DEVELOPMENT OF DISTRIBUTED CONTROL METHODS FOR DISTRIBUTED STORAGE DEVICES IN MICROGRIDS

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Background

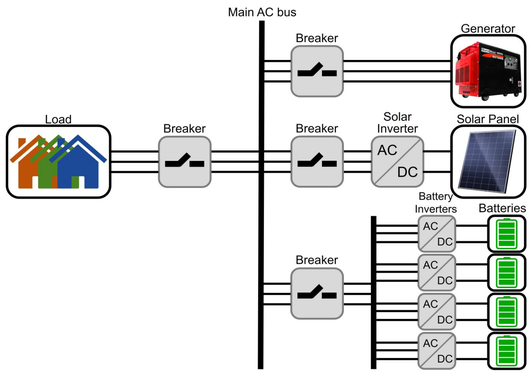
Microgrids:
- Solution to rapid energy growth
- Better equate real-time supply with demand
- Incorporate renewable energy & energy storage technology [1]

Energy storage:
- Solution to efficiency, quality, & need for fossil fuels
- Can suffer from single point of failure & burden system financially

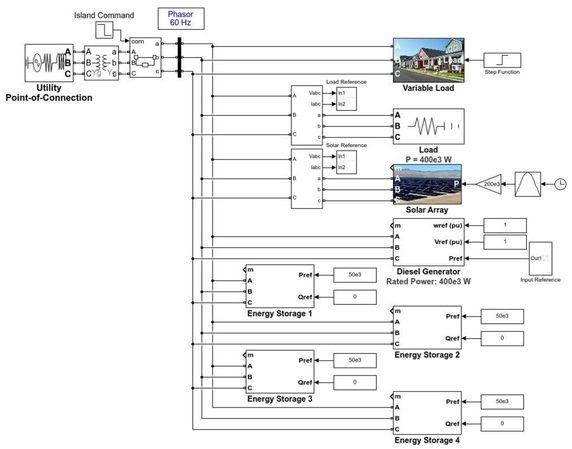
Research:
- How microgrids can save carbon dioxide emissions by application of energy storage
- Detailed cost analysis: diesel vs. solar & battery storage

System Diagram & Model

The system includes:
- 400kW diesel generator
- 200kW solar panel
- 400kW constant load
- 50kW battery storage devices (4)



Block Diagram (simplified)

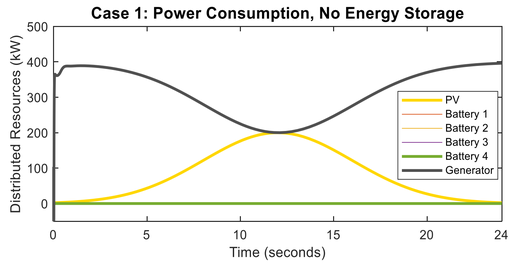


Simulation Model (Simulink – MATLAB)

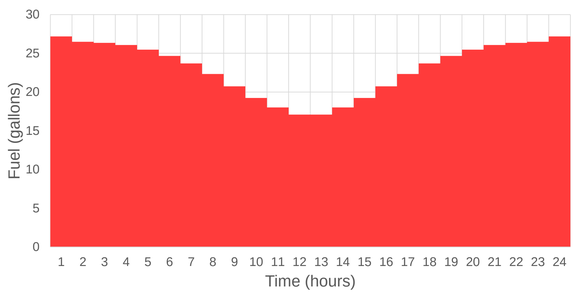
Case Studies

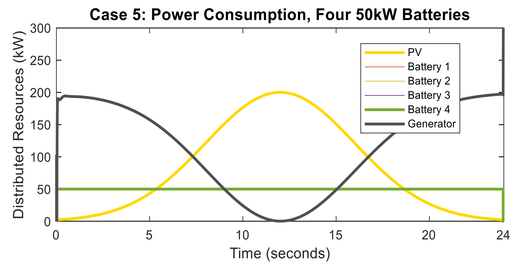
Cases 1 – 5: 400kW diesel generator & 200kW solar panel
1. Zero 50kW batteries
2. One 50kW battery
3. Two 50kW batteries
4. Three 50kW batteries
5. Four 50kW batteries

Cases 6 – 8: no diesel generator & four batteries
6. 200kW solar panel
7. 300kW solar panel
8. 400kW solar panel

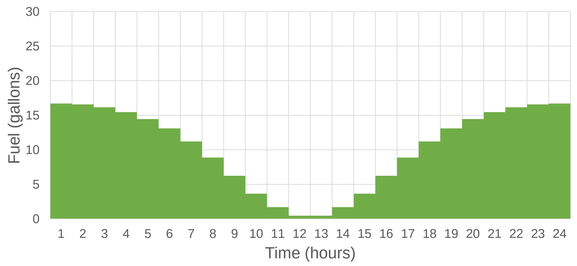


Average Fuel Consumed over 24 Hours (No Batteries)



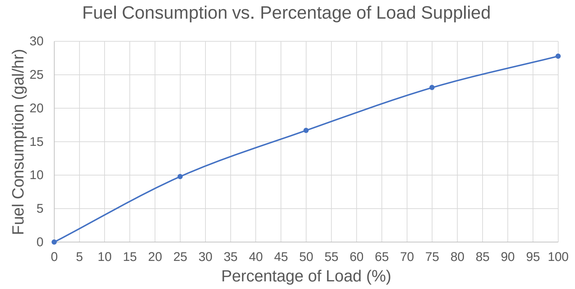


Average Fuel Consumed over 24 Hours (Four 50kW Batteries)



Fuel Consumption

- 400kW diesel generator consumes varied amounts of fuel based on percentage of load it supplies [2]
- % values interpolated from graph trend for hourly calculations



CO_2 Emission Reduction

400kW diesel generator CO_2 emission rate: 11.36 kg CO_2 / gal fuel [3]

	Case 1	Case 2	Case 3	Case 4	Case 5
total gal fuel	554.5076	492.482	423.1252	340.7912	249.1256
total kg CO_2	6,297	5,593	4,805	3,870	2,829
Reduction	0%	11.18%	23.69%	38.54%	55.07%

- Increments of 10% reduction interpolated from the graph trend and matched to total amounts of energy in kW (average over 24 hours) and MWh (total capacity)
- **Average of 282kW** of energy storage needed for **100% reduction**.

Total Energy Storage Needed Over 24 Hours		
CO_2 Reduction	Average (kW)	Capacity (MWh)
0%	0	0
10%	44.5874	1070.098
11.18%	50	1200
20%	85.2199	2045.278
23.69%	100	2400
30%	122.2934	2935.042
38.54%	150	3600
40%	155.8079	3739.39
50%	185.7634	4458.322
55.07%	200	4800
60%	212.1599	5091.838
70%	234.9974	5639.938
80%	254.2759	6102.622
90%	269.9954	6479.89
100%	282.1559	6771.742

Cost Analysis

- Solar system: $3,050 / kW before 30% tax credit reduction[$] [4]
- 400kW diesel generator: $60,470 [5]
- Diesel generator fuel: $3.17 / gallon [6]
- Lithium-ion energy storage battery: $209 / kWh [7]

	Case 1	Case 2	Case 3	Case 4
	Solar: 200kW Generator: 400kW 0 Batteries	Solar: 200kW Generator: 400kW 1 Battery: 50kW, 1.25MWh each	Solar: 200kW Generator: 400kW 2 Batteries: 100kW, 1.25MWh each	Solar: 200kW Generator: 400kW 3 Batteries: 150kW, 1.25MWh each
Solar system	$427,000.00	$427,000.00	$427,000.00	$427,000.00
Diesel generator	$60,470.00	$60,470.00	$60,470.00	$60,470.00
Diesel fuel	$1,757.79	$1,561.17	$1,341.31	$1,080.31
Batteries	$0.00	$260,832.00	$521,664.00	$782,496.00
Total	$489,227.79	$749,863.17	$1,010,475.31	$1,271,046.31

	Case 5	Case 6	Case 7	Case 8
	Solar: 200kW Generator: 400kW 4 Batteries: 200kW, 1.25MWh each	Solar: 200kW 4 Batteries: 1.99MWh each	Solar: 300kW 4 Batteries: 1.73MWh each	Solar: 400kW 4 Batteries: 1.46MWh each
Solar system	$427,000.00	$427,000.00	$640,500.00	$854,000.00
Diesel generator	$60,470.00	$0.00	$0.00	$0.00
Diesel fuel	$789.73	$0.00	$0.00	$0.00
Batteries	$1,043,328.00	$1,663,640.00	$1,446,280.00	$1,220,560.00
Total	$1,531,587.73	$2,090,640.00	$2,086,780.00	$2,074,560.00

[$] costs used assume this tax credit

Conclusions

- Diesel generator with no energy storage costs the least: energy storage currently non-cost-competitive (Case 1)
- No diesel generator with solar & four energy storage batteries: **6,297 kg** of CO2 emissions saved (Cases 6-8)
- 400kW solar panel & four energy storage batteries: investment of **$1,585,332.21** for 100% CO_2 reduction (Case 8)
- Solar energy has a slower cost increase than energy storage
- Distributing energy storage improves control and reliability

References

[1] Ton, D., & Smith, M. (2012, October). The U.S. Department of Energy's Microgrid Initiative. *The Electricity Journal*, *25*(8), 84-94.
[2] Generac (2015, June). Industrial Diesel Generator Set SD400. Retrieved June 24, 2019.
[3] Jakhrani, A. Q., Othman, A., Rigit, A. R. H., Samo, S. R., & Kamboh, S. A. (2012, March). Estimation of Carbon Footprints from Diesel Generator Emissions. *2012 International Conference in Green and Ubiquitous Technology*, 1-4.
[4] EnergySage (2019, May). How much do solar panels cost in the U.S. in 2019? Retrieved June 24, 2019.
[5] American Generators (2019). 400 kW Perkins Diesel Generator Set – EPA. Retrieved July 1, 2019.
[6] Assurance Power Systems (2018, July). How Much Does It Cost to Run a Generator? Retrieved July 1, 2019.
[7] Fu, R., Remo, T., & Margolis, R. (2018, November). 2018 U.S. Utility-Scale Photovoltaics-Plus-Energy Storage System Costs Benchmark. *National Renewable Energy Laboratory*, 1-32.

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Project Drawdown
drawdown.org