Executive Summary:

1. Grouping messages can speed up the simulation by 1 order of magnitude compared to PSDS when using 2 second time steps (≈15× real time).
2. Grouping messages increases the average time spent sending a single message while reducing the total number of messages sent.
3. An optimal message size may be found to maximize these benefits.

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

Listing 1: Initial terminal output of timings and counters.

```
*** Simulation Timings
     Total Simulation Time:           28.592126
         PY3 Dynamics CPU Time:        3.267116
                 PY3 Send Time:        0.648147
              PY3 Recieve Time:       24.517481
        Uncounted PY3 Time:           0.159382
                 IPY distPacc Time:    0.233406
             IPY PSLF Get/Set Time:    1.391693
              PSLF Power-Flow Time:   10.516975
                 IPY Msg Make Time:    0.085266
                     IPY Send Time:   10.390213
        Uncounted IPY Time:           1.899927

*** Simulation Counters
              Power-Flow Solutions:         206
                 Sent PY3 Messages:        6157
                 Sent IPY Messages:       32037

*** Simulation etc
                     Simulated Time:   90.000000
              Simulation Time Step:    0.500000
                 Real time Speedup:    3.147720
                      Ave P-F Time:    0.051053
           Ave. P-F per Time Step:     1.138122
                 Ave. PY3 msg send:    0.000105
                 Ave. IPY msg send:    0.000324
```

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).

The easiest path forward to gain the most possible speed up is message grouping.

Grouping Results: AMQP message grouping was applied to entire types of agent message updates (i.e., all machine updates in one message, bus updates in another, and load updates in a third). Table 1 shows the results of tested grouping options. Option C has the largest speed up benefit caused by reducing the number of IPY messages by 59 times while also slightly increasing PY3 Dynamic time and IPY average message 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	28.5921	20.9700	19.6769	1.3635	1.4531	C
PY3 Dynamics CPU Time	3.2671	3.3688	3.4066	0.9698	0.9590	A
PY3 Send Time	0.6481	0.0659	0.6425	9.8307	1.0088	B
IPY distPacc Time	0.2334	0.2071	0.2553	1.1270	0.9141	B
IPY PSLF Get/Set Time	1.3917	0.9648	1.0922	1.4425	1.2742	B
IPY Msg Make Time	0.0853	0.0300	0.0259	2.8437	3.2967	C
IPY Send Time	10.3902	1.5310	1.5348	6.7866	6.7699	B or C
Uncounted PY3 Time	0.1594	0.1492	0.1431	1.0681	1.1140	B or C
Uncounted IPY Time	1.8999	4.2369	1.9203	0.4484	0.9894	C
PSLF Power-Flow Time	10.5170	10.4163	10.6561	1.0097	0.9869	
Simulation Counters						
Sent PY3 Messages	6157.0000	184.0000	6157.0000	33.4620	1.0000	B
Sent IPY Messages	32037.0000	543.0000	543.0000	59.0000	59.0000	B or C
Power-Flow Solutions	206.0000	206.0000	206.0000	1.0000	1.0000	
Simulation Summary						
Real time Speedup	3.1477	4.2918	4.5739	1.3635	1.4531	C
Average PY3 Send Time	0.0001	0.0004	0.0001	0.2933	1.0096	A or C
Average IPY Send Time	0.0003	0.0028	0.0028	0.1149	0.1146	A
Average Power-Flow Time	0.0511	0.0506	0.0517	1.0097	0.9869	
Average Power-Flow / Time Step	1.1381	1.1381	1.1381	1.0000	1.0000	
Simulated Time	90.0000	90.0000	90.0000	1.0000	1.0000	
Simulation Time Step	0.5000	0.5000	0.5000	1.0000	1.0000	

For this particular case, grouping messages by type can reduce the total number of messages sent by 33-59× while increasing the average message sending time by 3-10×. A happy medium could be pursued to only group a certain number of messages to allow for maximum message reduction with minimal send time increase. Size of grouped messages from IPY are 23, 34, and 120 (corresponding to load, machine, and bus groupings). In the larger WECC case, a grouping method that limits size of messages will probably be required as the number of objects will be respectively ≈480, 124, and 182× larger. Additionally, more messages will be sent as more agents are added to the system.

However, for the moment, a speed up of 1.45 enables the 2 second time step simulations to be 15× faster than real time (≈ 1 order of magnitude faster than PSDS ⟶ Speed Goal).