

Simulation results with time step = 1.0 second.

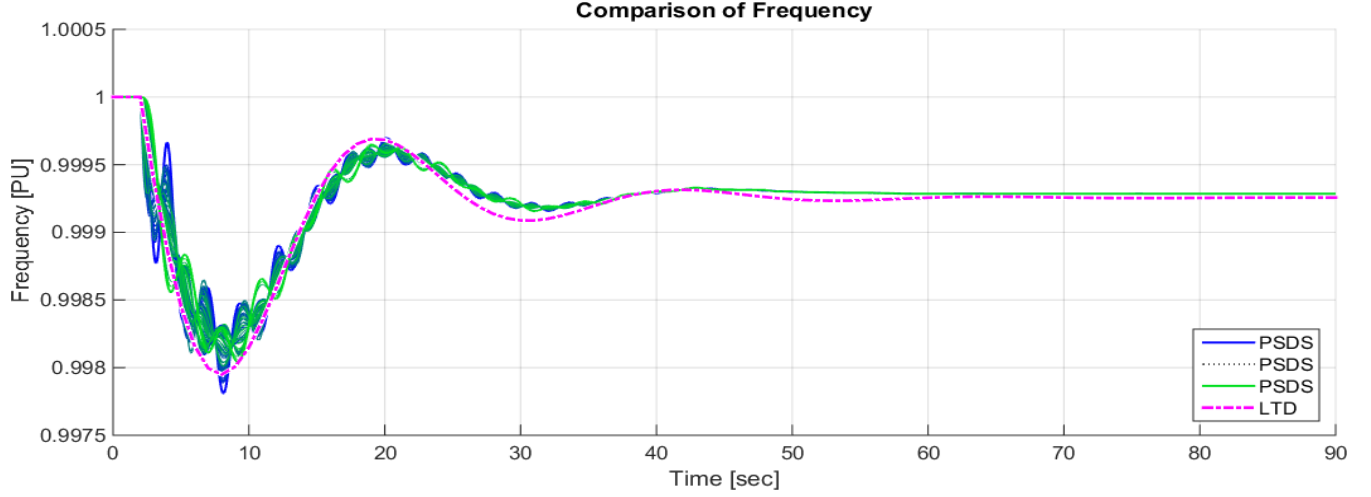


Figure 1: All PSDS bus frequencies and LTD system frequency response.

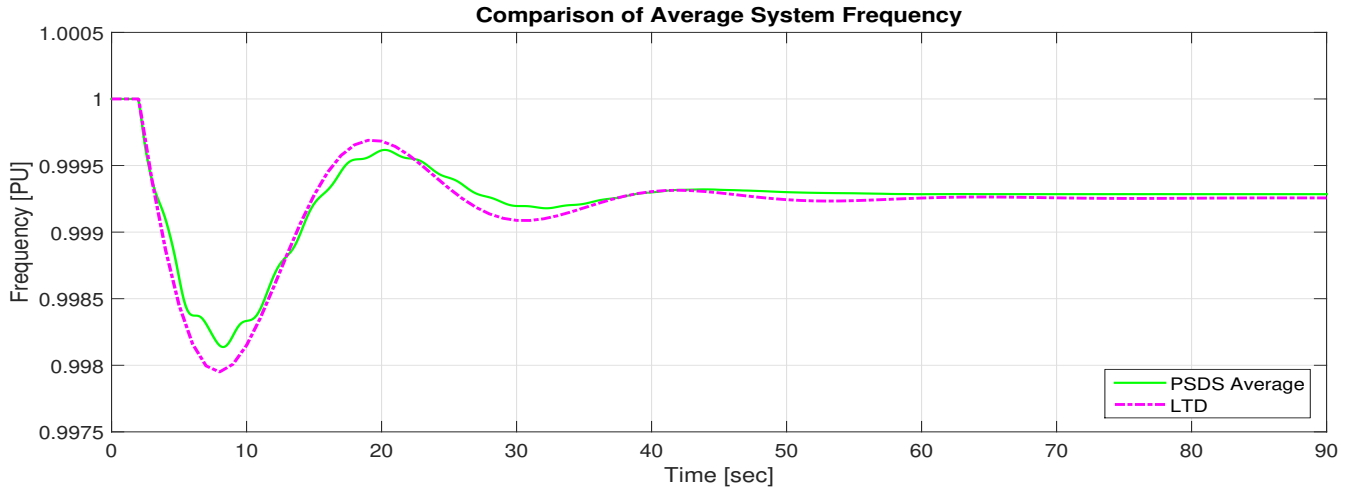


Figure 2: Averaged PSDS system response against LTD frequency. (Difference at $t(90) \approx 2.84E-5$).

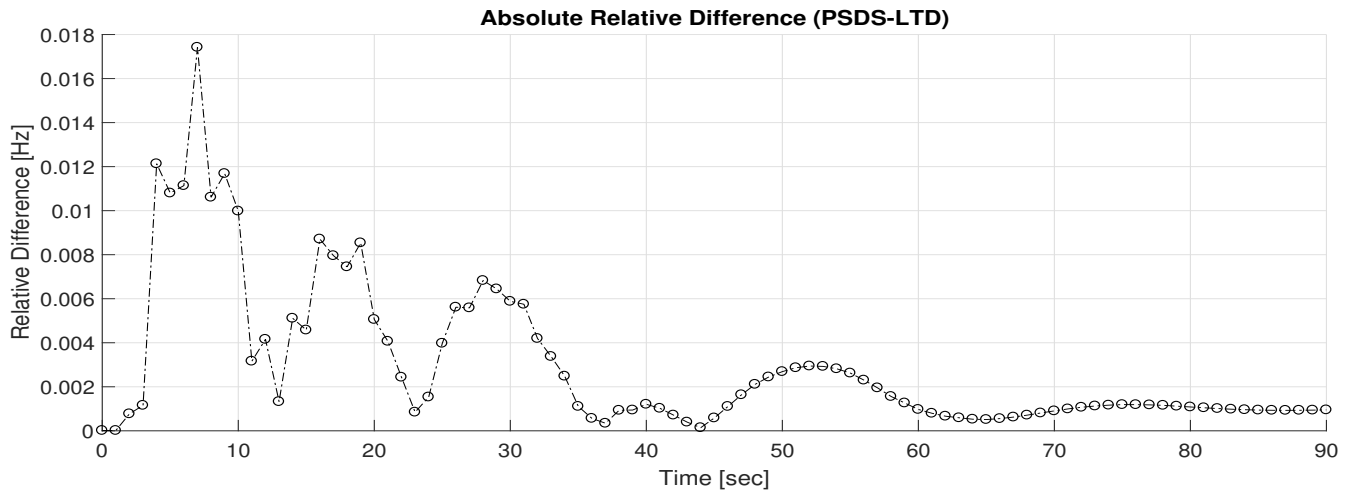


Figure 3: Relative Hz difference of PSDS - LTD $\left(\text{i.e. } \left| \frac{f_{PSDS}(t) - f_{LTD}(t)}{f_{PSDS}(t)} \right| \times 60\text{Hz} \right)$.

MiniWECC Model:**Simulation Results (60 Second Run):**

Buses 120		PSDS	LTD
Generators 34	Timestep	4.167 ms	1 sec
Loads 23	Produced Data File Size	35,492 KB	423 KB
Generation 107,509 MW	Simulation Run Time	41.42 sec	11.75 sec
Load 105,985 MW	Speed up from PSDS	1	3.52

Possible reasons for Steady State Variance

1. Mishandled Machine Parameters: PSDS and LTD Generator H and MWcap were verified as being the same for all machines in system.

2. AMQP JSON message behavior: The coded AMQP procedure sends data as a json message and as shown below, a value with many decimals is rounded to be represented as a floating point (Line 6), and then truncated when added to a dictionary (Line 9). This rounded and truncated value is what is sent as the AMQP message (Line 11). Note that Python reports these values as the same (Lines 12-17). The **numpy** (numerical python) package may have an alternate approach to this rounding / truncation behavior.

```

1 >>> import json
2 >>> lval = 123.123456789012345678901234567890
3 >>> lval
4 123.12345678901235
5 >>> print('% .30f' % lval)
6 123.123456789012351464407402090728
7 >>> msg = {'mval': lval}
8 >>> msg
9 {'mval': 123.12345678901235}
10 >>> print(json.dumps(msg))
11 {"mval": 123.12345678901235}
12 >>> 123.123456789012345678901234567890-123.123456789012351464407402090728
13 0.0
14 >>> print('% .30e' % (123.123456789012345678901234567890 - lval))
15 0.00000000000000000000000000000000000000000000000000000e+00
16 >>> 123.123456789012345678901234567890 == 123.12345678901235
17 True

```

3. Slack Tolerance: Decreasing the slack tolerance to 0.001 MW (from 1 MW) had no effect on relative difference - though did increase simulation time by $\approx 7x$ due to the number of power flows required to solve each time step.

4. Simulation Length: The simulation was run for 120 seconds and relative difference was found to vary slightly over time but stay between 3.3E-3% and 2.1E-3%.

5. Integration method Euler and RK-45 were found to have similar results and did not change relative difference.

6. Differences in load distribution: As shown in Figure 4, the steady state mechanical output does not change by the same amount in the two simulation environments.

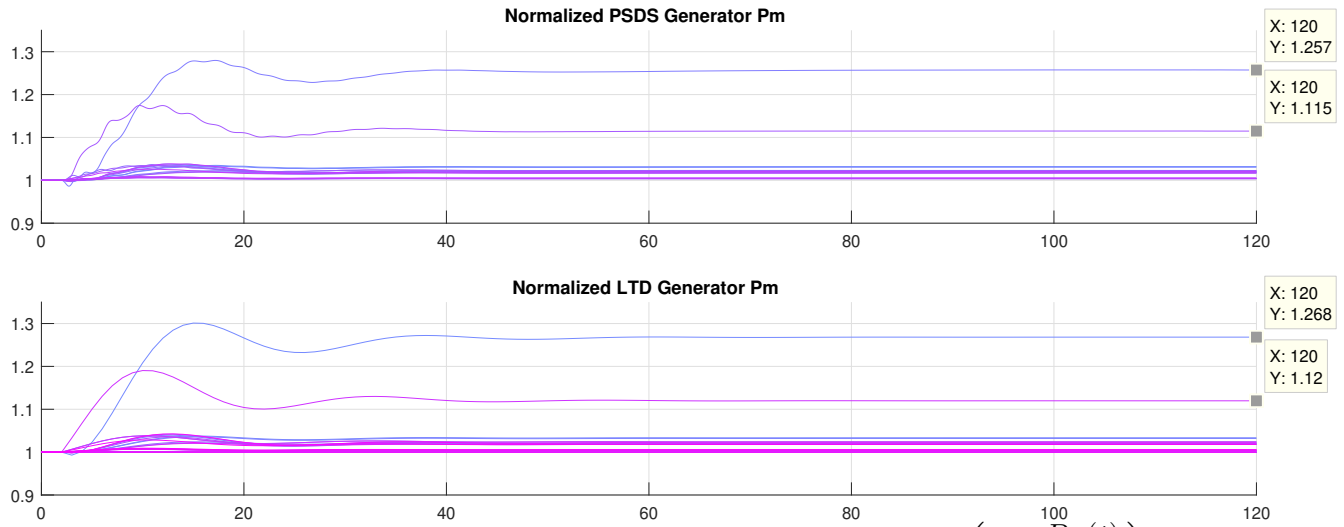


Figure 4: Normalized P_M from all machines in system. $\left(\text{i.e. } \frac{P_m(t)}{P_m(0)} \right)$

The table below quantified this difference for the two generators that had the largest % change from $t(0)$.

Generator	PSDS	LTD	% Δ Dif.	MW Dif.
WA-GEN (slack top line)	1.257	1.115	0.011	5.1
SDG GEN (lower line)	1.115	1.120	0.005	2.2

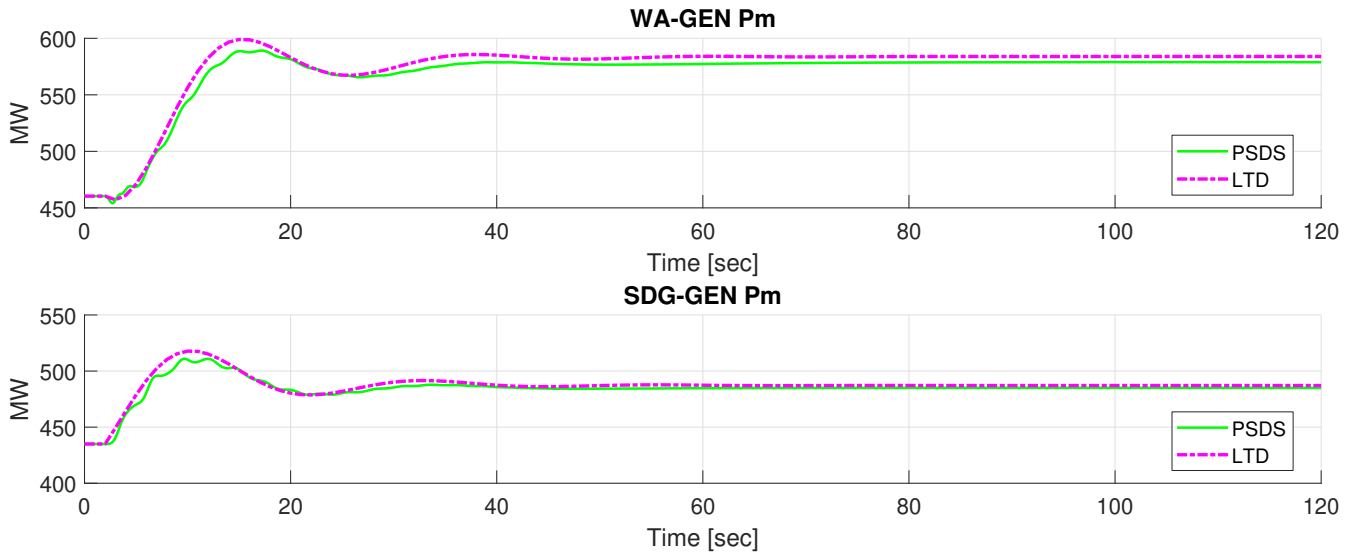


Figure 5: P_M from the machines that changed the most from $t(0)$.

7. Time step resolution: NOTE: Code changed after all previously listed test were ran. Changing the time step affects accuracy, size of data collected, and simulation run time. The following data was collected from a 90 second simulation. LTD uses rk45 integration and 0.5 MW slack tolerance — it is also run from the command line. The PSDS system has exciters and PSS included in dyd file. Theoretical steady state frequency was calculated as

$$f = 1 + \Delta f = 1 + \frac{\Delta P}{S_{base} \beta} = 1 + \frac{-1200 MW}{100 \times 15,555} = 0.999228543876567 = 59.953712632594019 Hz$$

	Time step	Simulation Time [sec]	Data File Size [KB]	Real time Speed up	PSDS Speed up	Reduction of file size	Steady State f error [Hz]
PSDS	4.167 ms	56.12	35,070.00	1.60	1.00	1.00	0.0034
LTD	2 sec	9.41	300.00	9.56	5.96	116.90	0.0017
LTD	1 sec	17.39	496.00	5.18	3.23	70.71	0.0017
LTD	0.5 sec	33.05	888.00	2.72	1.70	39.49	0.0017
LTD	0.25 sec	63.67	1,672.00	1.41	0.88	20.97	0.0017

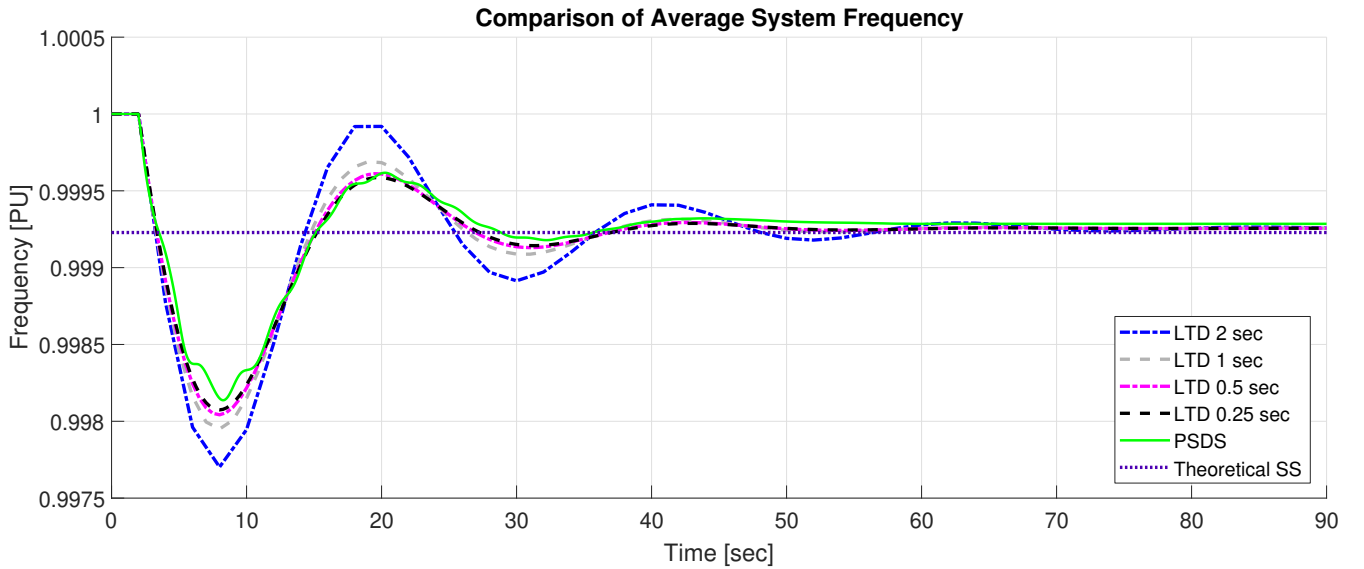


Figure 6: Comparison of system frequency among different time steps.

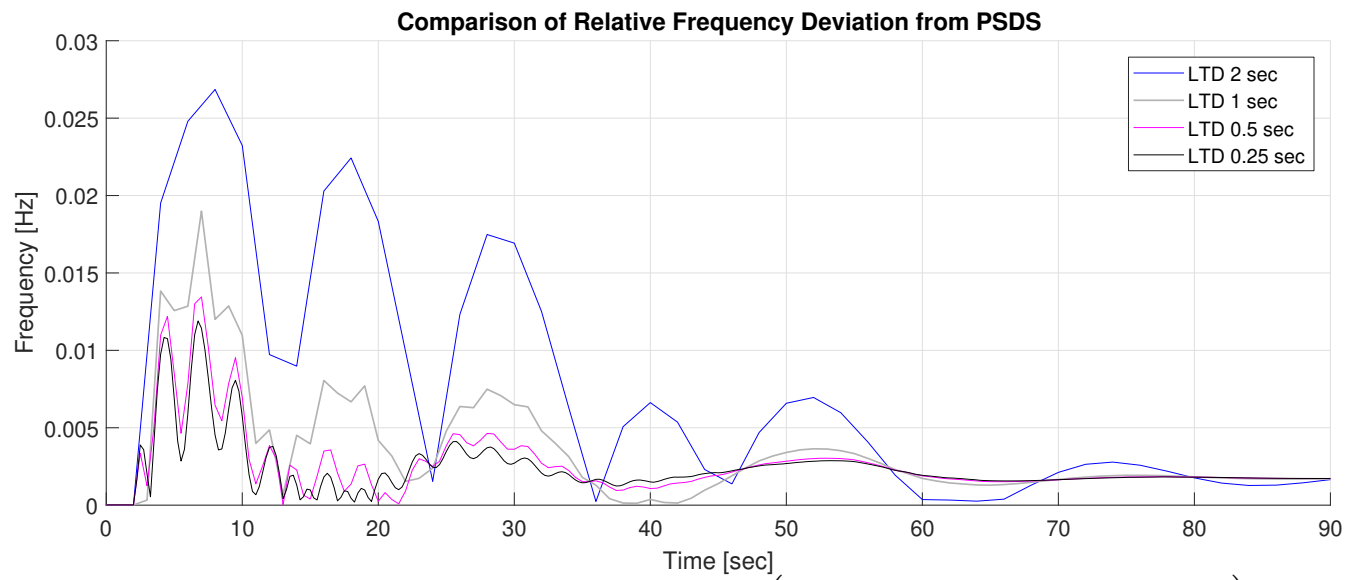


Figure 7: Relative Hz difference of PSDS - LTD (i.e. $|f_{PSDS}(t) - f_{LTD}(t)| \times 60\text{Hz}$).