PRINCETONIAN ELECTRICITY: MANAGING AN ISOLATED MICROGRID

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The major insights of the thesis are:

(1) Increasing dispatchable generation decreases demand shortage metrics and percentage of outages.
(2) Modularization of generation capacity does not necessarily mean greater reliability.
(3) Battery storage along with dispatchable generation can ensure close to zero demand shortages. Further, increasing dispatchable generation decreases the size of battery required for the microgrid.
(4) Cost-wise, it is always preferable to have a technology setup with batteries and dispatchable generators rather than without batteries for an isolated microgrid. This is also advisable for reliability reasons.
(5) The best technological setup for an islanded Princeton University microgrid, given analysis of data from the month of April would be a 0.71MWh battery, two 7MW generators in addition to the existing generation assets. This would have a net present cost in the range of $55 million - $85million, depending on financial assumptions made.
(6) The cost-preferred technology setup would have an LCOE of 7.03 cents/kWh, which is 17% more expensive than the current cost of electrical usage during intermediate demand times.

From a research perspective, the main contributions of the thesis are:

(1) Establishing a mathematical model for secondary control of an isolated microgrid.
(2) Providing trends using simulator-generated output on the demand-shortage behavior in isolated microgrids.
(3) Proposing the cost-optimality of always incorporating battery storage in isolated microgrids if additional dispatchable generation also needs to be included.

Select charts, graphs and key findings are given below:

1. 3 Additional Generators Considered for Combinations:

Technical Data (60HZ/720RPM)	**Unit**	**9L34DF** ***small***	**16V34DF** ***medium***	**20V34DF** ***large***
Power, electrical	MW (kW)	4 (4170)	7 (7430)	9 (9340)
Heat Rate	kJ/kWh	8048	8048	8036
Electrical Efficiency	%	44.7	44.7	44.8
Total Co-gen Efficiency (including HRSG)	%	90.7	90.7	90.8
Ramp Rate	% /min	>100	>100	>100
Start Time (Cold Start)	min	<10	<10	<10
Start Time (Warm Standby)	min	<6	<6	<6
Stop Time (100% to zero)	min	<1	<1	<1

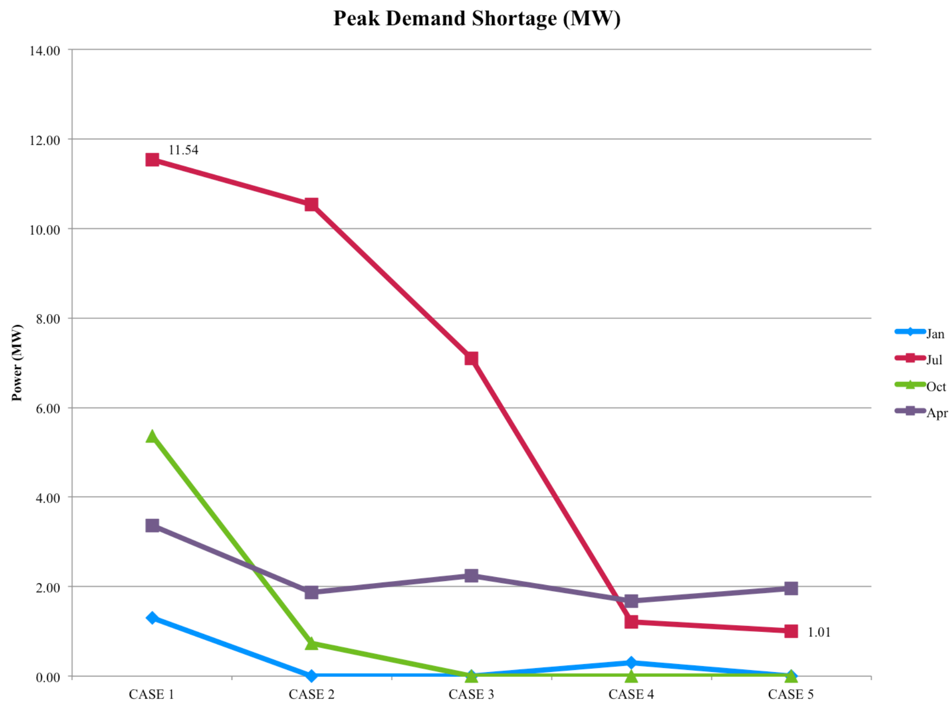
Table 6-1: Wärtsilä Tri-Fuel Engine Configurations

2. Combinations of Additional Generators Considered:

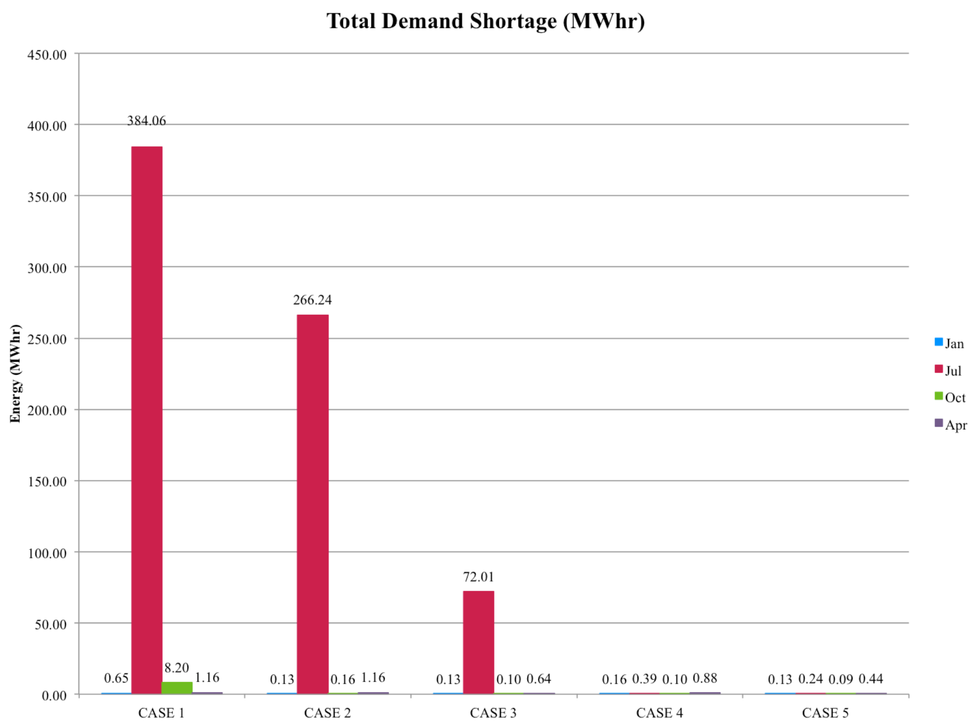
Setup	**Description**	**Additional Capacity Breakdown**	**Total Additional Rated Power**	**Overall Rated Dispatchable Power (excl. solar)**
Case 0	No Addition	-	-	15MW
Case 1	Small + Large	4MW + 9MW	13MW	28MW
Case 2	Medium + Medium	7MW + 7MW	14MW	29MW
Case 3	Medium + Large	7MW + 9MW	16MW	31MW
Case 4	Large + Large	9MW + 9MW	18MW	33MW
Case 5	Small + Medium + Large	4MW + 7MW + 9MW	20MW	35MW

Table 6-2: Combinations of Different Technological Setups

3. Summary of Simulation Output for Cases 1 – 5:

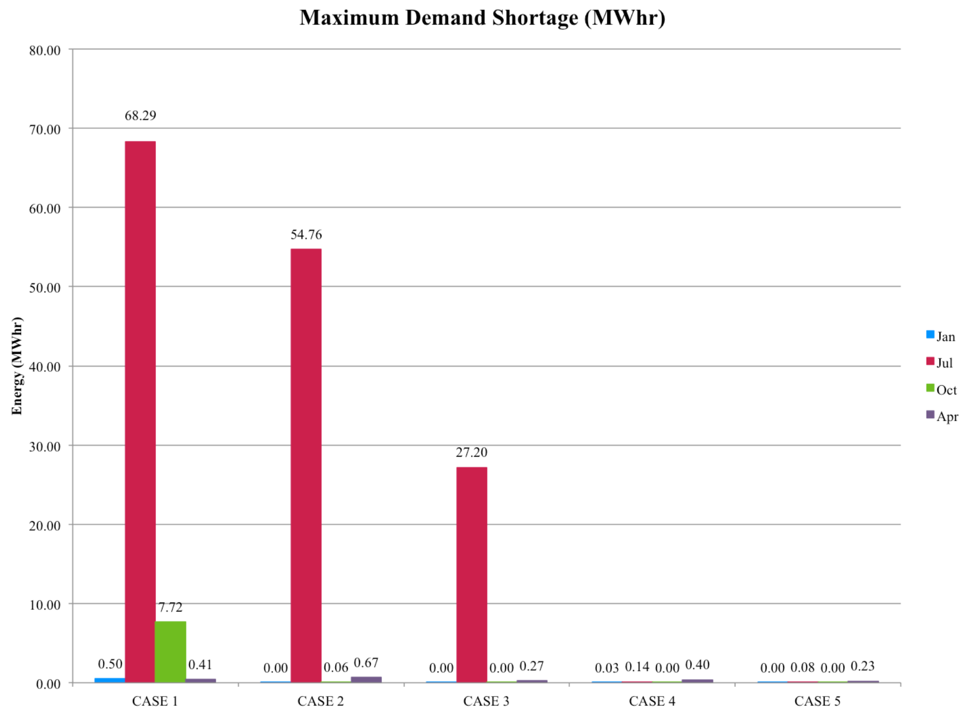


(a) Peak Demand Shortage (MW)

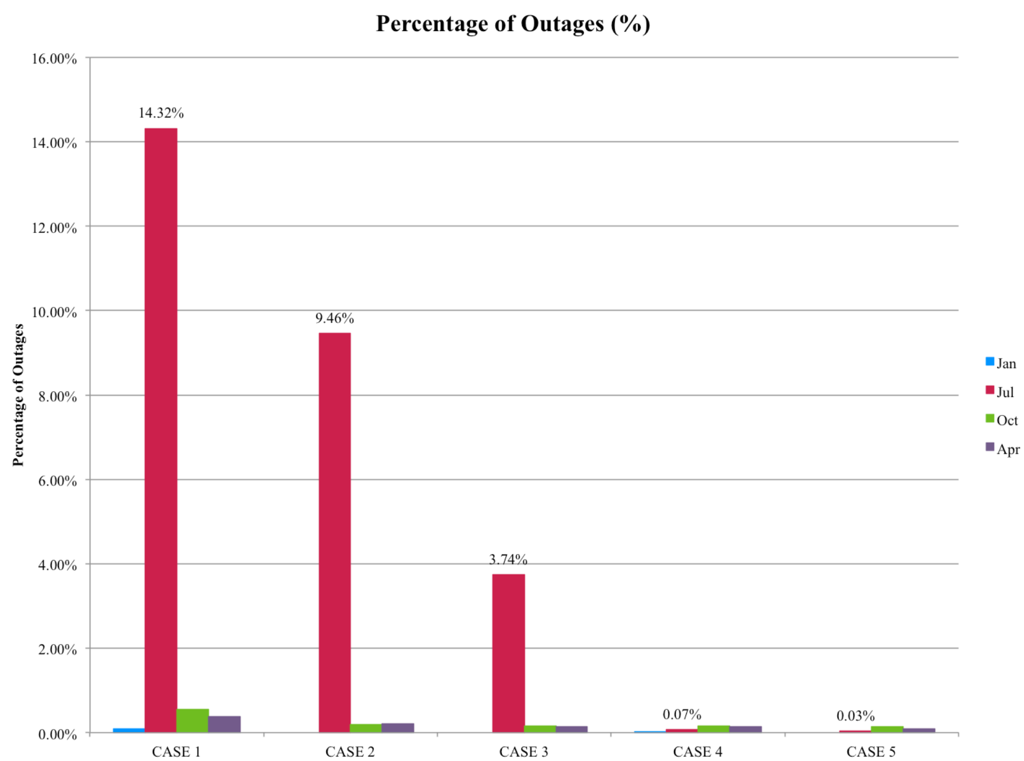


(b) Total Demand Shortage (MWhr)

Figure 6-3: (I) Summary of Simulation Output for 5 Technological Setups



(c) Maximum Demand Shortage (MWhr)



(d) Percentage of Outages (%)

Figure 6-3: (II) Summary of Simulation Output for 5 Technological Setups

4. Demand Shortage Statistics

Peak Demand Shortage (MW)						
Scenario	**CASE 0: No Addition**	**CASE 1: 13MW**	**CASE 2: 7MW+7MW**	**CASE 3: 9MW+7MW**	**CASE 4: 9MW+9MW**	**CASE 5: 9MW+7MW +4MW**
Jan-14	11.46	1.31	0.00	0.00	0.31	0.00
Jul-14	24.54	11.54	10.53	7.10	1.21	1.01
Oct-14	18.60	5.37	0.74	0.00	0.00	0.00
Apr-14	15.81	3.36	1.87	2.25	1.68	1.96

Total Demand Shortage (MWhr)						
Scenario	**CASE 0: No Addition**	**CASE 1: 13MW**	**CASE 2: 7MW+7MW**	**CASE 3: 9MW+7MW**	**CASE 4: 9MW+9MW**	**CASE 5: 9MW+7MW +4MW**
Jan-14	2024.97	0.65	0.13	0.13	0.16	0.13
Jul-14	6955.98	384.06	266.24	72.01	0.39	0.24
Oct-14	2890.83	8.20	0.16	0.10	0.10	0.09
Apr-14	2063.49	1.16	1.16	0.64	0.88	0.44

Maximum Demand Shortage (MWhr)						
Scenario	**CASE 0: No Addition**	**CASE 1: 13MW**	**CASE 2: 7MW+7MW**	**CASE 3: 9MW+7MW**	**CASE 4: 9MW+9MW**	**CASE 5: 9MW+7MW +4MW**
Jan-14	637.45	0.50	0.00	0.00	0.03	0.00
Jul-14	3069.16	68.29	54.76	27.20	0.14	0.08
Oct-14	591.42	7.72	0.06	0.00	0.00	0.00
Apr-14	455.93	0.41	0.67	0.27	0.40	0.23

Percentage of Outages* (%)						
Scenario	**CASE 0: No Addition**	**CASE 1: 13MW**	**CASE 2: 7MW+7MW**	**CASE 3: 9MW+7MW**	**CASE 4: 9MW+9MW**	**CASE 5: 9MW+7MW +4MW**
Jan-14	95.89%	0.09%	0.00%	0.00%	0.01%	0.00%
Jul-14	98.53%	14.32%	9.46%	3.74%	0.07%	0.03%
Oct-14	88.86%	0.54%	0.19%	0.16%	0.15%	0.14%
Apr-14	78.96%	0.38%	0.21%	0.14%	0.14%	0.08%

***Assuming an 'outage' is whenever >=0.01% of total demand remains unsatisfied.**

Peak Overages# (MW)						
Scenario	**CASE 0: No Addition**	**CASE 1: 13MW**	**CASE 2: 7MW+7MW**	**CASE 3: 9MW+7MW**	**CASE 4: 9MW+9MW**	**CASE 5: 9MW+7MW +4MW**
Jan-14	-0.001	-0.001	-0.001	-0.001	-1.724	-0.001
Jul-14	-0.001	-0.001	-0.001	-1.844	-1.282	-1.844
Oct-14	-13.537	-18.372	-19.483	-16.504	-17.666	-15.666
Apr-14	-10.224	-10.998	-9.000	-9.357	-10.998	-8.998

#Assuming an 'overage' is whenever power supply exceeds demand. Displayed as a negative number.

5. Battery Sizes Required (See Pages 92-98)

April Setup	Peak Shortage of Demand (MW)	Peak Discharge of Trial 1's Initial Battery (MW)	Trial 1 Initial Battery Size (MWh)	Trial 2 Battery Size (MWh)	Recommended Battery Size (MWh)
Case 0	15.81	15.83	950.00	2012.26	2012.26
Case 1	3.36	3.36	201.60	0.88	0.88
Case 2	1.87	1.87	112.20	0.71	0.71
Case 3	2.25	2.25	134.85	0.38	0.38
Case 4	1.68	1.68	100.77	0.47	0.47
Case 5	1.96	1.96	117.39	0.33	0.33

Table 6-5: Battery Sizes for April

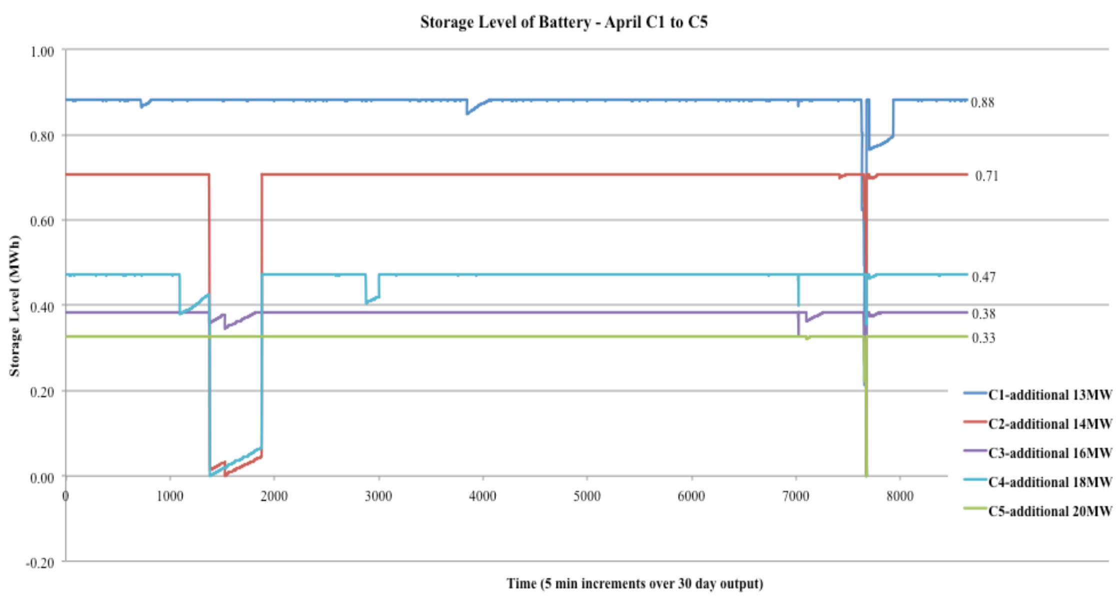


Figure 6-10: Battery Storage Level and Demand for April C1-C5

Cost Analysis of Introducing Battery Storage is done using three methods and different financial assumptions (Page 99, page 100 and page 103).

6. LCOE of Adding Battery Storage (Method 2 of Cost Analysis)

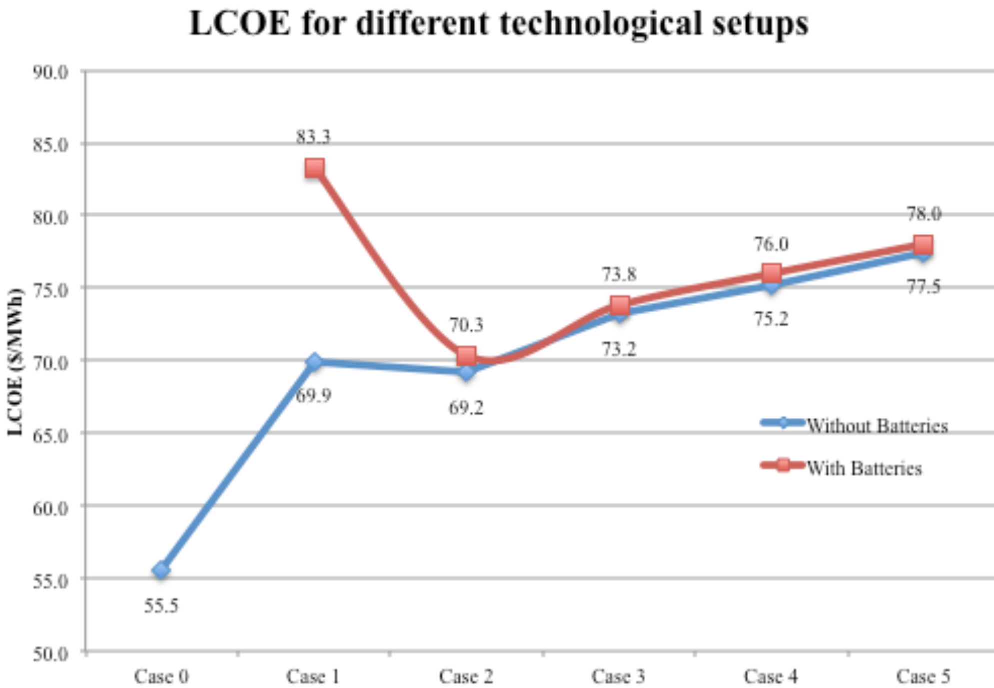


Figure 6-12: Levelized Costs for Setups C0-C6 with and without batteries

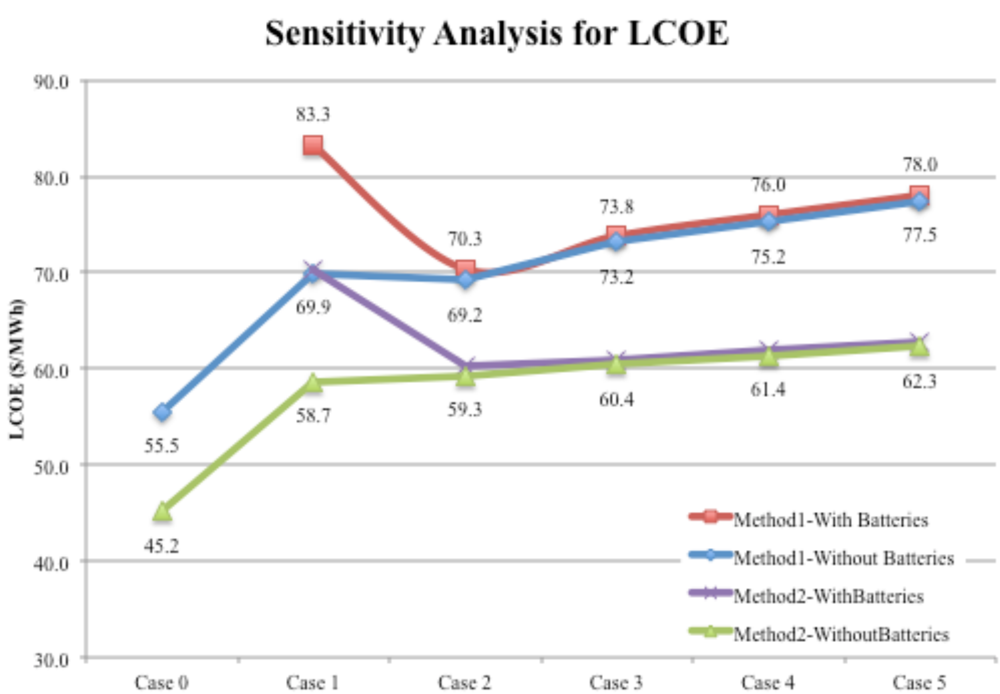


Figure 6-13: Sensitivity analysis of LCOE with and without batteries