

**Executive Summary:**

1. Grouping messages can speed up simulations of the MiniWECC by  $\approx 8\times$  compared to PSDS when using 2 second time steps ( $\approx 13\times$  real time).
2. Grouping messages increases the average time spent sending and handling a single message while reducing the total number of messages sent.
3. Optimized message groupings will vary depending on system size. Main speed up comes from reduction of sent IPY messages.
4. Power system structure (size) and perturbances will affect total simulation time.

**Initial Timings:** Non-grouped results of a 90 second MiniWECC step test with a 0.5 second time step are shown in Listing 1. Solving the power-flow, sending IPY messages, and running PY3 dynmaics are the top three time usage operations in the simulation.

Listing 1: Initial timings and counters.

1	Simulation Timings		
2	Total Simulation Time:	34.024235	
3	PY3 IPV CPU Time:	0.069717	
4	PY3 Dynamics CPU Time:	3.845773	
5	PY3 Message Send Time:	0.706144	
6	PY3 Agent Find Time:	0.059150	
7	IPY Agent Find Time:	0.042694	
8	IPY distPacc Time:	0.278694	
9	IPY PSLF Get/Set Time:	1.731987	
10	IPY Message Make Time:	0.142670	
11	IPY Message Send Time:	12.753098	
12	Uncounted PY3 Time:	0.174387	
13	Uncounted IPY Time:	2.964542	
14	PSLF Power-Flow Time:	11.357224	
15	Simulation Counters		
16	Sent PY3 Messages:	6157	
17	Sent IPY Messages:	32037	
18	PY3 Dynamic Solutions:	7602	
19	Power-Flow Solutions:	206	
20	Simulation Summary		
21	Real time Speedup:	2.645173	
22	Ave. PY3 msg send:	0.000115	
23	PY3 Message Group Size:	1	
24	Ave. IPY msg send:	0.000398	
25	IPY Message Group Size:	1	
26	Ave. Dynamic Soln. Time:	0.000506	
27	Ave Power-Flow Time:	0.055132	
28	Ave. P-F / Time Step:	1.138122	
29	Mirror Creation Time:	0.286514	
30	Simulated Time:	90.000000	
31	Simulation Time Step:	0.500000	

**Speedup Paths:** Various ideas were generated to reduce the time spent on the top three tasks:

1. Group AMQP messages: The number of IPY messages could be greatly reduced by grouping agent update messages together.
2. Variable Time Step: The number of power-flows could be reduced if the time step was automatically changed based on some threshold value of a measurable quantity.
3. Grouping Dynamics: Instead of solving many small state-space systems each time step, machine governor dynamics could be combined into two larger systems that would only need to be solved once per time step. At least two systems would be required to handle non-linear characteristics. This would require each machine agent to track it's corresponding state location in the larger system(s).
4. Increase Slack Error Tolerance: This tolerance level could be increased so that fewer power flows would have to be solved. This would decrease the accuracy of the simulation.

The easiest path to gain the most possible speed up without reducing accuracy is message grouping.

**Grouping Results:** Table 1 shows the results of tested grouping options. Option B has the largest speed up benefit caused by reducing the number of IPY messages by  $59\times$  and the number of PY3 messages by  $4.8\times$ . This also causes a slight increase in PY3 Dynamic time, IPY average message time, and uncounted IPY time.

Table 1: Timings and group message benefits of a 90 second MiniWECC load step test.

Message Grouping	Option A None	Option B IPY & PY3	Option C IPY	Option B Benefit	Option C Benefit	Best
Simulation Timings	[sec]	[sec]	[sec]	[abs]	[abs]	[Option]
Total Simulation Time	33.0290	22.3783	22.6910	1.4759	1.4556	B
PY3 IVP CPU Time	0.0657	0.0757	0.0708	0.8671	0.9268	A
PY3 Dynamics CPU Time	3.7752	3.9727	3.9143	0.9503	0.9645	A
PY3 Message Send Time	0.6839	0.2093	0.6953	3.2670	0.9837	B
PY3 Agent Find Time	0.0622	0.0381	0.0413	1.6334	1.5033	B
IPY Agent Find Time	0.0372	0.0281	0.0386	1.3244	0.9634	B
IPY distPacc Time	0.2752	0.2554	0.2677	1.0776	1.0283	B
IPY PSLF Get/Set Time	1.6461	1.3088	1.3219	1.2577	1.2452	B
IPY Message Make Time	0.1342	0.1036	0.1194	1.2956	1.1244	B
IPY Message Send Time	12.2257	1.8719	1.8328	6.5310	6.6705	C
Uncounted PY3 Time	0.1705	0.1769	0.1765	0.9638	0.9660	A
Uncounted IPY Time	2.8740	3.0596	3.0556	0.9393	0.9406	A
PSLF Power-Flow Time	11.1785	11.3443	11.2367			
Simulation Counters						
Sent PY3 Messages	6157.0000	1270.0000	6157.0000	4.8480	1.0000	B
Sent IPY Messages	32037.0000	543.0000	543.0000	59.0000	59.0000	B or C
PY3 Dynamic Solutions	7602.0000	7602.0000	7602.0000			
Power-Flow Solutions	206.0000	206.0000	206.0000			
Simulation Summary						
Real time Speedup	2.7249	4.0218	3.9663	1.4759	1.4556	B
Average PY3 message send	0.0001	0.0002	0.0001	0.6727	0.9823	A
PY3 Message Group Size	1.0000	5.0000	1.0000	0.2000	1.0000	
Average IPY msg send	0.0004	0.0034	0.0034	0.1108	0.1132	A
IPY Message Group Size	1.0000	60.0000	60.0000	0.0167	0.0167	
Average Dynamic Soln. Time	0.0005	0.0005	0.0005			
Average Power-Flow Time	0.0543	0.0551	0.0545			
Average P-F / Time Step	1.1381	1.1381	1.1381			
Mirror Creation Time	0.2757	0.2578	0.2849			
Simulated Time	90.0000	90.0000	90.0000			
Simulation Time Step	0.5000	0.5000	0.5000			

**Conclusion:** For this particular case, PY3 groupings of 5 and IPY groupings of 60 provide the best results. This may vary for different size cases as the main speed up comes from reduction of IPY messages sent.

This speed up enables the tested MiniWECC simulations with a 2 second time steps to be  $\approx 13\times$  faster than real time or  $\approx 8\times$  faster than PSDS.