Simulation results with time step = 1.0 second.

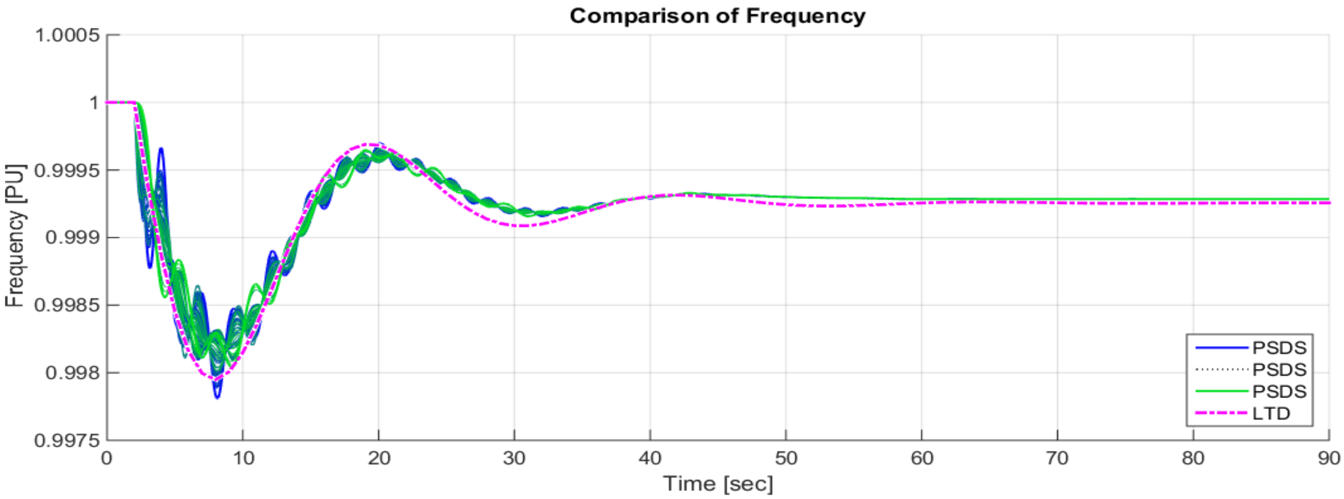

Figure 1: All PSDS bus frequencies and LTD system frequency response.

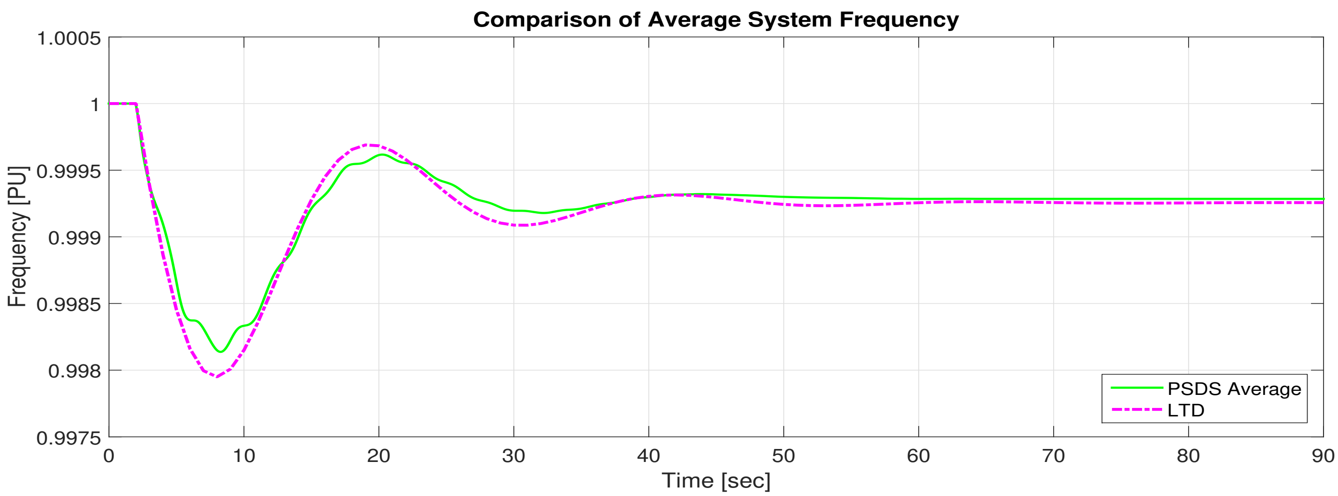

Figure 2: Averaged PSDS system response against LTD frequency. (Difference at $t(90) \approx 2.84\text{E-}5$).

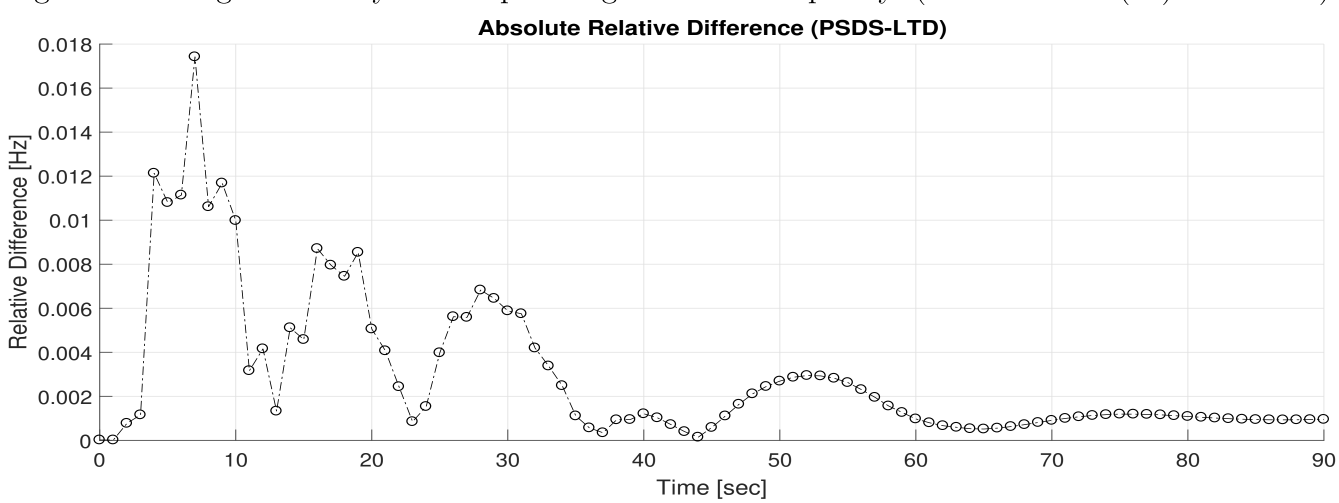

Figure 3: Relative Hz difference of PSDS - LTD $\left(\text{i.e.}\ \left|\frac{f_{PSDS}(t) - f_{LTD}(t)}{f_{PSDS}(t)}\right| \times 60\text{Hz}\right)$.

MiniWECC Model:

Buses 120

Generators 34

Loads 23

Generation 107,509 MW

Load 105,985 MW

Simulation Results (60 Second Run):

	PSDS	LTD
Timestep	4.167 ms	1 sec
Produced Data File Size	35,492 KB	423 KB
Simulation Run Time	41.42 sec	11.75 sec
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 0.000000000000000000000000000000e+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 ≈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.

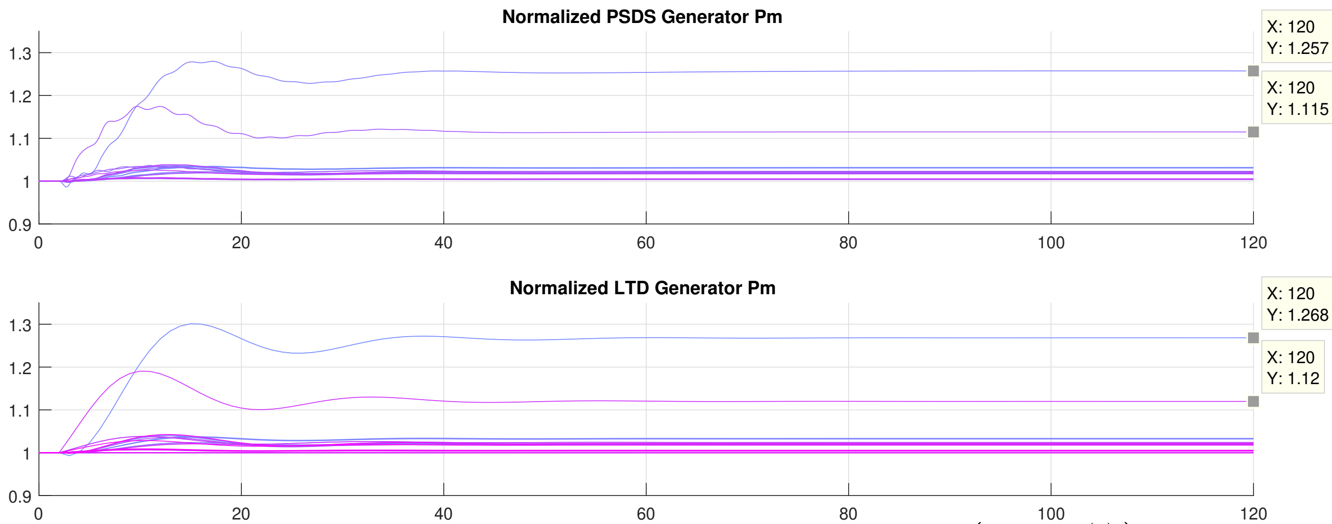

Figure 4: Normalized P_M from all machines in system. $\left(\text{i.e. } \dfrac{P_m(t)}{P_m(0)}\right)$

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

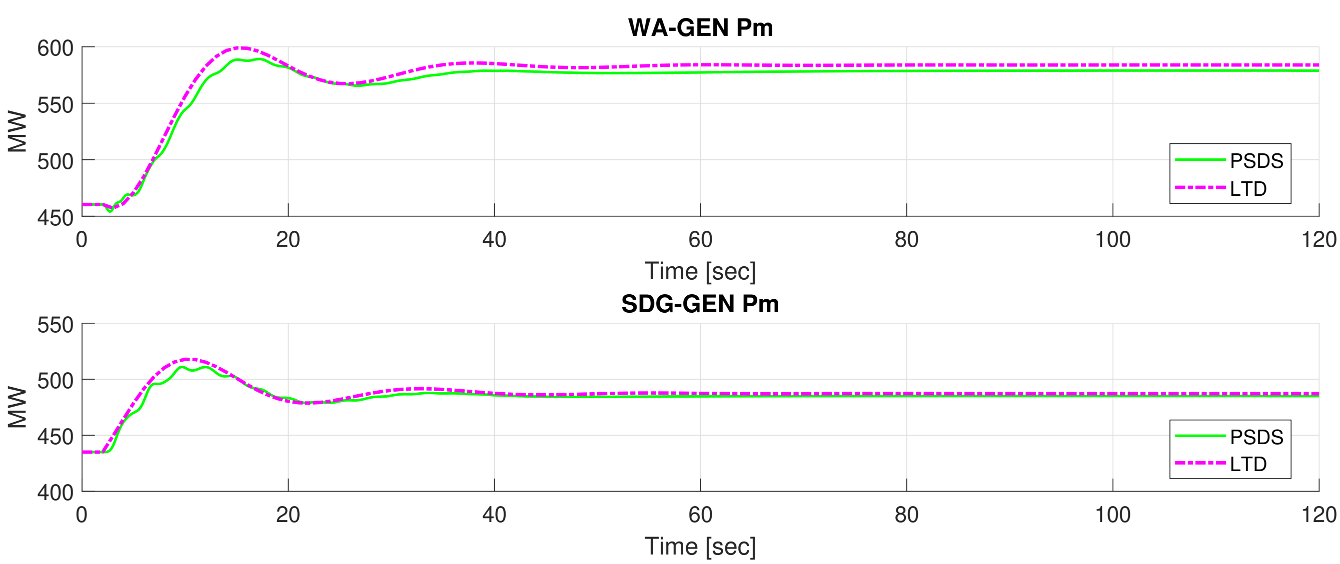

Figure 5: P_M from the machines that changed the most from $t(0)$.

7. Time step resolution: 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.

	Time step	Simulation Time [sec]	Data File Size [KB]	Real time Speed up	PSDS Speed up	Reduction of file size	Steady State f varience [Hz]
PSDS	4.167 ms	56.12	35,070	1.60	1	1	0
LTD	2 sec	13.79	238	6.53	4.07	147.35	NA
LTD	1 sec	27.22	479	3.31	2.06	73.21	9.50E-4
LTD	0.5 sec	53.56	871	1.68	1.05	40.26	9.71E-4
LTD	0.25 sec	104.76	1,655	0.86	0.54	21.19	9.77E-4

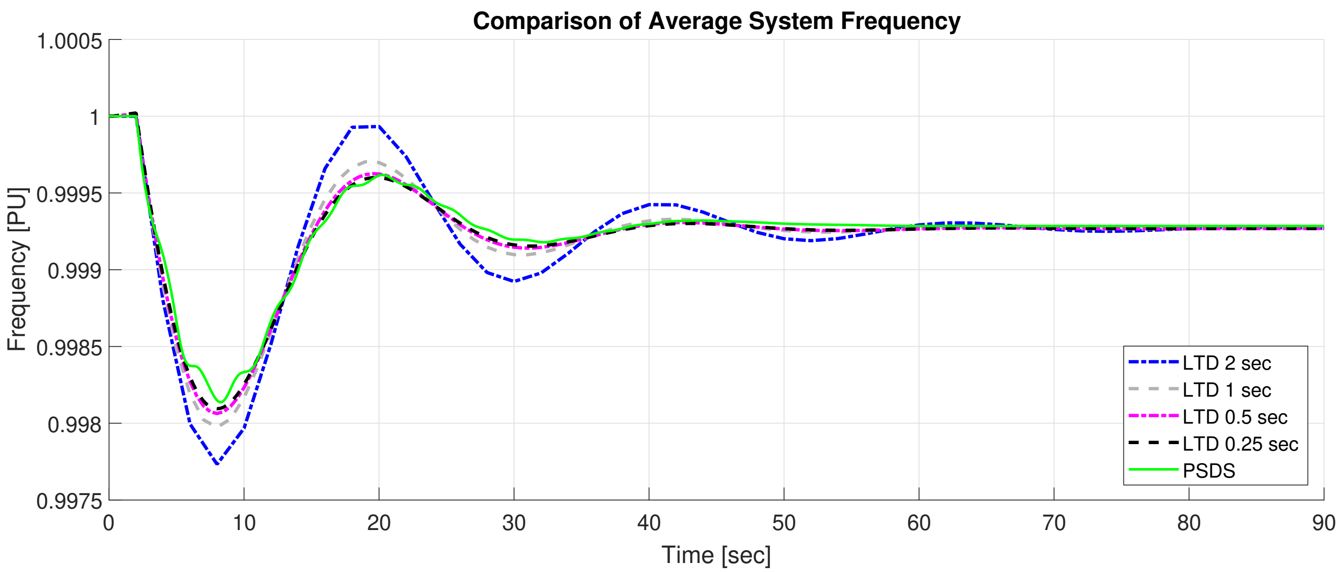

Figure 6: Comparison of system frequency among different time steps.

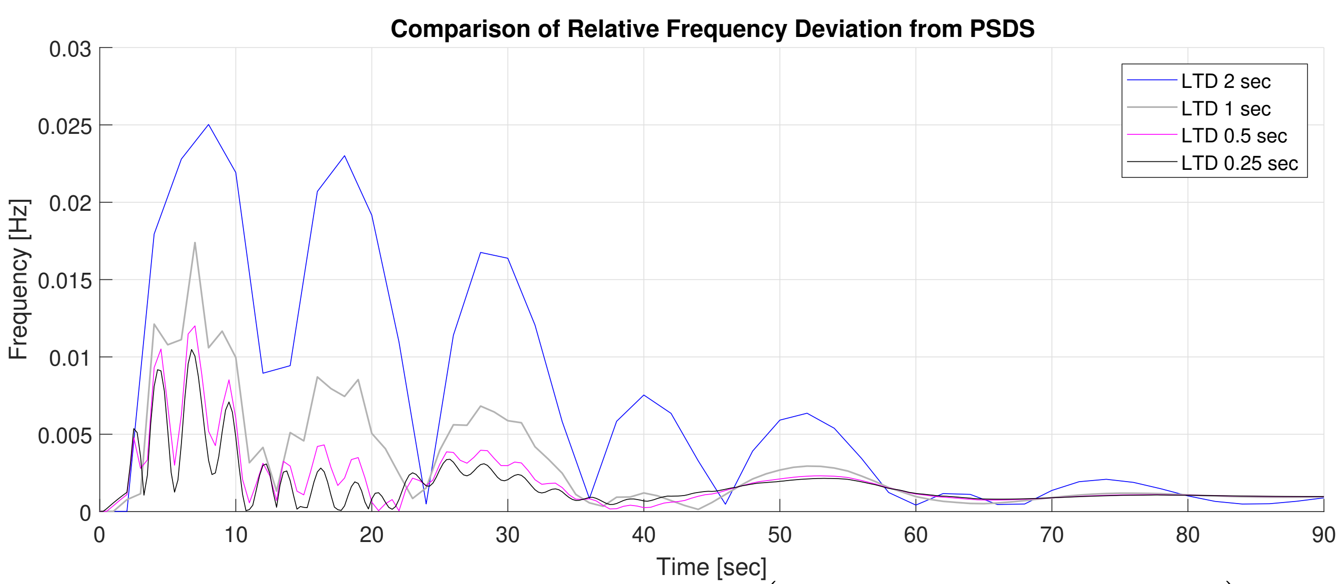

Figure 7: Relative Hz difference of PSDS - LTD $\left(\text{i.e. } \left|f_{PSDS}(t) - f_{LTD}(t)\right| \times 60\text{Hz}\right)$.