ETAP Transient Stability
Validation Cases and Comparison Results

Case No. 4
9-Bus Multi-Machine System Benchmark
ETAP TS V&V Case Number TCS-TS-126

Comparison with *Power System Control and Stability* by Anderson and Fouad

Highlights:

- Comparison between the ETAP Transient Stability simulation results and a 9-Bus Multi-Machine System Benchmark (*Power System Control and Stability* by Anderson and Fouad)
- Rotor angle stability study in a multi-machine transmission system
- 9-bus 3-machine benchmark system
- End of transmission line fault and fault isolation simulation
- Synchronous generator rotor angle post-fault response study
- ETAP built-in synchronous machine dynamic model
- ETAP built-in excitation/AVR model
- Comparison of generator relative and absolute rotor angle responses
- Nearly identical results in terms of the initial rotor angles, maximum rotor angles, oscillation frequency, and the overall curves of the rotor angle swing

1. System Description

A 9-bus 3-machine system transient stability study is applied in this validation case. The system is documented in *Power System Control and Stability* by Anderson and Fouad. The system includes three generators and three large equivalent loads connected in a meshed transmission network through transmission lines as shown in Figure 1. The generators are dynamically modeled with the classical equivalent model.

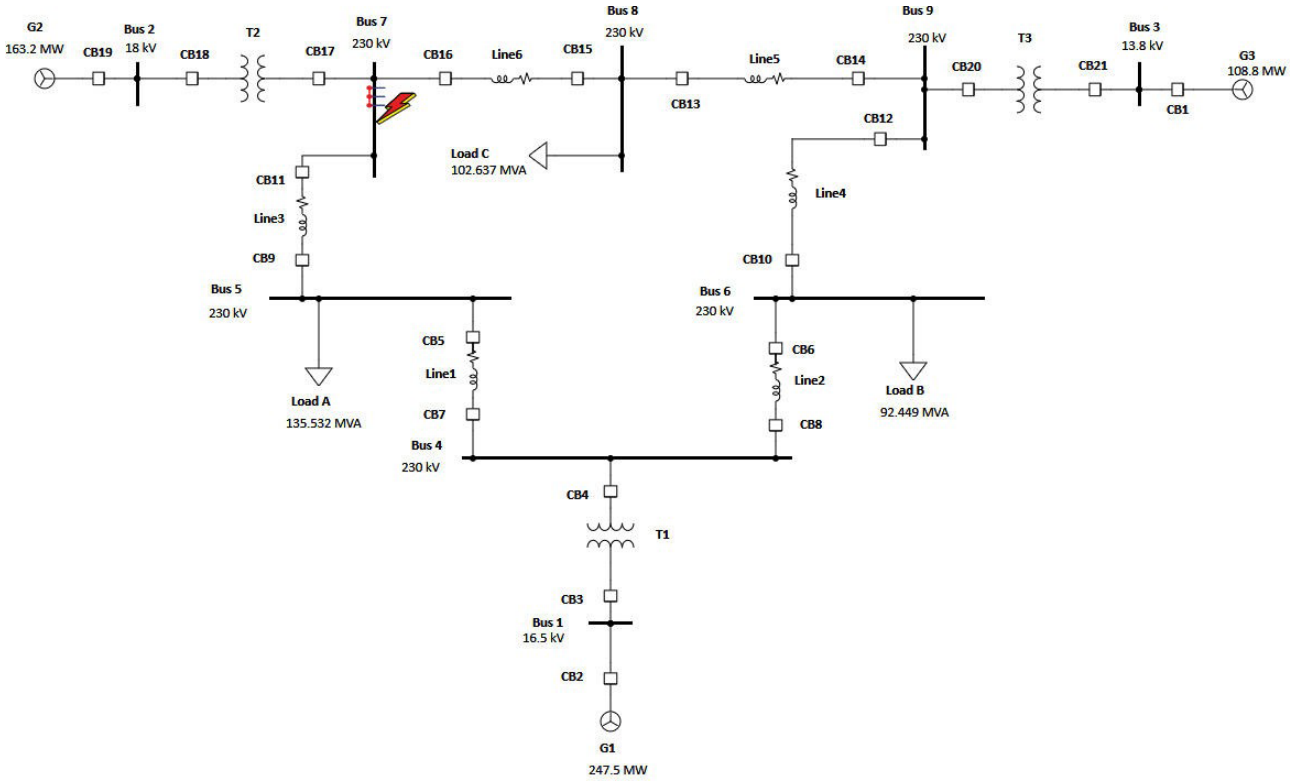

Fig. 1. 9-Bus Multi-Machine Benchmark System

2. Simulation Events

Simulation events for this system are set up as follows:

- 3-phase fault at the end of Line3 (near Bus7) @ t = 0
- Clear fault @ t = 0.083 second and open CB9 and CB11 @ t = 0.084 second

3. Simulation Result Comparisons with the 9-Bus Multi-Machine Benchmark System

In this study, the generator relative rotor angle and absolute rotor angle response behaviors will be investigated following the simulation events. The following plots (Figures 2-5) show the generator relative rotor angle and absolute rotor angle simulation results by ETAP and the 9-Bus Benchmark System as published in P*ower System Control and Stability* by Anderson and Fouad.

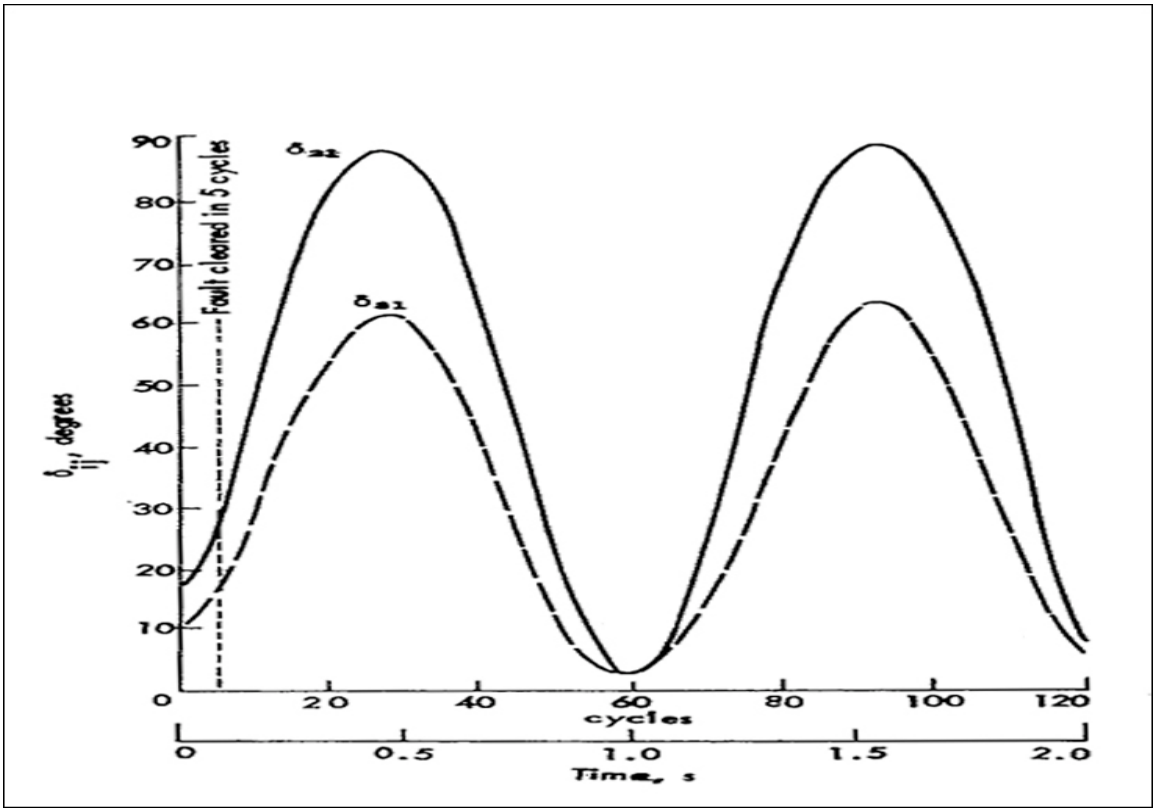

Fig. 2. Generator Relative Rotor Angle Responses for the 9-Bus Multi-Machine System

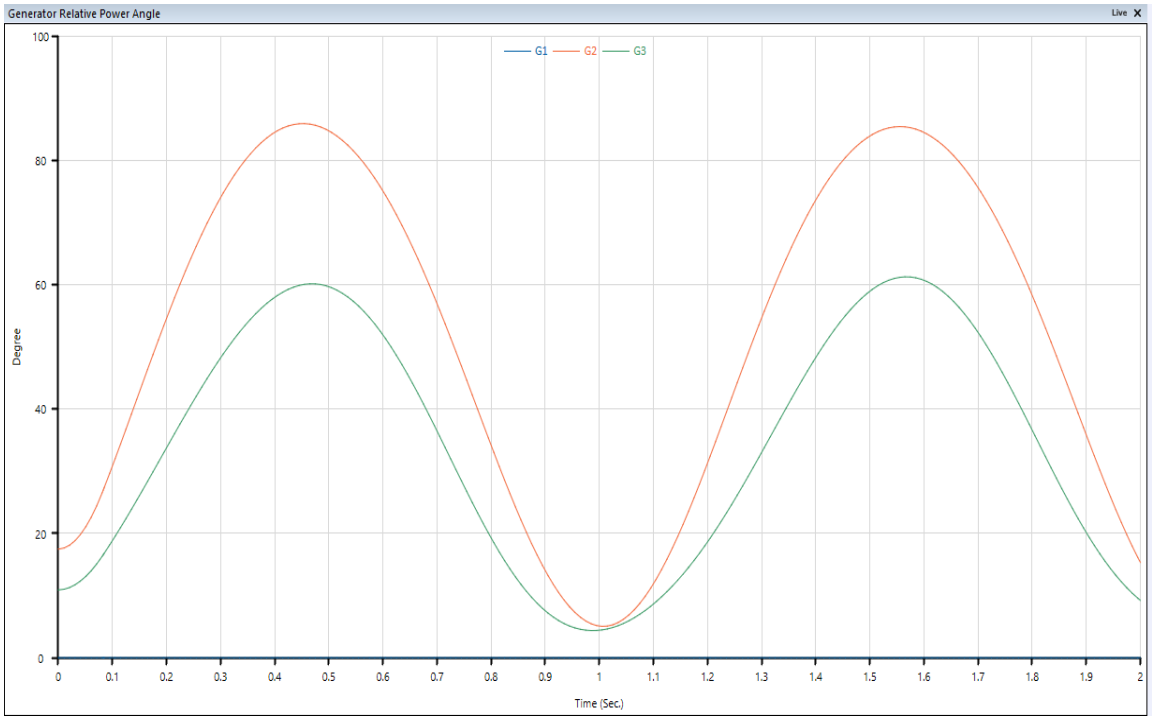

Fig. 3. Generator Relative Rotor Angle Responses by ETAP

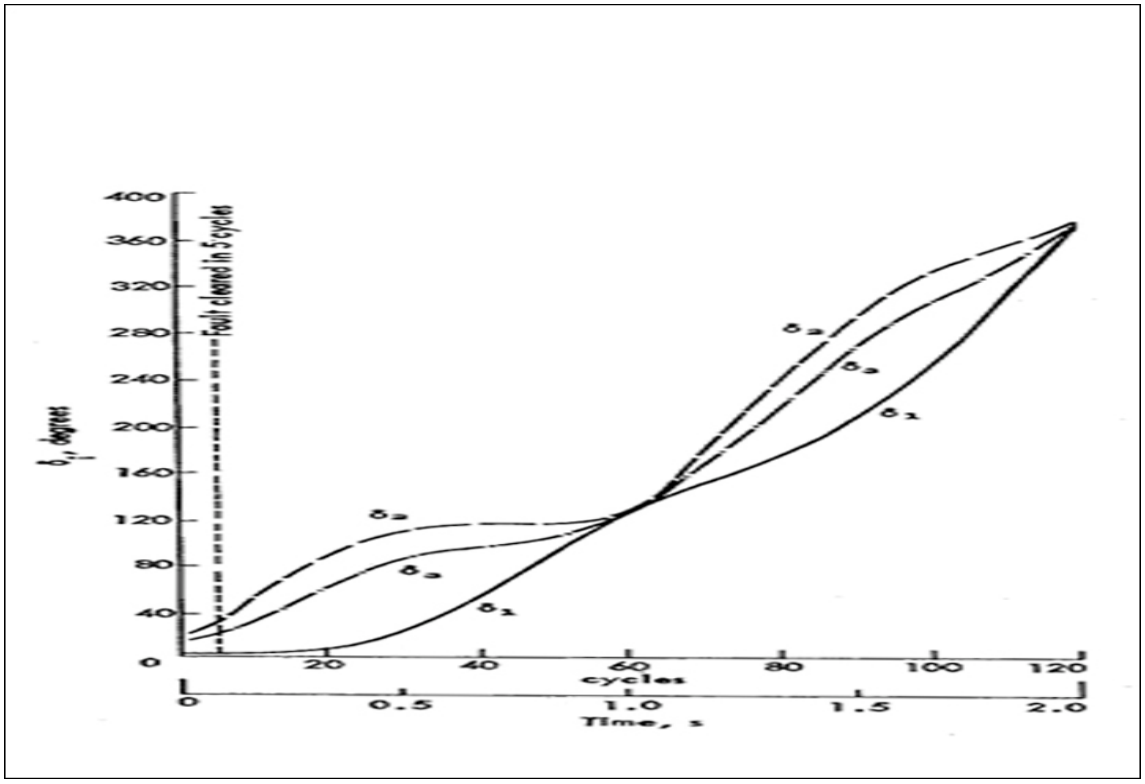

Fig. 4. Generator Absolute Rotor Angle Responses for the 9-Bus Multi-Machine System

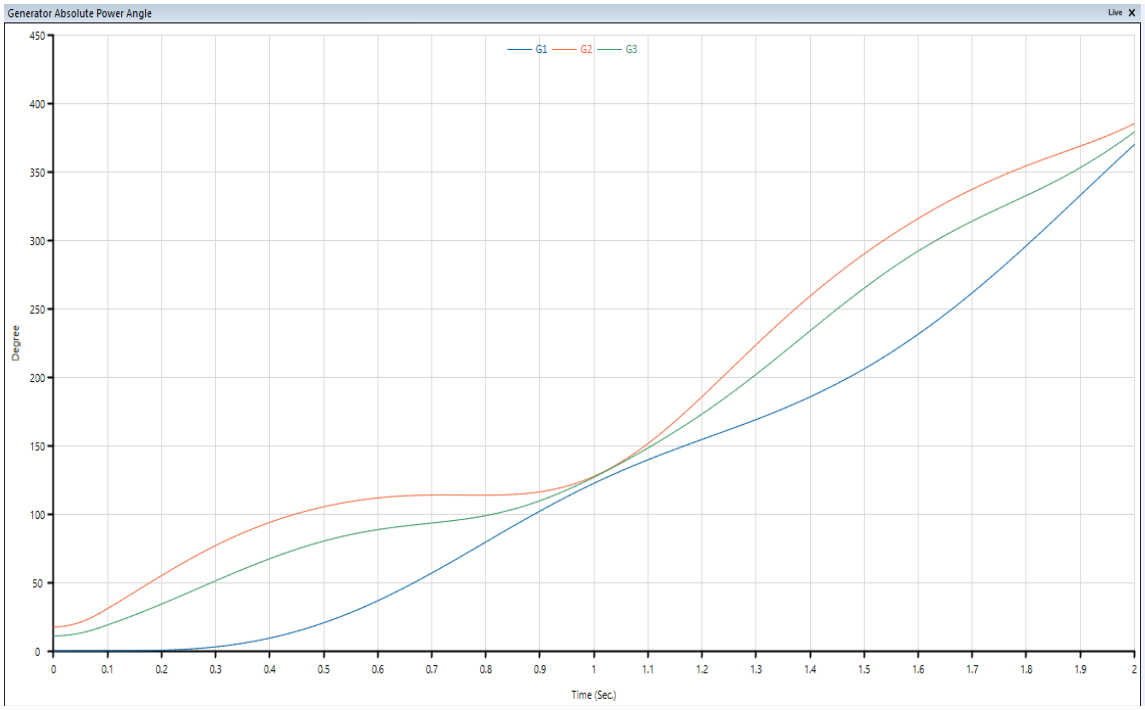

Fig. 5. Generator Absolute Rotor Angle Responses by ETAP

From the above figures, the initial generator relative rotor angles, relative rotor angle oscillation frequencies, maximum relative rotor angles, maximum absolute rotor angles, and the overall response curve shapes for both relative and absolute rotor angles are compared. Note that a very close correlation between ETAP results and the benchmark are noticed. The slight difference for G2 maximum relative rotor angle and the difference in the final values of the absolute angles may be due to the fact that the generator damping coefficients are not available in the publication and typical values are used in the ETAP simulation.

4. Conclusions

In this study, the ETAP Transient Stability generated simulation results for both the generator relative and absolute angle response behaviors, including their initial values, maximum values, oscillation frequencies, and overall shapes are all almost identical to the benchmark results.

Reference:

1. P.M. Anderson and A.A. Fouad, *Power System Control and Stability*, Vol. 1, The Iowa State University Press, Ames, Iowa, USA, 1977.

2. ETAP Transient Stability V&V Documents, Test Case Number TCS-TS-126, 2023.