Department of Electrical and Electronic Engineering

EEEN60342: Power System Dynamics and Quality of Supply

Laboratory: Power System Dynamic Performance Report

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This report contains the observations and conclusions of Voltage Stability analysis and Rotor angle stability analysis for a large disturbance behaviour in a 6-bus test Power System network.

1 Steady State Voltage Stability Assessment

1.1 Initial State of the system

The initial values of load at Bus 4,5 and 6 were 50MW, 50MW, and 150MW respectively. Active power at each bus is incremented in steps of 10MW.

Load increment (MW)	Bus 4 (pu, degree)	Bus 5 (pu, degree)	Bus 6 (pu, degree)
0	1.004, -11.7	0.988, 4.2	0.987, 3.4
10	0.998, -14.7	0.987, 0.2	0.986, -0.6
20	0.989, -17.8	0.986, -3.8	0.984, -4.8
30	0.977, -21.1	0.983, -8.0	0.982, -9.0
40	0.961, -24.6	0.979, -12.3	0.978, -13.4
50	0.941, -28.4	0.975, -16.9	0.973, -18.1
60	0.915, -32.7	0.968, -21.8	0.966, -23.2
70	0.879, -37.8	0.959, -27.5	0.957, -29.0
80	0.821, -44.9	0.946, -34.5	0.943, -36.3

Table 1: Voltage Stability - Initial State

System Critical load : 490MW (130MW, 130MW, 230MW at Bus 4, Bus 5 and Bus 6)
Voltage at Bus 4 collapses first in the system.

1.2 Reactive power limits

Reactive power limits of -50MVAR and 50MVAR is introduced at generators and experiment conducted same as the previous case.

Load increment (MW)	Bus 4 (pu)	Bus 5 (pu)	Bus 6 (pu)
0	1.004	0.988	0.987
10	0.998	0.987	0.986
20	0.989	0.986	0.984
30	0.977	0.983	0.982
40	0.961	0.979	0.978
50	0.941	0.975	0.973
60	0.915	0.968	0.966
70	0.879	0.959	0.957

Table 2: Voltage Stability - With reactive power limits

The total system critical load is 460MW

1.3 Graphs for section 1.1 and 1.2

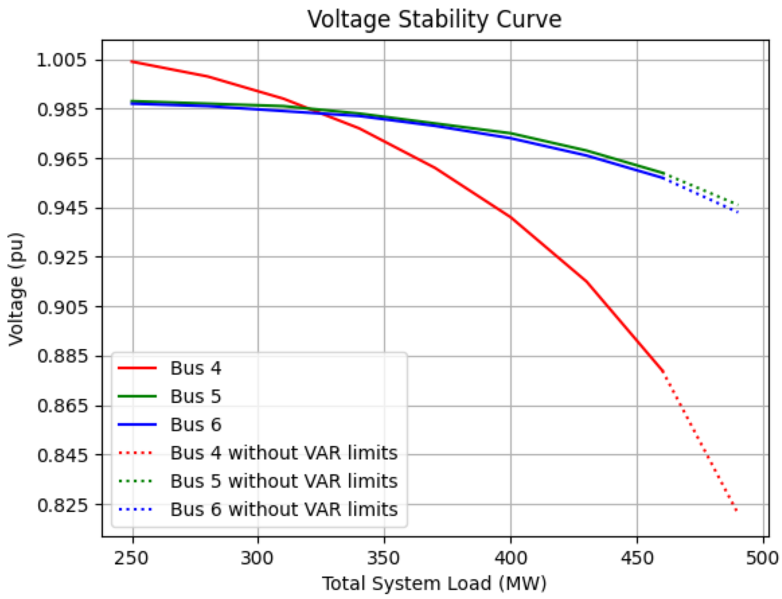

Figure 1: Voltage Stability with and without MVAR limits

- The system collapses faster with VAR limits
- More power could be transferred to load points without VAR limits.

1.4 Load change at Bus 4

Procedure from section 1.1 is repeated but, only the active power at bus 4 is incremented in steps of 20 MW.

Load increment (MW)	Bus 4 (pu)	Bus 5 (pu)	Bus 6 (pu)
0	1.004	0.988	0.987
20	0.989	0.986	0.984
40	0.972	0.984	0.980
60	0.951	0.981	0.976
80	0.925	0.977	0.970
100	0.891	0.972	0.963
120	0.841	0.964	0.953

Table 3: Voltage Stability - Active power change at Bus 4

The total system critical load is 370MW

1.5 Constant Impedance model

Procedure in section 1.4 is repeated for a constant impedance load model.

Load increment (MW)	Bus 4 (pu)	Bus 5 (pu)	Bus 6 (pu)
150	1.003	0.988	0.987
200	0.974	0.984	0.981
250	0.941	0.979	0.974
300	0.905	0.974	0.966
350	0.869	0.969	0.959
400	0.833	0.963	0.951
450	0.797	0.958	0.944
500	0.761	0.949	0.931
550	0.725	0.936	0.914

Table 4: Voltage Stability - Constant impedance model

The total system critical load is 850MW

1.6 Constant Power vs Constant Impedance load model

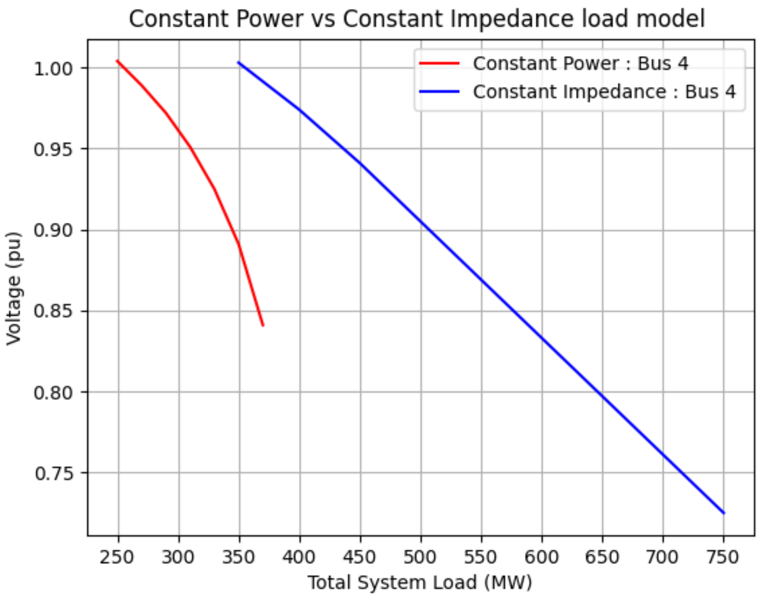

Figure 2: Constant Power vs Constant Impedance load model

1.6.1 Observations

1. The impedance curve is linear whereas power curve bends towards the nose point
2. The active power in the system can only be increased to an extent in constant power model
3. Impedance model keeps the ratio constant by reducing the voltage

2 Large Disturbance Transient Stability Assessment

2.1 Transient Stability without controls

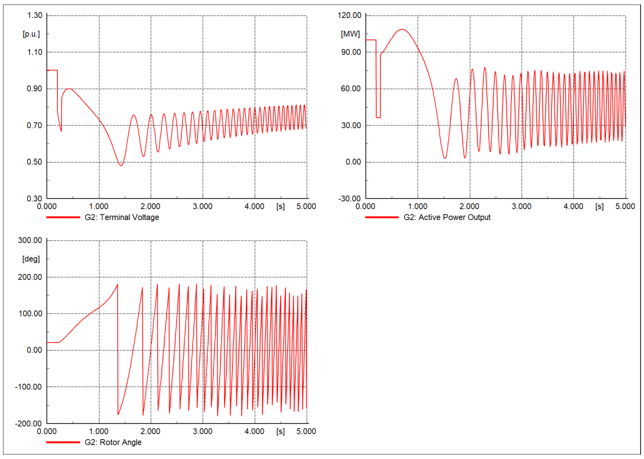

Figure 3: EMT Analysis of the system without controls

2.2 Transient Stability with AVR activated

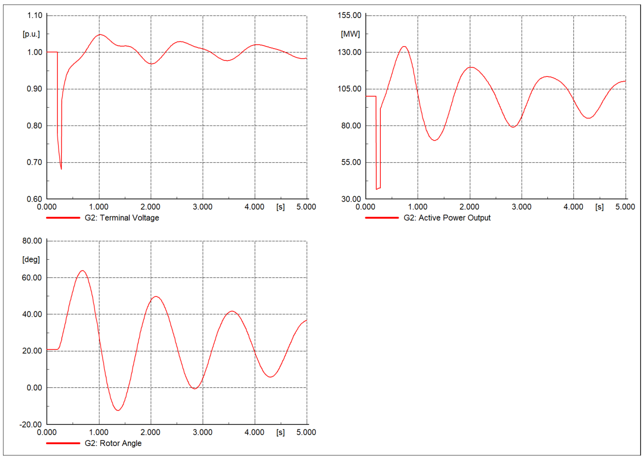

Figure 4: EMT Analysis with AVR (Kavr = 100, Tavr = 0.05 s)

1. AVR helps in transient stability of the system by adjusting the excitation voltage
2. AVR helps in reducing the initial rotor angle swing following the fault
3. This is accomplished by boosting the voltage applied to the field winding through the action of the amplifiers in the forward path of the voltage regulators. The increased air gap flux exerts a restraining torque on the rotor, which tends to slow down its motion.

$$Frequency = \frac{1}{(2 * t_{pp})} \tag{1}$$

where, t_{pp} is the time between peak to peak angle of the final oscillation within the simulation time.

The frequency of the critical mode is 0.657Hz

2.3 Effect of Automatic Voltage Regulator on System Stability

Varying the gain and time constant of for the previous system,

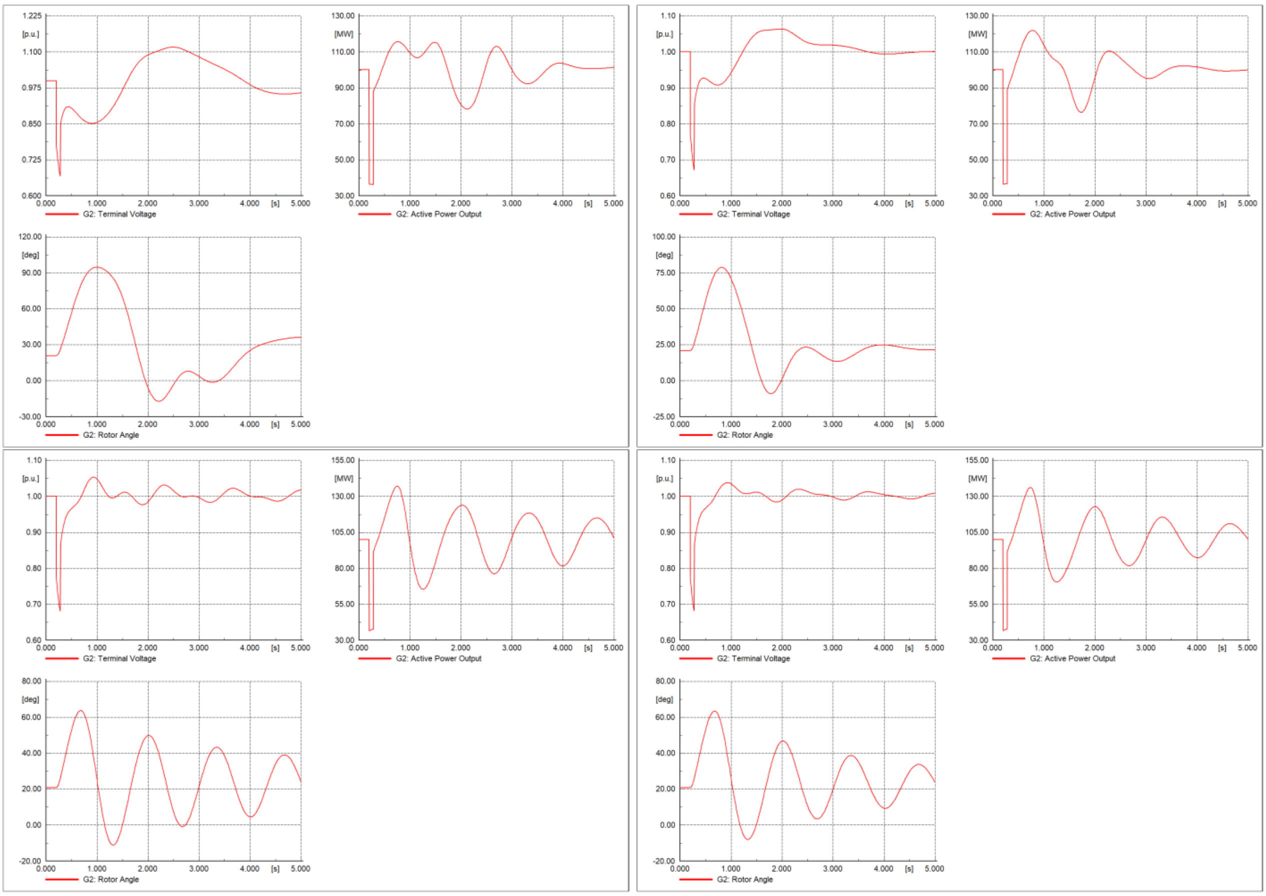

Figure 5: EMT Analysis for AVR at [Kavr/Tavr = 20/0.5, 20/0.1, 200/0.1, 200/0.05] (Left to Right)

2.3.1 Observations

1. Higher the AVR gain, higher the synchronising torque
2. Increasing AVR gain makes the system oscillate around the steady state value, but it introduces negative damping
3. Reducing time constant reduces the settling time and attains steady state quickly. Speed of the response high meaning system has to respond quickly which might not be ideal for Electro-mechanical systems

2.3.2 Optimal Combination

The Kavr/Tavr of **200/0.1** is identified as optimal. The system with gain of 20, tries to settle around a new operating point, so Kavr = 200 is preferred. Response time of 0.05 is high for slow Electro-mechanical systems. Hence Tavr=0.1 is preferred.

2.4 System Controls and Modal Analysis

2.4.1 EMT Analysis by increasing the fault duration towards Instability

The figure below shows the generator response for the following cases

1. Constant excitation - System without AVR or PSS

- Fault is cleared at 0.22s and at 0.23s
- The critical fault clearing time before system loses stability is 30ms

2. AVR activated (Kavr = 100, Tavr = 0.05s)

   - Fault is cleared at 0.28s, and at 0.34s
   - The critical fault clearing time before system loses stability is 140ms

3. AVR and PSS activated (Kpss = 5, T1/T2 = 0.6/0.65, T3/T4 = 0.3/0.01)

   - Fault is cleared at 0.28s, and at 1.03 sec
   - The critical fault clearing time before system loses stability is 840s

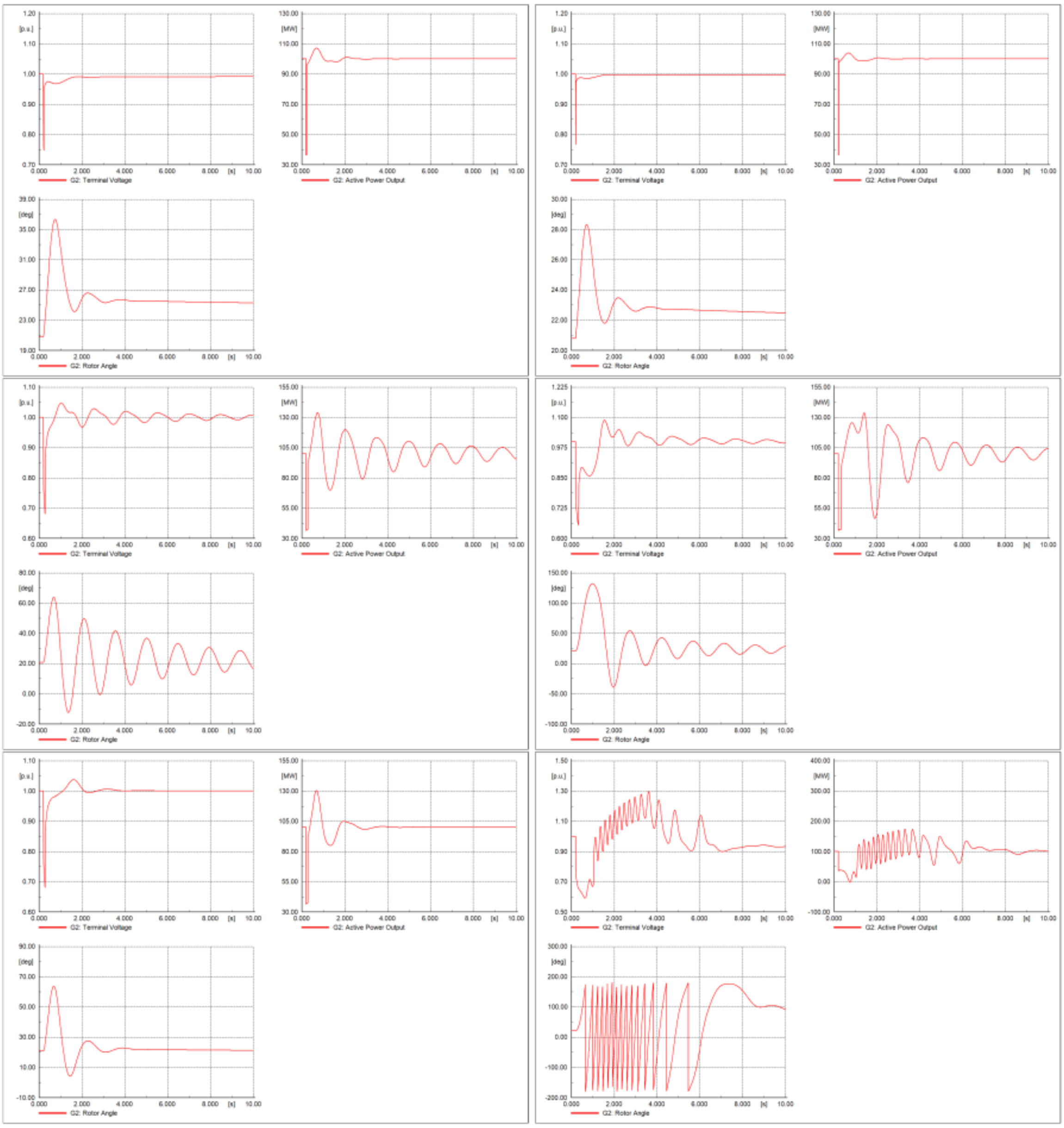

Figure 6: EMT Analysis at different fault clearing time, for adequate damping(Column 1) and Verge of instability(Column 2) with No controls(Row 1), AVR(Row 2), AVR and PSS(Row 3)

2.4.2 Effect of fault clearing times on System Stability

Critical clearing time is the maximum elapsed time from the initiation of a fault until its isolation such that the system is transiently stable.

1. The quicker the fault is cleared, faster system returns to stable operating point
2. With AVR added, the system can afford longer time before it collapses to instability, but this causes negative damping
3. AVR with PSS, enables the longer clearing times and increases the damping

2.4.3 Frequency of the critical mode

Using the equation (1) , the frequency of critical modes are calculated as follows:

	Constant excitation	AVR	AVR and PSS
t_{pp} (sec)	2.89 - 2.279 = 0.6126	9.367 - 8.524 = 0.843	8.846 - 7.475 = 1.371
Frequency (Hz)	0.8162	0.593	0.365

Table 5: Frequency of critical mode

2.4.4 Damping of the critical mode for system without controls

Using logarithmic decrement method and considering two successive peaks, If x1 is the first Maximum Peak Overshoot amplitude and x2 is the successive peak overshoot amplitude, then:

$$\delta = \ln \frac{x1}{x2} \tag{2}$$

The damping ratio is then found by:

$$\zeta = \frac{1}{\sqrt{1 + (\frac{2\pi}{\delta})^2}} \tag{3}$$

For x1 = 10.2 degrees and x2 = 0.6 degrees, δ = 2.833;

Damping ratio, ζ = 0.411

2.4.5 Modal Analysis

1. Order of system and controls

	Order of the system
System without controls	17 x 17
AVR activated	21 x 21
AVR and PSS activated	27 x 27
Order of model of controllers	10 x 10

Table 6: Modal Analysis

2. Modes and Damping

Electro-mechanical modes	Frequency (Hz)
-1.208±9.618	1.531
-1.21±4.319	0.687
-0.187±0.018	0.003

Table 7: Modal Analysis : Constant Excitation

	Electro-mechanical modes	Frequency (Hz)
AVR	-1.031±9.589	1.526
	-0.179±4.329	0.689
	-0.506±0.02	0.003
AVR+PSS	-1.169±3.825	0.609
	-0.504±0.02	0.003

Table 8: Modal Analysis : Constant Excitation with AVR and PSS

- Real Eigen values and Faster Poles/Zeros(far left from the imaginary axis) are ignored
- AVR+PSS shows the ideal controls for the power system
- Provides stable system response using negative feedback, and positive damping with PSS.

2.5 Effect of Power System Stabilisers on System Stability

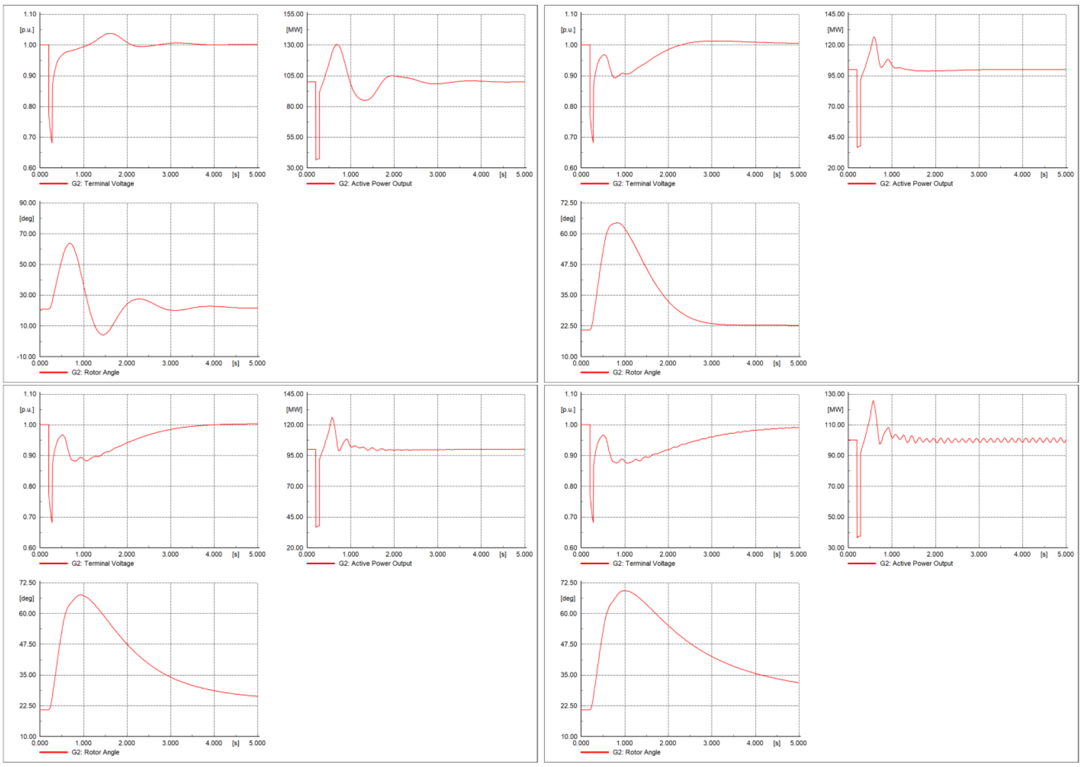

Figure 7: EMT Analysis for different values of PSS 5, 50, 100, and 150. [Left to Right]

2.5.1 Observations

1. PSS is used to avoid subsequent signal variation after first swing control by AVR
2. PSS increases the damping torque and hence the damping of the system and reduces the synchronising torque to and extent
3. System bandwidth is also reduced

2.6 Effect of Fault Location on System Stability

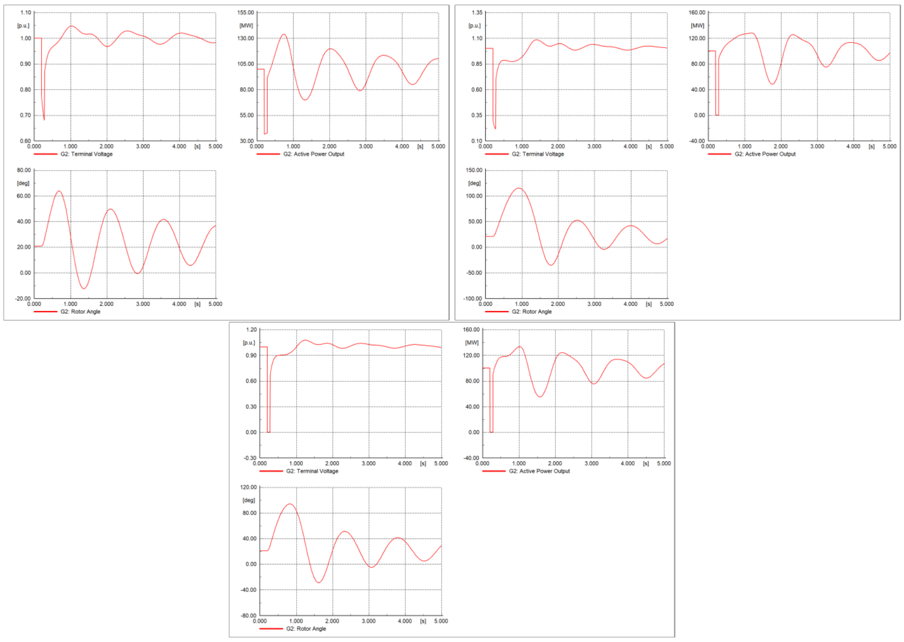

Figure 8: EMT Analysis Fault location. Bus 4, Bus 5 and Bus 2. [Left to Right]

1. Farther the fault, more power is transferred into the system and is hence is subtracted from the power input to the generator
2. When more power is transferred to the system during the fault, the lower the acceleration of the machine rotor and greater the degree of stability

2.7 Effect of Initial generator loading on System Stability

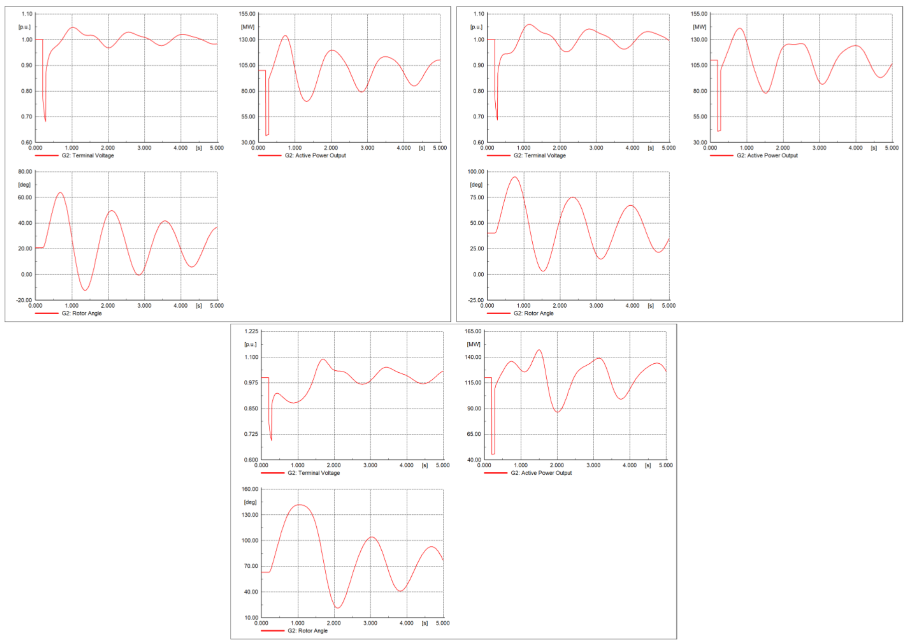

Figure 9: EMT Generator Initial Loading. P2=P3 = 100 MW, P2=P3 = 110 MW, P2=P3 = 120 MW [Left to Right]

2.7.1 Observations

1. Higher the initial loading, higher the system instability
2. The starting rotor angle magnitude is large initial loading is high
3. System inertia is reduced if the power rating at the start is high

Using the equation (1) , the frequency of critical mode is:

Generator Loading (MW)	Critical mode frequency(Hz)
110	0.588

Table 9: Effect of Initial Generator loading

2.8 Effect of System Inertia on System Stability

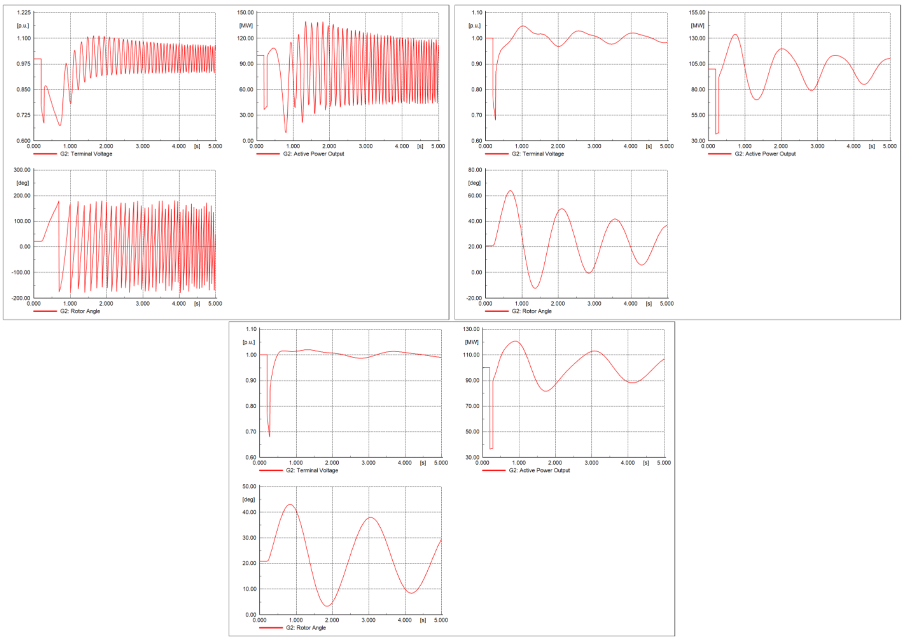

Figure 10: EMT Analysis for System inertia H = 1.1 s, 3.84 s and H = 10 s. [Left to Right]

2.8.1 Observations

1. Smaller the H, larger the angular swing during any time interval
2. If the Inertia constant of the system generators are decreased, the frequency variation will be high in the system
3. Higher rate of change of frequency will push the system stability into critical mode

Using the equation (1) , the frequency of critical modes are:

Inertia Constant (s)	Critical mode frequency(Hz)
3.84	0.625
10	0.455

Table 10: Effect of System Inertia

3 Conclusion

Power System, in terms of Voltage Stability and Rotor Angle stability was analysed and experimented on a test model using DigSilent PowerFactory software. Voltage Stability depends on the Reactive power. The type of load modelling has a profound impact on the analysis. Rotor Angle stability concerns with the Real Power transfer in the system and its effect. The stability and damping improves significantly with Negative feedback and control parameters. Generator properties and system loading and Fault characteristics affects the stability in general.

4 References

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