

ETAP Transient Stability Validation Cases and Comparison Results

Case No. 1 Generator Start-Up Simulation

ETAP TS V&V Case Number TCS-TS-143

Comparison with Field Measurement Data

Highlights:

- Comparison between the ETAP Transient Stability/Generator Start-Up simulation results and field measurement data
- Special study of the emergency generator start-up for a nuclear generation plant
- ETAP built-in frequency dependent synchronous generator, induction machine, and network models
- ETAP built-in IEEE Standard 2.1 synchronous machine model
- ETAP built-in hydro turbine and speed governor/gate control model, including water tunnel system.
- ETAP built-in IEEE ST1D excitation and AVR model, including DC flashing and V/Hz switching control.
- ETAP built-in double-cage induction machine model
- Multiple voltage levels, multiple substations, and multiple loads
- Comparisons include starting generator frequency, voltage, output current and power, starting motor voltage, current and input power.
- Excellent correlation between ETAP simulation results and the field measurements data
- Accepted report by the client and NRC (Nuclear Regulation Commission)
- Published paper in IEEE IAS Transaction (see reference)

1. System Description

The studied hydro generation station shown in Figure 1 is a backup power source for a nuclear power generation plant. Under emergency conditions, hydro generators of the station must be started as a black start source to pick up the auxiliary loads of the nuclear generation plant. In this study, the generator is dynamically modeled with ETAP IEEE Standard 2.1 type. The Exciter/AVR and Turbine/Governor are modeled with ETAP built-in exciter STD1 type and governor HYDR type. The induction motors in the system are dynamically modeled with ETAP double-cage independent bars type. The system including generator, motor, and network is flagged using frequency-dependent model.

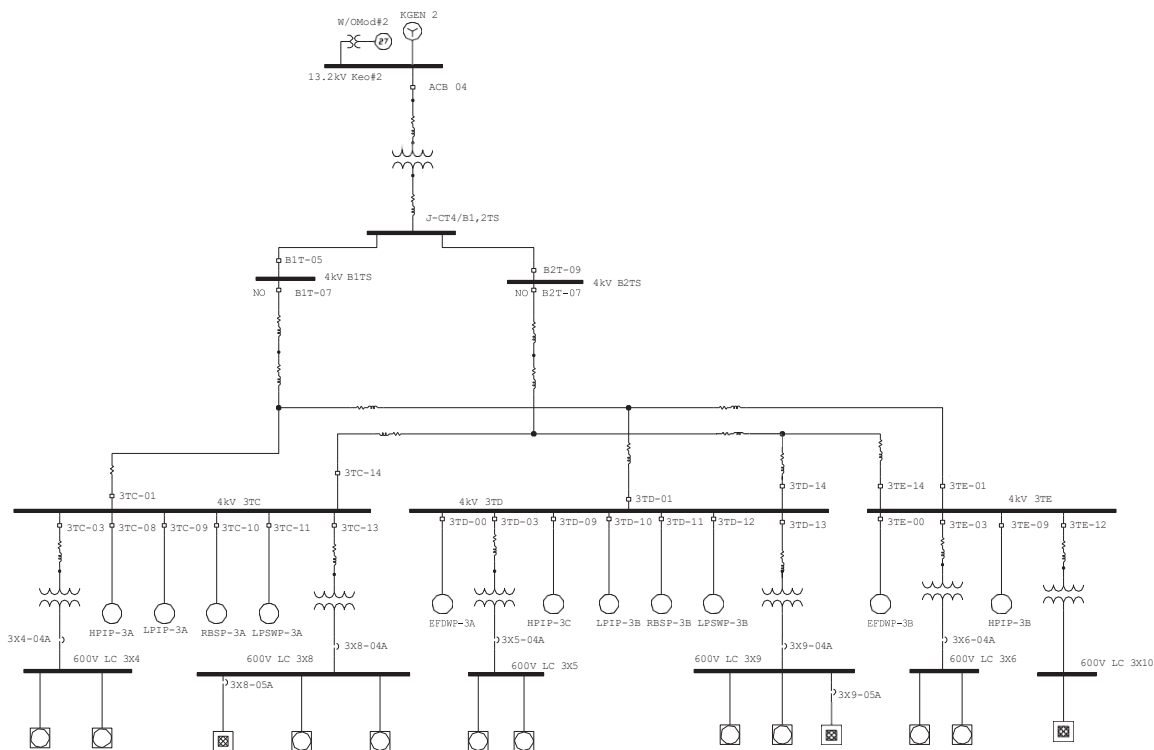


Fig. 1. Hydro Generation Station System One-Line Diagram

2. Simulation Events

The simulation events on the study are set up exactly the same as the site test procedures, which are as follows:

- Start generator, with the exciter running in field flushing mode and governor in start control mode, @ t = 0 second
- The voltage-per-hertz switch continuously checks the generator terminal V/Hz value.
- Exciter will switch to AVR mode when it reaches 74% V/Hz
- The voltage relay checks the generator terminal voltage, if it reaches 76% V, it will trip to close the main feeder circuit breakers.
- A sequence loading will follow by starting-up motors and adding loads by closing individual circuit breaker.

3. Simulation Result Comparisons with the Site Measurement Data

The following plots (Figures 2 to 17) show some of the comparisons between the simulation results and field measurements for the starting generator and some starting induction motors.

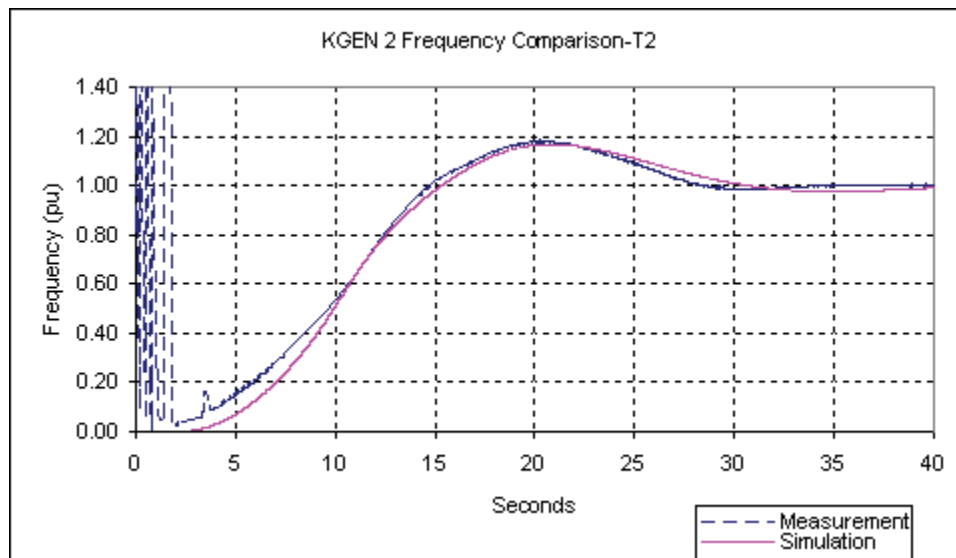


Fig. 2. Generator Frequency/Speed

In Figure 2, the measurement spikes at the start-up (up to 8 seconds) are noise related. The simulated result at the more critical portion of the curve (generator speed above 50% of its rated value) has a very close correlation with the field measurement data.

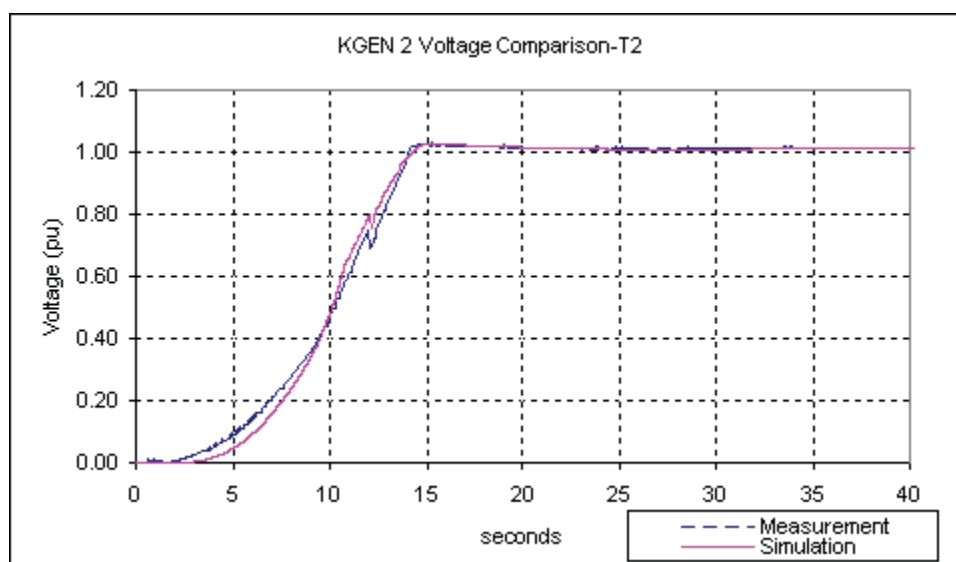


Fig. 3. Generator Terminal Voltage

Similar to the speed response, the generator voltage response in Figure 3 from the simulation also closely correlates the field measurement, in particular in the region more critical (voltage above 50% of its nominal value).

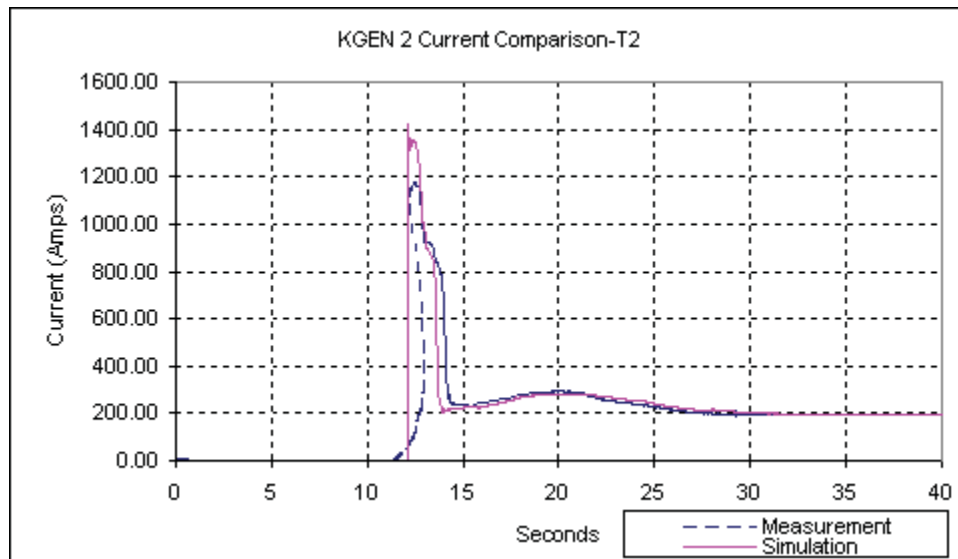


Fig. 4. Generator Current

The generator current from the ETAP simulation and the field measurement in Figure 4 shows almost identical results in the final settle down time and final values. The difference at the beginning (initial transient in the generator current) may be due to an error with the measuring device, i.e., difficulty with recording fast changing signals.

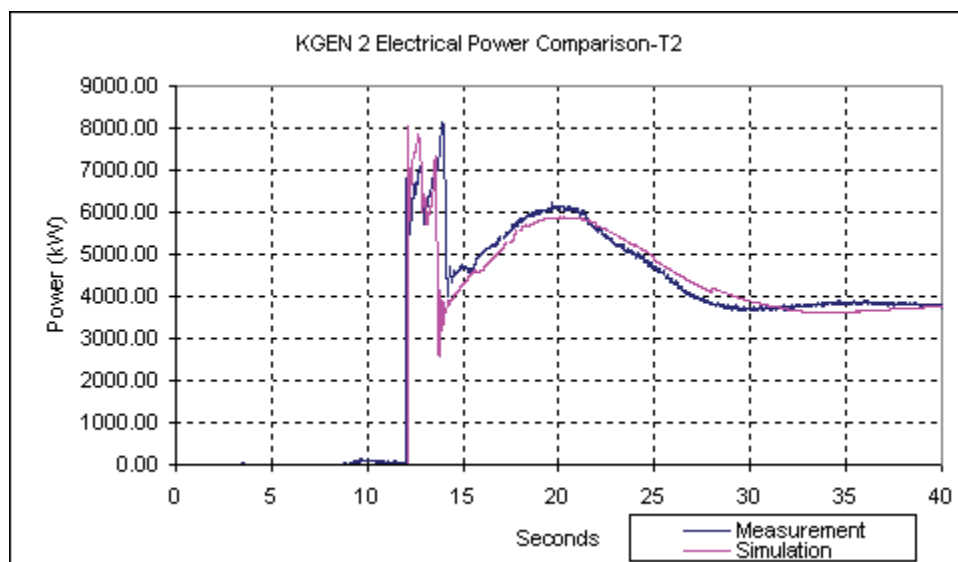


Fig. 5. Generator Electrical Power

The comparison for generator electrical power response in Figure 5 shows close correlation for the major parameters, including the peak of oscillation, settle down time, and final values. The difference in the initial high-speed transient is probably due to the responding time of the measuring equipment.

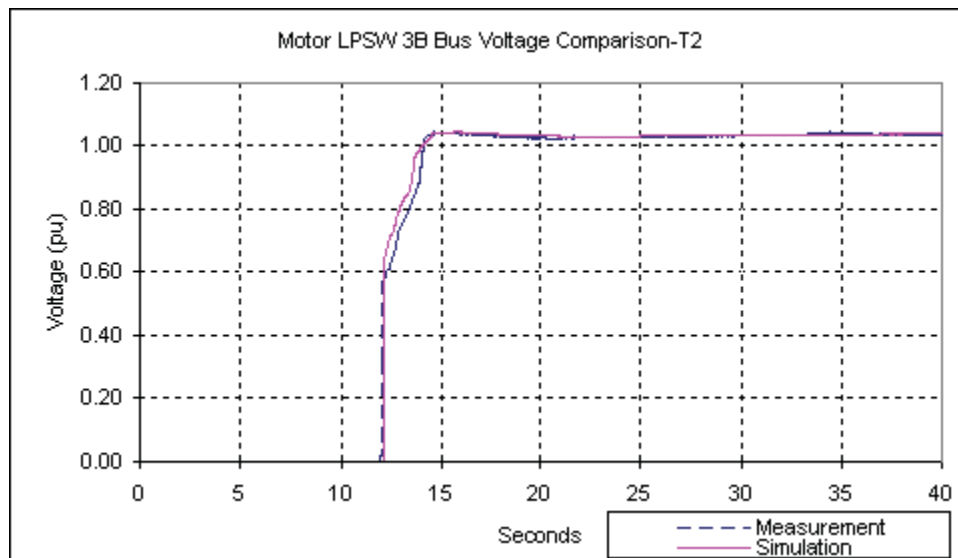


Fig. 6. Motor LPSW-3B Terminal Voltage

The motor voltage response for motor LPSW-3B in Figure 6 from the simulation very closely agrees to the measured data.

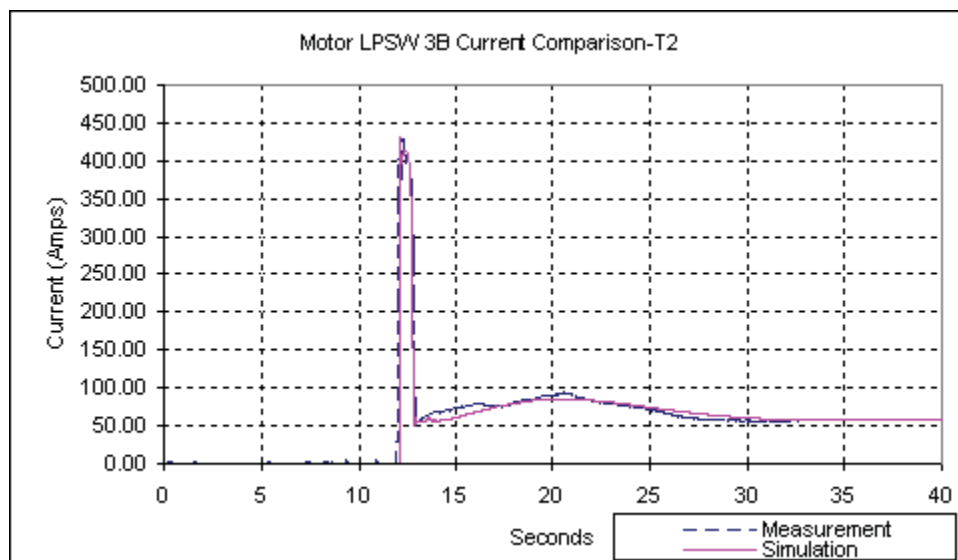


Fig. 7. Motor LPSW-3B Current

The motor current response for motor LPSW-3B in Figure 7 from the simulation also very closely agrees to the measured current curve.

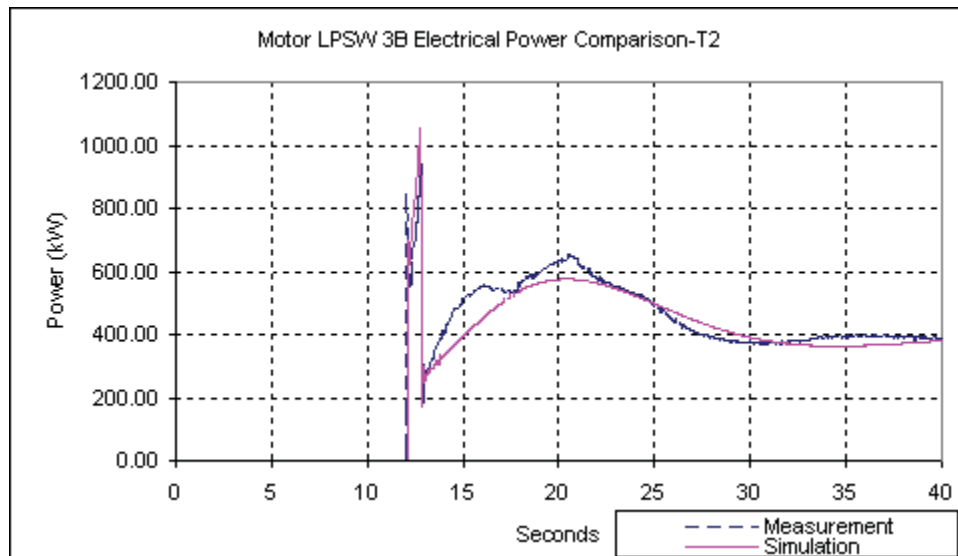


Fig. 8. Motor LPSW-3B Electrical Power

The motor electrical power response for motor LPSW-3B in Figure 8 from the simulation closely agrees to the measured electrical power curve. In particular, the motor starting time (duration of the inrush time) and the full load power both are identical between the simulation and the measurement.

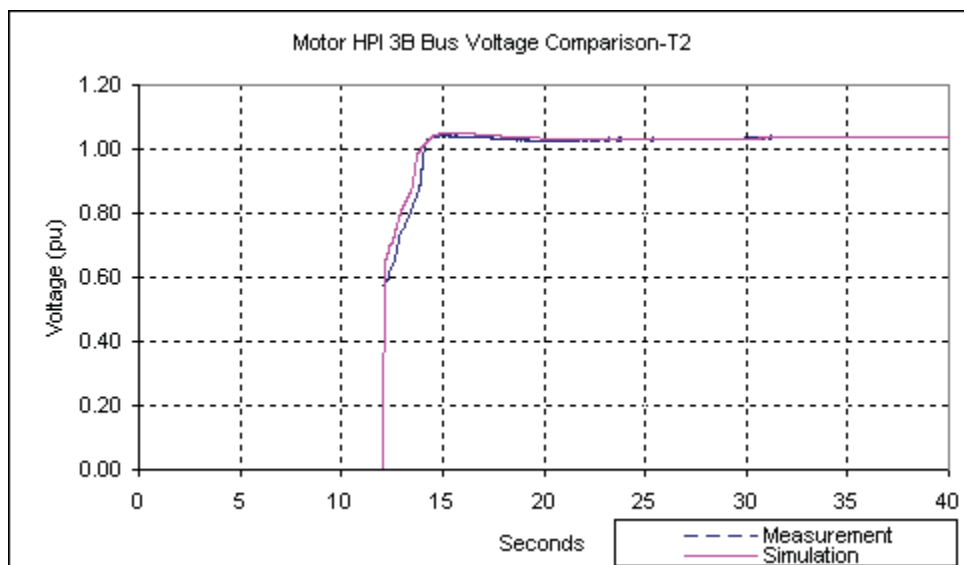


Fig. 9. Motor HPI-3B Terminal Voltage

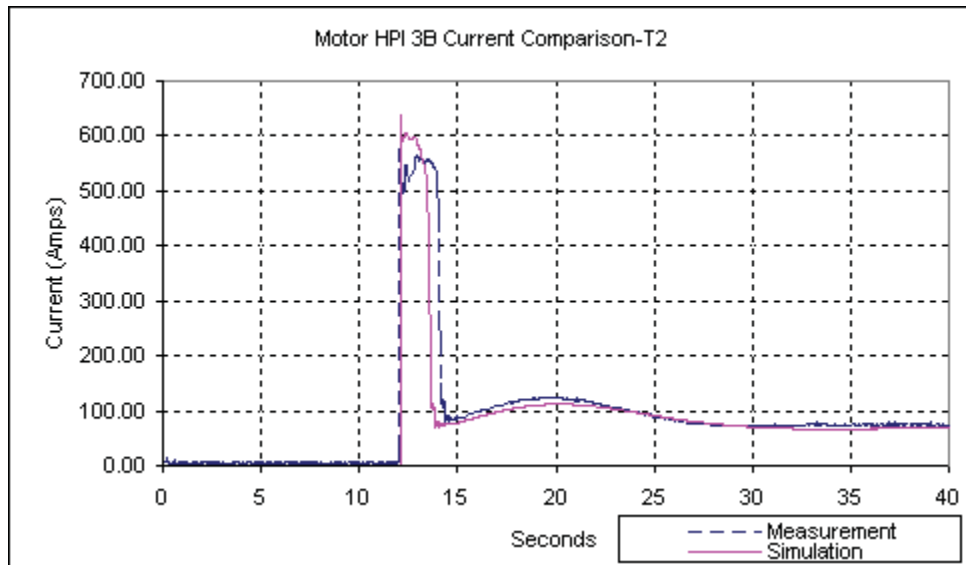


Fig. 10. Motor HPI-3B Current

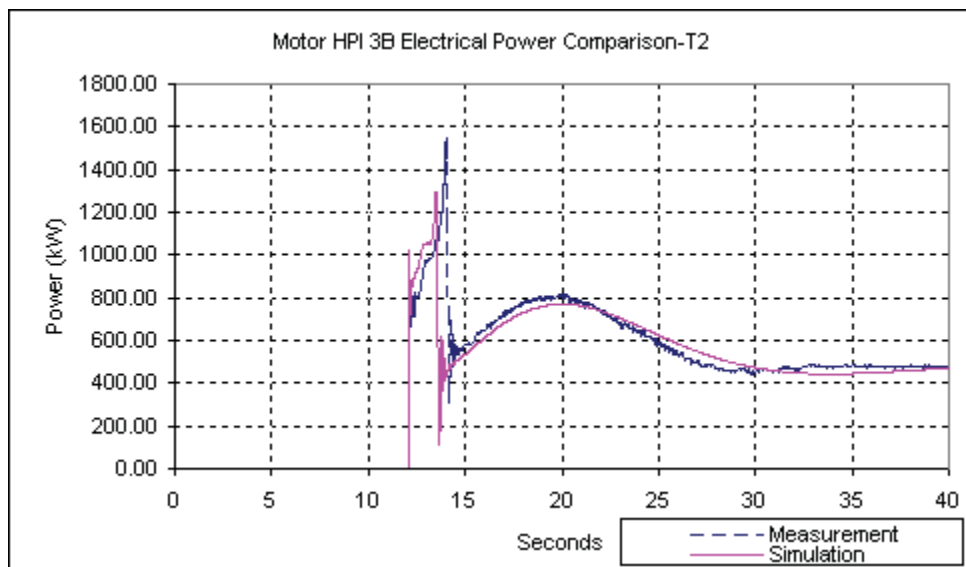


Fig. 11. Motor HPI-3B Electrical Power

Figures 9-11 show motor voltage, current, and electrical power comparison for motor HPI-3B. Simulation results also very closely agree to the measured data.

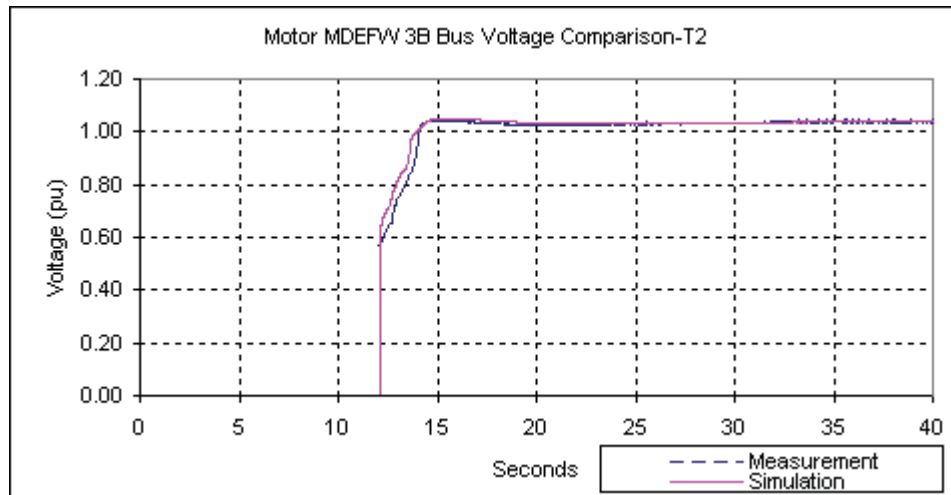


Fig. 12. Motor MDEFW-3B Terminal Voltage

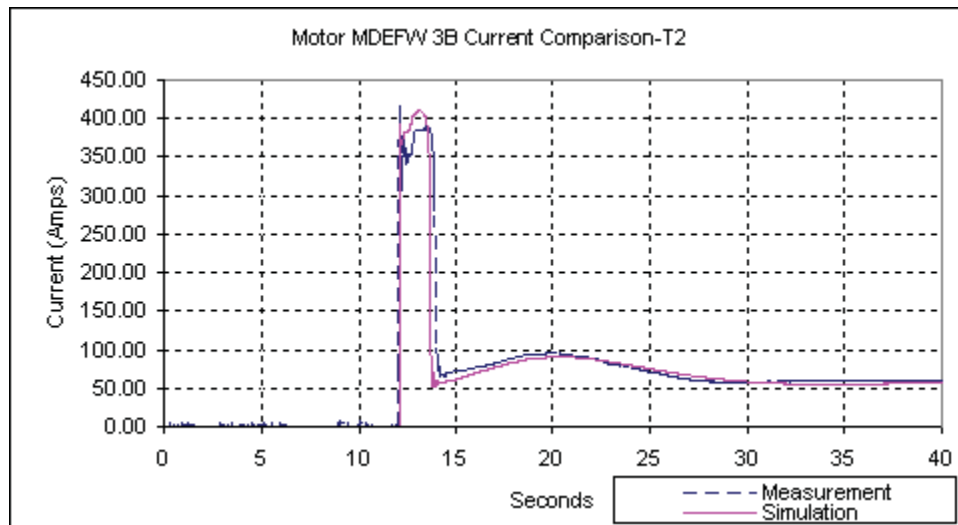


Fig. 13. Motor MDEFW-3B Current

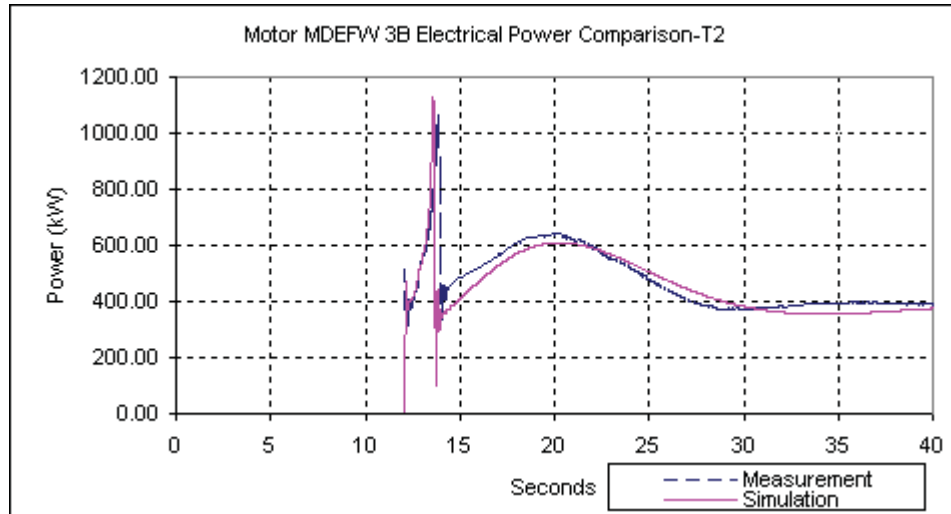


Fig. 14. Motor MDEFW-3B Electrical Power

Similar results and conclusions can be reached for another starting motor MDEFW-3B as seen in Figures 12-14.

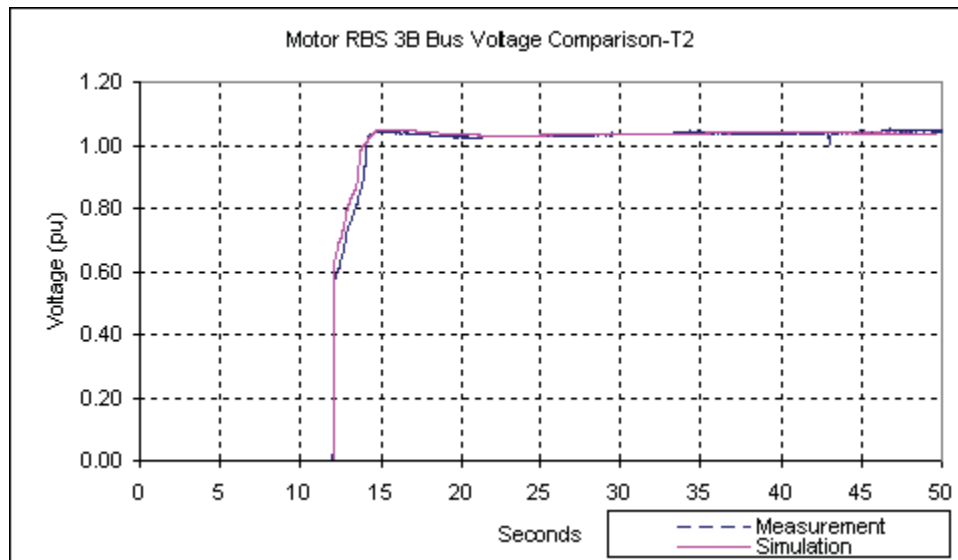


Fig. 15. Motor RBS-3B Terminal Voltage

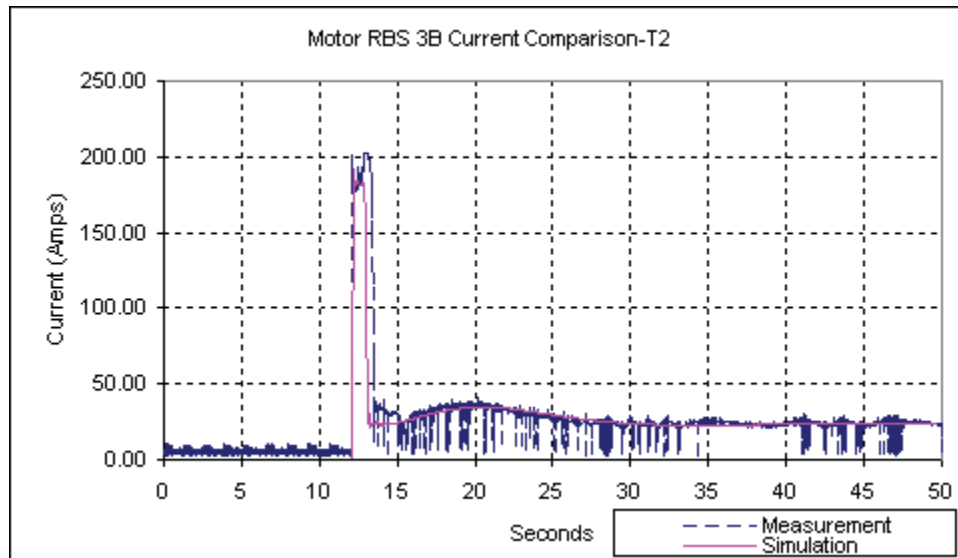


Fig. 16. Motor RBS-3B Current

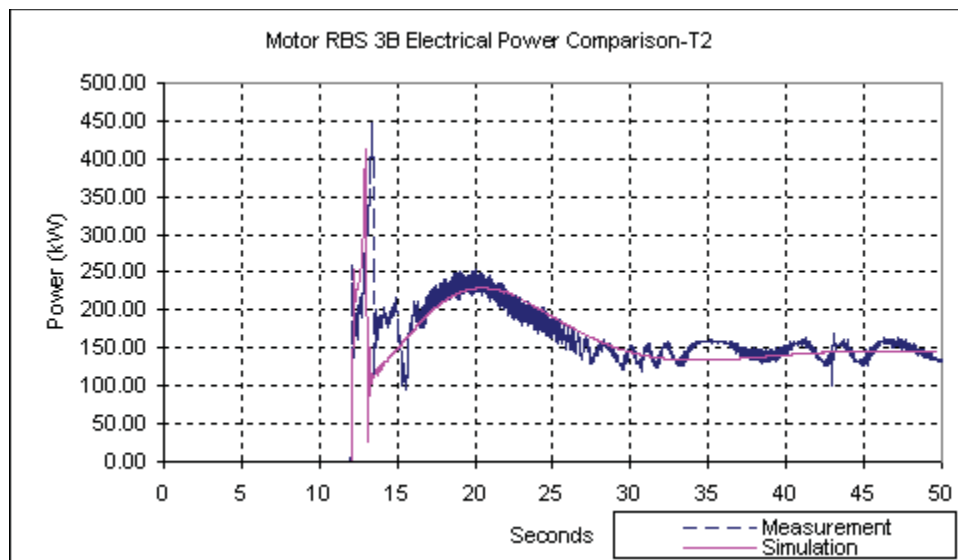


Fig. 17. Motor RBS-3B Electrical Power

The results and conclusions for comparison of the accelerating motor RBS-3B in Figures 15-17 are the same as for the other motors in the previous figures.

4. Conclusions

In this comparison case, a nuclear generation plant emergency backup generator start-up condition is studied. The actual generator start in the real system is performed and all the key variable responses are recorded. ETAP Transient Stability/Generator Start-Up program is used to simulate the real system and the results are compared to the field measurements. A close examination shows the ETAP simulation results closely correlate to all the field measurement data that have been compared. Note that some of the dynamic parameters for the generator and motors (including inertia constants and shaft damping constants) are estimated due to lack of actual data. These factors have direct effect on the motor acceleration times.

Reference:

1. JJ Dai, Di Xiao, Farrokh Shokooh, Christopher Schaeffer, and Aldean Benge, "Emergency Generator Start-Up Study of a Hydro Turbine Unit for a Nuclear Generation Facility," *IEEE Transactions on Industry Applications*, Vol. 40, pp.1191-1199, September 2004.
2. ETAP Transient Stability V&V Documents, Case Number TCS-TS-143, 2023.