieved was approx. 135 ms

- The difference between maximum and minimum swing is approx. 4 degrees, which is insufficient to influence the first swing stability.

- Inherent latency in ramping of the field voltage despite fast transient forcing of excitation


Generator Relative Power Angle
TIME IN SECONDS
Fixed
AC7B-1
AC7B-2
AC7B-3
ST1A-1
ST1A-2
ST2A
AC7B-3 with PSS ON
180
160
140
120
100
80
60
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5


120
100
80
60
40
20
0
MV Bus Voltage
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
TIME IN SECONDS
Fixed
AC7B-1
AC7B-2
AC7B-3
ST1A-1
ST1A-2
ST2A
AC7B-3+PSS ON


Fixed
AC7B-1
AC7B-2
AC7B-3
ST1A-1
ST1A-2
AC7B-3+PSS ON
ST2A
Exciter Voltage
TIME IN SECONDS
0
2
4
6
8
10
12
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

# Summary & Recommendations

- Reduction in the overall system reactance
- Adding shunt reactor banks and/or synchronous condensers
- Operating the Generator at greater than 1.0 per unit voltage
- Adding fly wheels
- High-speed protection
- Fast unloading of the machine during disturbance through governor action

# Q & A