Microgrid Distributed Generation and Storage

Final Report by: Dan Craig

Jesus De La Cruz

Jacob Dolan

Faculty Advisor - Dr. Herb Hess

Graduate Advisor - Jordan Scott

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University of Idaho
College of Engineering

AVISTA®

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Executive Summary

Smart Spokane is working with Avista to empower the anticipated Spokane smart grid by laying the groundwork for solar roofs, battery installations, and generator fuel conversions. This smart grid will increase the control and reliability of the Spokane grid which was found lacking after the 2015 windstorm. The smart grid will enable downtown Spokane to isolate itself from any power surges and blackouts that affect the area outside of the microgrid.

Smart Spokane has planned for the 2 hydroelectric dams, 17,000 solar panels divided among 38 locations, 18 converter hospital generators, in conjunction with 29 battery installations will provide 9 critical services standard operating power during grid isolation.

The smart grid will increase reliability of the Spokane grid by protecting it from blackouts and surges that affect the rest of the system. During daily use, the increase in generation should help to lower energy costs after the new assets have been fully paid for.

Background

On November 17, 2015, a strong windstorm hit the Spokane area. The strong winds severed the power transmission lines from the Columbia River generating stations. This event led to a large scale power outage for the area. Avista Utilities crews fully restored power service after four long weeks.

This event revealed a need for a more reliable system. Meanwhile in other parts of the country a new system was being developed, the microgrid. The microgrid is a subsection of the larger power grid that can isolate itself from the larger whole in case of emergency and supply power to its loads.

Avista Utilities is working with federal programs such as Smart Cities to develop a smart grid for downtown Spokane. As a part of the smart grid package, a microgrid will be developed for the downtown area. These developments will improve the reliability of the power service and therefore raising the level of service quality, while also decrease cost of damages caused by blackouts.

Problem Definition

Project Goals:

Due to the lack of a backup system that could sustain critical loads in downtown Spokane, a micro-grid system has being proposed. The micro-grid design consists of four main power supplies; solar panels, battery banks, diesel/natural gas generators, and two hydropower plants. Along with this is a synchronization system, detailed budget, and a PowerWorld simulation.

Project Deliverables:

- PowerWorld simulation of the microgrid
- Photovoltaic (PV) locations and power output available
- Battery location(s) and detailed specs
- Gridtie inverters specs, brand, and type for PV and battery banks
- Options for converting hospital generators to natural gas
- Specs of the chosen synchronizer to parallel hospital generators with the grid
- Detailed cost estimation for design installation

Project Plan

Roles and Responsibilities:

Jesus De La Cruz:

Team Leader - represent the team in client / public meetings
Treasurer - manage the budget, keep track of all receipts, and seek alternative purchases

Dan Craig:

Primary Client Contact - correspond and update the client
Meeting Organizer - schedules meetings and reserves the meeting room

Jacob Dolan:

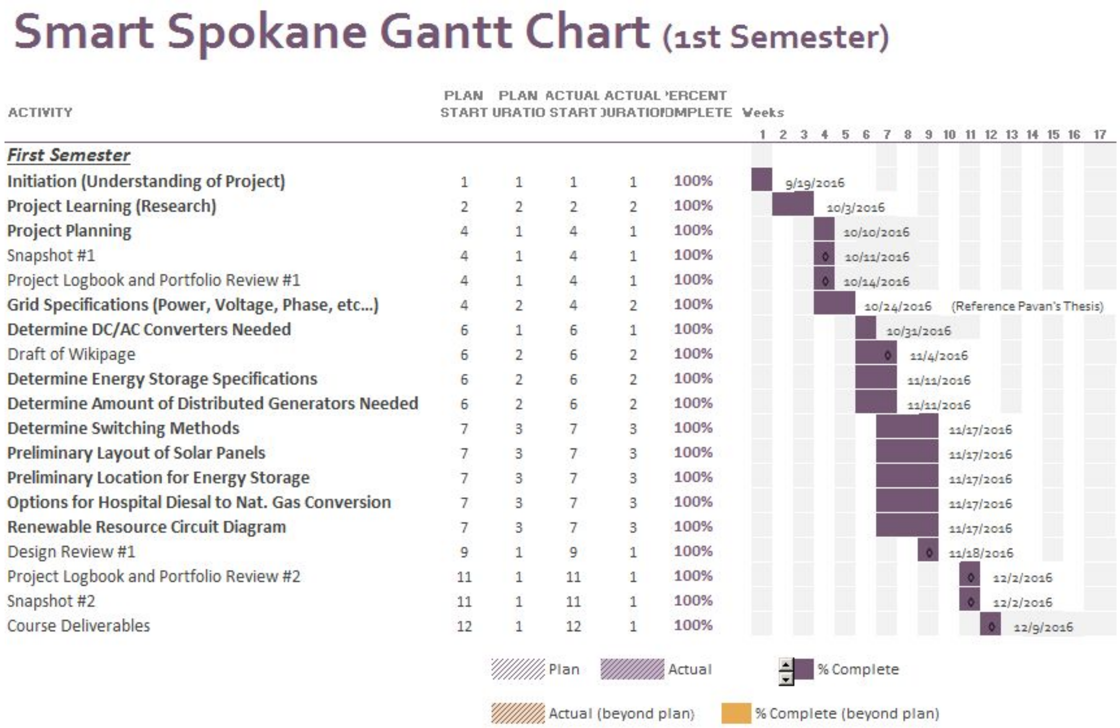
Editor - review documentation and advise changes
Secondary Client Contact - primary client contact backup
Driver - licenced University of Idaho driver for team field trips

Rotating Roles:

Master of Ceremonies - create the meeting agenda, distribute it, and lead the meetings
Secretary - record the meeting minutes and distribute it

Project Timeline:

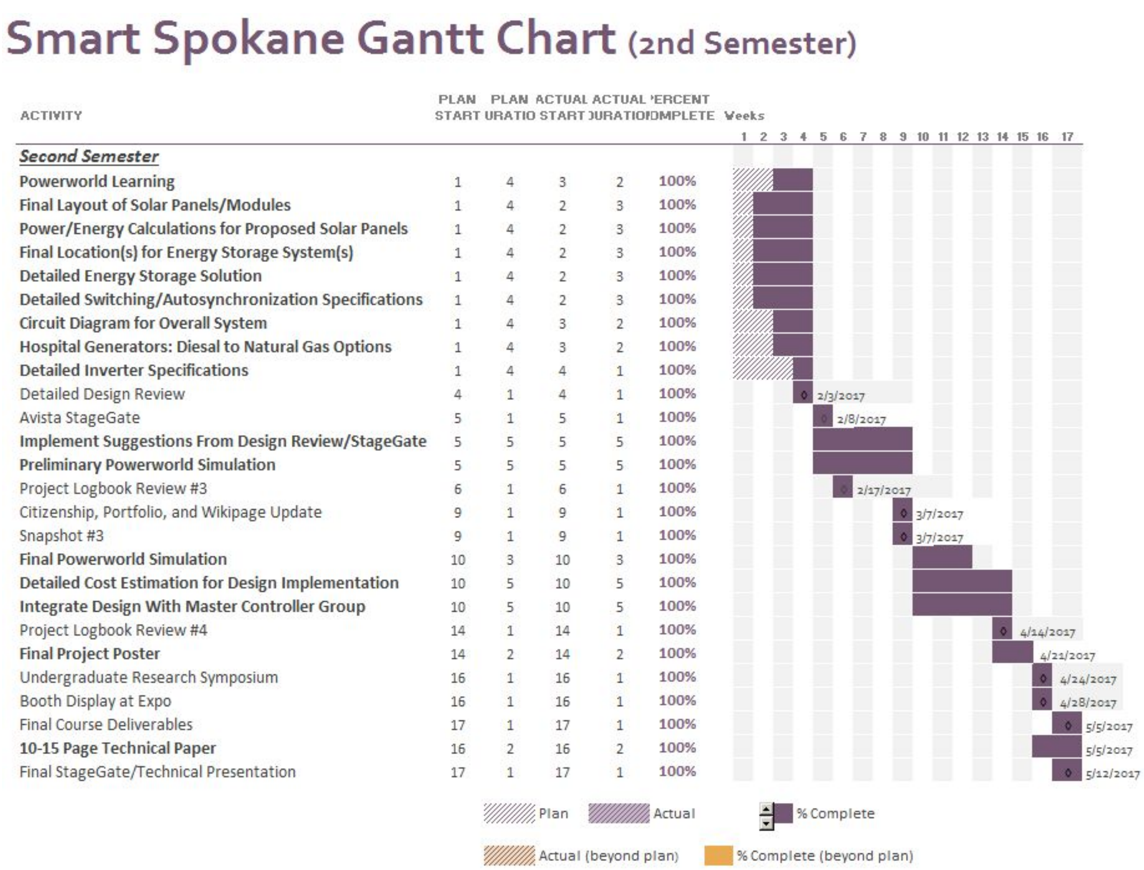
Table 1: Project Timeline - 1st Semester



Smart Spokane Gantt Chart (1st Semester)

ACTIVITY	PLAN START	PLAN DURATIO	ACTUAL START	ACTUAL DURATIO	PERCENT COMPLETE	Weeks
First Semester						
Initiation (Understanding of Project)	1	1	1	1	100%	9/19/2016
Project Learning (Research)	2	2	2	2	100%	10/3/2016
Project Planning	4	1	4	1	100%	10/10/2016
Snapshot #1	4	1	4	1	100%	10/11/2016
Project Logbook and Portfolio Review #1	4	1	4	1	100%	10/14/2016
Grid Specifications (Power, Voltage, Phase, etc...)	4	2	4	2	100%	10/24/2016 (Reference Pavan's Thesis)
Determine DC/AC Converters Needed	6	1	6	1	100%	10/31/2016
Draft of Wikipage	6	2	6	2	100%	11/4/2016
Determine Energy Storage Specifications	6	2	6	2	100%	11/11/2016
Determine Amount of Distributed Generators Needed	6	2	6	2	100%	11/11/2016
Determine Switching Methods	7	3	7	3	100%	11/17/2016
Preliminary Layout of Solar Panels	7	3	7	3	100%	11/17/2016
Preliminary Location for Energy Storage	7	3	7	3	100%	11/17/2016
Options for Hospital Diesel to Nat. Gas Conversion	7	3	7	3	100%	11/17/2016
Renewable Resource Circuit Diagram	7	3	7	3	100%	11/17/2016
Design Review #1	9	1	9	1	100%	11/18/2016
Project Logbook and Portfolio Review #2	11	1	11	1	100%	12/2/2016
Snapshot #2	11	1	11	1	100%	12/2/2016
Course Deliverables	12	1	12	1	100%	12/9/2016

Table 2: Project Timeline - 2nd Semester



Smart Spokane Gantt Chart (2nd Semester)

ACTIVITY	PLAN START	PLAN DURATIO	ACTUAL START	ACTUAL DURATIO	PERCENT COMPLETE	Weeks
Second Semester						
Powerworld Learning	1	4	3	2	100%	
Final Layout of Solar Panels/Modules	1	4	2	3	100%	
Power/Energy Calculations for Proposed Solar Panels	1	4	2	3	100%	
Final Location(s) for Energy Storage System(s)	1	4	2	3	100%	
Detailed Energy Storage Solution	1	4	2	3	100%	
Detailed Switching/Autosynchronization Specifications	1	4	2	3	100%	
Circuit Diagram for Overall System	1	4	3	2	100%	
Hospital Generators: Diesel to Natural Gas Options	1	4	3	2	100%	
Detailed Inverter Specifications	1	4	4	1	100%	
Detailed Design Review	4	1	4	1	100%	2/3/2017
Avista StageGate	5	1	5	1	100%	2/8/2017
Implement Suggestions From Design Review/StageGate	5	5	5	5	100%	
Preliminary Powerworld Simulation	5	5	5	5	100%	
Project Logbook Review #3	6	1	6	1	100%	2/17/2017
Citizenship, Portfolio, and Wikipage Update	9	1	9	1	100%	3/7/2017
Snapshot #3	9	1	9	1	100%	3/7/2017
Final Powerworld Simulation	10	3	10	3	100%	
Detailed Cost Estimation for Design Implementation	10	5	10	5	100%	
Integrate Design With Master Controller Group	10	5	10	5	100%	
Project Logbook Review #4	14	1	14	1	100%	4/14/2017
Final Project Poster	14	2	14	2	100%	4/21/2017
Undergraduate Research Symposium	16	1	16	1	100%	4/24/2017
Booth Display at Expo	16	1	16	1	100%	4/28/2017
Final Course Deliverables	17	1	17	1	100%	5/5/2017
10-15 Page Technical Paper	16	2	16	2	100%	5/5/2017
Final StageGate/Technical Presentation	17	1	17	1	100%	5/12/2017

Analysis of Renewable Energy Resources

A critical component of a functional microgrid is the distributed generation (DG). Downtown Spokane already has two hydroelectric dams to supply power. To supplement this current power supply the following renewable DGs were considered and a comparative matrix was built to represent the decision of main DG.

The criteria of the decision matrix was graded on a scale from 0-5 (5 high). The scores were averaged for each option and the highest score was chosen.

Solar Panels: Downtown Spokane contains plentiful roof space for solar panels and few towering buildings to cast shadows. This mature technology is already employed at the Avista solar farm.

Wind Turbines: Spokane is located in a valley which shelters it from the wind.

Wave Generators: This immature technology relies on the presence of waves to generate electricity. Spokane River does not generate enough waves and the Spokane City Council is adverse to additional hydroelectric generators.

Instream Generators: While the Spokane River which runs through downtown Spokane could be used for instream generators the Spokane City Council is adverse to additional hydroelectric generators because the river is a public domain and Instream generators would create an "eye sore" in what is historic downtown area.

Biomass: This would be a very reliable resource in the Spokane area. There is a local facility that could provide biomass for energy generation located near the airport.

Rain/Solar Generators: This generator is much like solar panels except for the added ability to generate energy from rainfall. This is a recent technology so market is immature. [4]

Table 3: Distributed Generation Decision Matrix

Renewable Energy Comparative Matrix								
Source of Energy	Location	Cost	Power Output	Environmental Impact	Client Preference	Complexity	Reliability	Total (0-5)
Solar Panel	5	4	5	5	5	4	4	4.6
Wind Turbine	0	5	2	5	1	4	1	2.6
Wave Generator	1	1	1	5	2	1	1	1.7
Instream Generator	4	2	3	5	4	3	5	3.7
Biomass	5	1	1	3	3	3	5	3.0
Rain/Solar Generator	5	1	5	5	5	4	4	4.1

Improving Assets: Hospital Generator Fuel Conversion

There are currently 18 backup generators distributed in downtown Spokane among Sacred Heart, Deaconess, and Shriners Hospitals. Together all the generators can provide about 14.75 MW. This generation is significant and can be set in parallel to the microgrid to enhance power reliability. [8]

Currently, all the hospital backup generators are setup to feed only their respective facilities. There is no existing connection or method that can transfer the output to the local distribution system. See the Synchronization section for details of how power from these converted generators could be synchronized to the local grid.

The hospital generators are currently diesel-fueled. Because of environmental restrictions, the use of diesel generators is limited to short durations during emergencies. To increase the use of the generators, environmental standards require a change to a more eco-friendly fuel source such as natural gas. After the change, the generators will be recommissioned and approved for longer run times. It is anticipated that the conversion will allow the generators to offset the daily peak load and therefore reduce peak load rise of energy prices.

The University of Idaho Microgrid team has spoken with Avista representatives about a potential Avista Incentive Program for the hospitals to purchase and use generator conversion kits. The team has spoken with a Florida company, GFS Corp about their generator conversion kits. This company is experienced in converting commercial grade diesel generators to a hybrid of diesel and natural gas. Most of their projects provide the customer's old generators with a peak shaving capabilities. GFS Corp has the is able to perform this conversion for the hospital generators through distributors in Washington

According to a representative with the company, the conversion process will provide the following aspects to the newly converted engines:

1) Non-invasive retrofit. The existing engines will not need to be taken apart for any part of the conversion process. [5]
2) The engines will start up on diesel, then convert to a hybrid operation of diesel and natural gas. [5]
3) Maximum operation of 70% natural gas to 30% diesel. [5]
4) Conversion for one unit usually takes two days (one day to install and another day to re-commission). [5]
5) No power loss after the conversion process. [6]
6) Extends generator run time using pipelined natural gas [6]
7) Price quote for Caterpillar 3412 Engine located in Deaconess: ~ $35,000 [5]

An estimated pricing table of the entire conversion is given in Appendix E. From the representative giving the price quote, the prices vary depending on KW rating and brand of the engine. Thus the pricing below is a rough estimate based off the quote for the engine given in the aspects list (Caterpillar 3412 750 kW) that is roughly $35,000.

Solar Panels

Since the hydroelectric dams cannot supply enough power to the city, the generation with be supplemented with solar panels. This decision was influenced by the a conversation with Randy, the Avista contact, who mentioned that the Spokane Event center had contacted Avista about installing solar panels.

The chosen solar panel is the Sunmodule Bisun SW 330 XL duo. A large percentage of Spokane roofs are horizontal and painted white, which are some of the ideal conditions for increasing the efficiency of the bifacial cells [11]. This solar panel will outshine the competitor brands during the sunny winter days where snow lies on the rooftops. While the snow cover on the front of the panels would block a single sided solar panel from operating, the duel-sided nature of the Bisun would gather more light on its opposing side from light reflection off the snow.

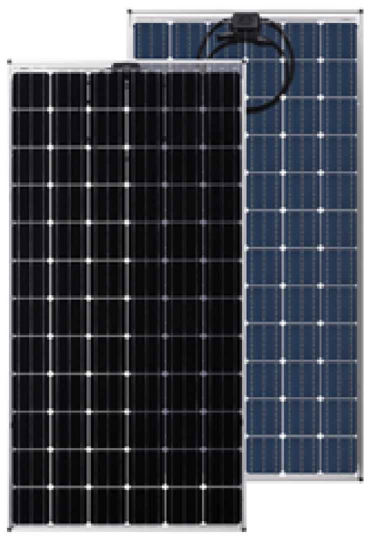


Figure 1: Sunmodule Bisun [12]

Using Google Earth, 38 locations were found for the Solar panels. These locations consist of the largest roofs in the same distribution zones the critical loads (Hospitals, jails, etc). Using the ruler tool of Google Earth and the dimensions of the solar panel, it is estimated that seventeen thousand solar panels can be placed in the first installation for a maximum power output of 5.6 MW.

Since the client did not provide an expected budget limit, the solar panels were divided into modules based on the distribution lines. It is expected that the client will implement one module at a time. [M1]

New Energy Storage

Energy storage is crucial for a microgrid since it eases the transition from the grid-connected mode to the grid-disconnected or "island" mode. This period allows the various customers time to shut down the processes and machines that would otherwise be damaged by the sudden drop or loss in power. The standard use of energy storage for this purpose is to charge the battery installations from the grid during normal operating conditions. Then the battery installations will be discharged later during an emergency. Depending on the energy storage, it could also store energy during low load to be later discharged during peak load.

The two options for MW energy storage were the standard Lithium-ion or Vanadium Flow batteries. The Vanadium Flow battery was chosen because it experiences no noticeable degradation of energy capacity from charge/discharge cycles. This trait allows for the secondary goal of peak load use for the batteries. Comparatively, the Lithium-ion is more energy dense but suffers from capacity degradation.

The team chose UniEnergy Technologies (UET), located in Mukilteo, WA, as the Vanadium Flow battery provider. This company has supplied Avista with the Vanadium Flow batteries in use at Schweitzer Engineering Laboratory in Pullman, WA. The battery system consists of 5 standard freight containers and can be easily relocated if needed because of the modular design. The batteries can also be double-stacked if needed.[16]

Specifications for UET Energy Storage System:

* Weight: 375,000 Lbs
* Space: 820 ft^2 (41'W X 20'L X 9.5'H)
* 5 containers per battery module
* 20 MW per acre, 40 MW per acre if double stacked
* Roundtrip Efficiency: ~ 70%
* Response Time: < 100 ms
* Lifespan: 20 yrs
* Unlimited Cycles
* Today's cost for Implementation: ~ $3.2 million

<u>3 Operating Conditions:</u>

1) $P\_peak1 := 600kW$

$Discharge1 := 2\cdot hr$

$Energy1 := P\_peak1\cdot Discharge1 = 1.2\cdot MW\cdot hr$

2) $P\_peak2 := 500kW$

$Discharge2 := 4\cdot hr$

$Energy2 := P\_peak2\cdot Discharge2 = 2\cdot MW\cdot hr$

3) $P\_peak3 := 275kW$

$Discharge3 := 8\cdot hr$

$Energy3 := P\_peak3\cdot Discharge3 = 2.2\cdot MW\cdot hr$

Figure 2: UET Battery Specifications [16]

System Power Cases:

The minimum number of UET batteries required was determined by analyzing the system power cases the seasonal balance of generation and the critical loads. The best-case and worst-case was developed. The worst-case scenario occurs during the summer when the air conditioning creates a high load draw while the river and hydroelectric generation is low. For this case, 29 battery sets are required to match the critical loads draw. The best-case scenario occurs during the spring during temperate climate and high river and hydroelectric generation. For this case, no batteries are needed since excess power would be generated.

The two cases give a range of the minimum batteries required to help the critical loads to run standard operation. Avista Utilities has the discretion to install as many or little batteries as they deem necessary. 29 battery modules will probably not be installed due to the heavy cost per installation.

The System Power Cases were based off of the data provided in Pavan Penkey's thesis, "Critical Load Serving Capability by Microgrid Operation". For the spring and summer scenarios, the peak daytime load for each critical load was taken to sum up the entire load draw for the seasons. Winter and fall seasons were analyzed but they fell in the middle of spring and summer in terms of amount of batteries needed for load matching. The information in the table below summarizes the findings and also aligns with the Powerworld model results in terms of MW provided by the batteries.

Table 4: Extreme point comparisons (best and worse case scenario) [8]

SYSTEM POWER CASES

	LOADS	GENERATION		
	Critical Loads (MW)	Photovoltaics (MW)	Hospital Generators (MW)	Hydro (MW)
Worst Case	44.37	4.468	14.745	11
Best Case	39.4	3.839	14.745	23

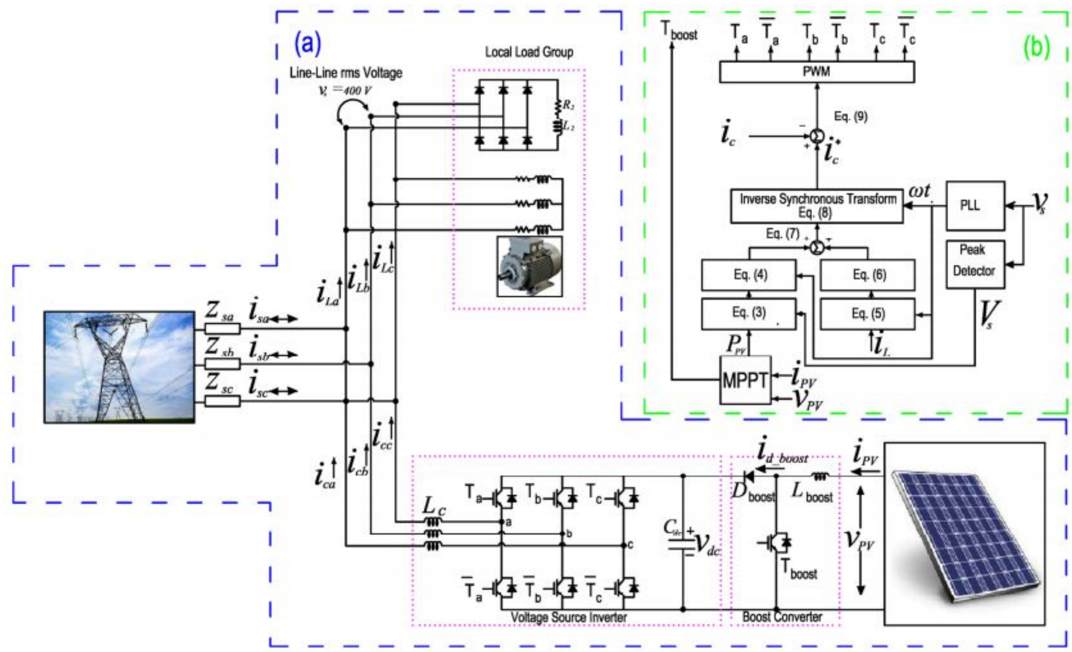
	Worst Case	Best Case
Total Load (MW)	44.37	39.4
Total Generation (MW)	30.213	41.584
Load Profile Deficit (MW)	-14.157	2.184
Batteries to Supply Load	29	0

* Batteries chosen are UET 500 kW for 4 Hours (2 MWhrs)
* Worst case is peak daytime load for highest load draw season and lowest generation season (Summer)
* Best case is peak daytime load for lowest load draw season and highest generation season (Spring)

Grid Synchronization:

The micro-grid will be fed from the distributed generation system (DGS). The DGS needs to synchronize safely with the grid to distribute power without damaging any DGS components. The best option to achieve this is to use Gridtie Inverters for the photovoltaics (PV) and battery banks, and generator auto-synchronizers for the hospital generators.

Gridtie Inverter – This device is used to convert a DC supply to an AC supply with a matching frequency, voltage magnitude and phase of the local grid. The battery and PV gridtie inverters work the same way.



Figure

Figure 3: Gridtie Inverter Schematic

a) The section boxed in blue on figure 1 shows how the PV is connected into the grid. When the PV supplies power, a boost converter amplifies the output of the PV using an algorithm of maximum power point tracking (MPPT). This allows the PV to operate at a point where it can supply the maximum power by adjusting its voltage and current to its best operating point. The output of the boost converter (V_{boost}, I_{boost}), is fed into a voltage source inverter, which transforms the DC supply into an AC supply. This output is then is fed into the grid. [1][[2][9]

b) The section boxed in green of figure 1 shows the gate controller of the IGBT. This controller handles the voltage source inverter (VSI) as well as the boost converter IGBT. The goal of this controller is to be able to take the measured grid values (frequency, voltage magnitude and phase) and generate a signal to control the gating of the VSI so that the AC output of the VSI matches the grids value. [1][[2][9]

Generator Auto-Synchronizer – The diesel/natural gas generators will connect to the micro-grid using auto-synchronizers. This device will adjust the synchronous generator governors and exciters until it matches the frequency, voltage magnitude, and angle of the grid. At this point, the breakers that link the generators and micro-grid closes.

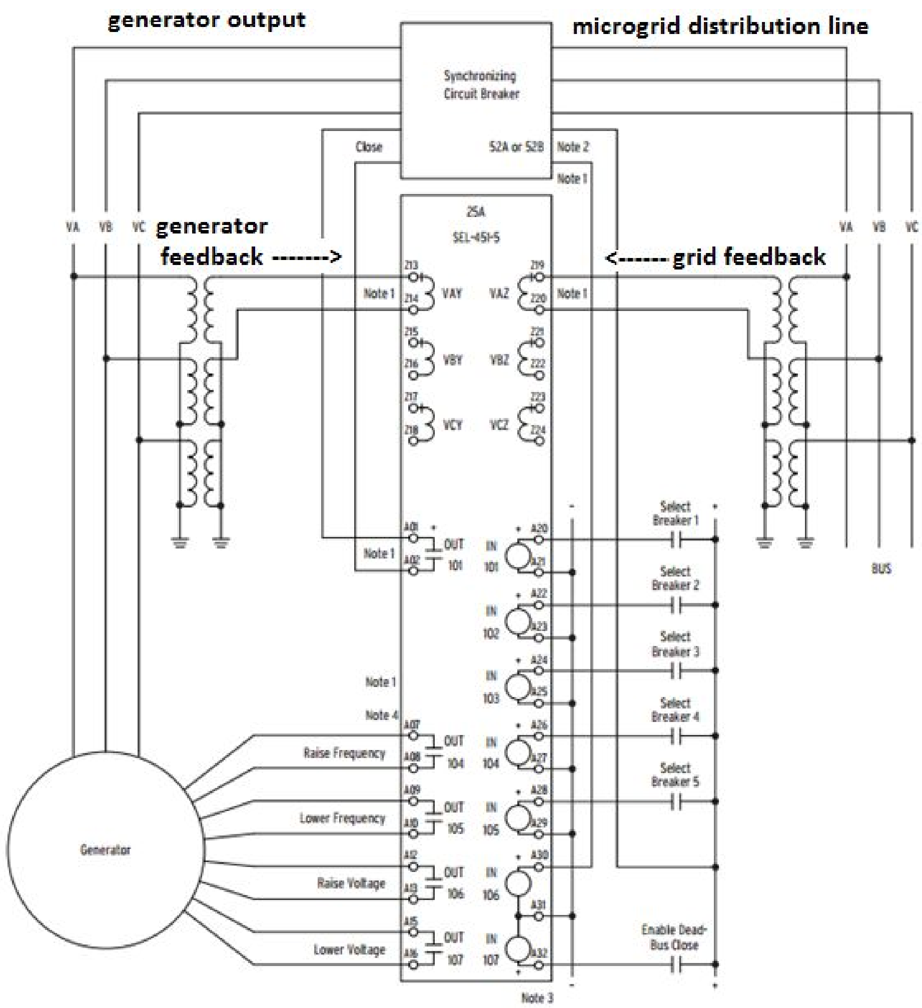


Figure 4: Generator Auto-synchronizer (GAS)

Figure 2 shows how a generator is synchronized into the system using a Generator Auto-Synchronizer (GAS). To start, the breaker that links the generator output and the micro-grid distribution line is open. Then the GAS reads through the connection leveled as “grid feedback.” Using this grid feedback values, the GAS starts adjusting the frequency by using the generator’s governor controls. This will set the generator output to have the same frequency as the grid. The GAS also adjusts the generator voltage amplitude output by controlling the generator exciter. [14][15]

The generators output reading is then fed back into the GAS to ensure close acceptance. The voltage output of the generators is adjusted to be slightly higher than of the micro-grid voltage so that the generators does not absorb any reactive power.

Finally when the micro-grid frequency and generator frequency are in phase or within the acceptance region, the breaker which links the generator output and the micro-grid distribution line closes and the synchronization process is complete.[14][15]

Results

Results

Table 5: Power and Price Results

	Power	**Price**
Shriners hospital	500kW	$30,000.00
Sacred Heart hospital	10.36MW	$400,000.00
Deaconess hospital	4.2MW	$205,000.00
Battery Banks	29 MW (worse case scenario)	$93,087,874.00
Photovoltaic module 1	1.456MW	$1,032,408.00
Photovoltaic module 2	1.889MW	$1,339,650.00
Photovoltaic module 3	1.886MW	$1,337,310.00
Photovoltaic module 4	3.54kW	$250,845.00

Future Work

This project has been divided into modules based on distribution lines. It is recommended that Avista confirms the boundaries of the modules. The Hospital module should be implemented first.

For future work more distributed generation sources could be considered. Solar roadways would be ideal for the large parking lots around the Veteran's Memorial Arena. Solar windows would be great for buildings with large glass walls. Solar tracking could be added to the current solar sites. New sources of biological based generation could be explored such as in the waste disposal plant.

The duration of any one or couple of these new works would be the same a senior design project. The cost of which would be about $200 for program licenses and gas fuel.

References

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[15] Thompson, M. (2016). *Advancements in Synchronizing Systems for Microgrids and Grid Restoration* (Rep. No. 113974). 13th International Conference on Developments in Power System Protection.

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Referenced Client Supplied Material

[M1] *AVA_Microgrid_Area_Map* [Png]. (n.d.).

Appendices

APPENDIX A - SYNCHRONIZATION SYSTEM

Battery Gridtie Inverter [7]

890GTB-1800	values
Input dc bus voltage (V)	730
Input dc bus voltage max (V)	800
Rater output up to 35°C (KVA)	1800
Rater output up to 50°C (KVA)	1620
Nominal output voltage (V)	480
Nominal output frequency (Hz)	50/60
Efficiency (%)	98.7

Photovoltaic Gridtie Inverter [3]

YC500A Microinverter	values
MPPT voltage range (V)	22-45
Max input current (A)	12
Rated output power (W)	500
Max output current (A)	2.08
Nominal output voltage (V)	240
Nominal output frequency/range (Hz)	60 / 59.3-60.5
Peak efficiency (%)	95.5
Nominal MPP tracking efficiency (%)	99.5

Generator Autosynchronizer [10]

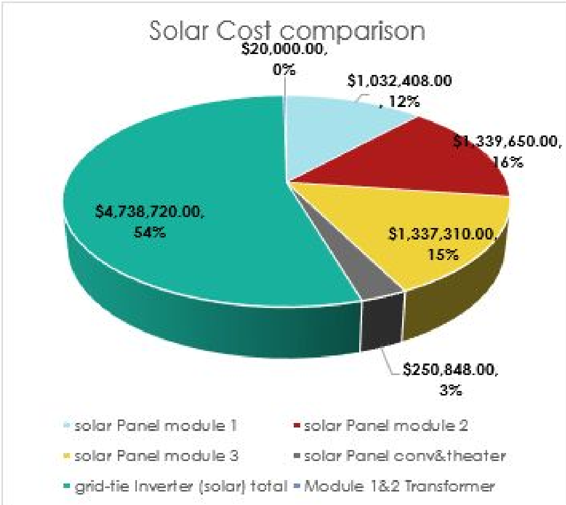
SEL-451-5 Autosynchronizer	values
Sensing: Generator and bus PT ratio Generator nominal voltage (V) Bus nominal voltage (V)	 1:10,000 turns 20-200 secondary 20-200 secondary
Initiate Autosync: Upper and lower frequency limit range (Hz) Upper and lower voltage limit range (per unit)	 45-65 0.8-1.2 pu
Close Acceptance: Slip Frequency range (Hz) Rate of change of the frequency range (Hz/s) Parralel close/operator permissive window (deg) Dead bus voltage (per unit) Breaker close time (cycles)	 0.025-0.5 0.01-1 3-80 0.01-0.5 1-30
Control: Frequency and voltage correction pulse (s) Frequency and voltage pulse width (s/Hz)	 1-30 0.01-100

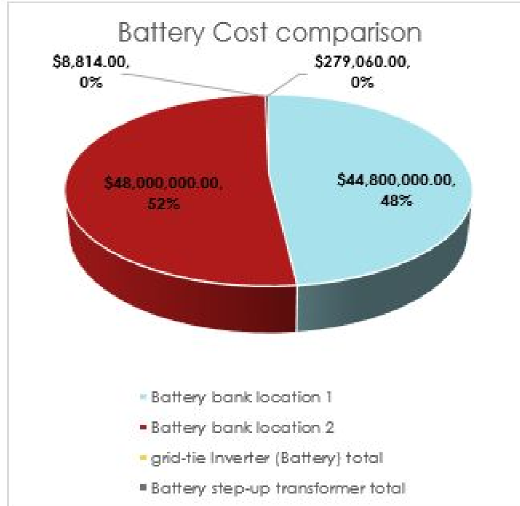
APPENDIX B - COST ESTIMATION

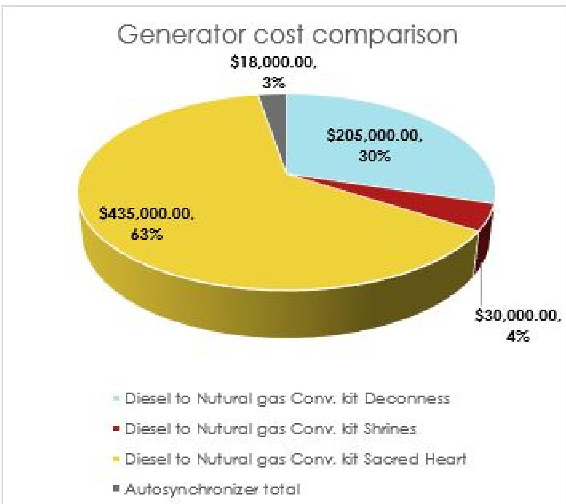
Implementation Expenses

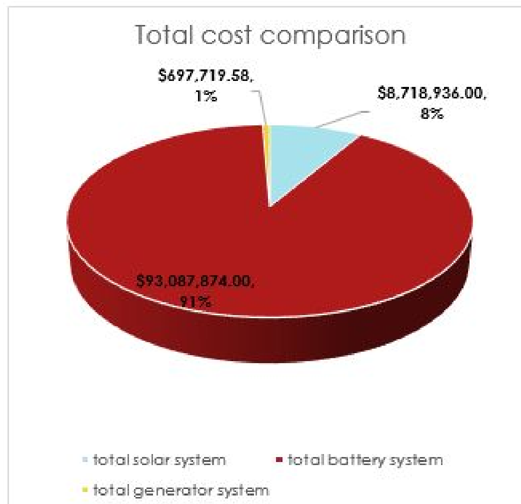
#UNITS	ITEMS	ACTUAL
1	solar Panel unit (500W)	$234.00
4412	solar Panel module 1	$1,032,408.00
5725	solar Panel module 2	$1,339,650.00
5715	solar Panel module 3	$1,337,310.00
1072	solar Panel conv&theater	$250,848.00
1	grid-tie Inverter (solar) unit	$280.00
16924	grid-tie Inverter (solar) total	$4,738,720.00
2	Module 1&2 Transformer	$20,000.00
	total solar system	**$8,718,936.00**
1	Battery bank (unit)	$3,200,000.00
14	Battery bank location 1	$44,800,000.00
15	Battery bank location 2	$48,000,000.00
1	grid-tie Inverter (Battery) unit	$1,469.00
6	grid-tie Inverter (Battery) total	$8,814.00
1	Battery step-up transformer unit	$9,302.00
30	Battery step-up transformer total	$279,060.00
	total battery system	**$93,087,874.00**
1	Cummins (1250kW) Diesel to Natural gas Conv. kit (unit)	$45,000.00
1	Cummins (250kW) Diesel to Natural gas Conv. kit (unit)	$25,000.00
1	Silver eagle (200kW) Diesel to Natural gas Conv. kit (unit)	$25,000.00
1	Onan (500kW) Diesel to Nutural gas Conv. kit (unit)	$30,000.00
1	Detroit (750kW) Diesel to Nutural gas Conv. kit (unit)	$35,000.00

#UNITS	ITEMS	ACTUAL
1	Diesel to Nutural gas Conv. kit Shrines	$30,000.00
12	Diesel to Nutural gas Conv. kit Sacred Heart	$435,000.00
1	Autosynchronizer unit	$4,500.00
4	Autosynchronizer total	$18,000.00
1	Autosynchronizer CD	$2,500.00
1	Autosynchronizer grid feedback VT unit	$254.14
1	Autosynchronizer grid feedback CT unit	$343.59
4	Autosynchronizer grid feedback VT total	1016.56
4	Autosynchronizer grid feedback CT total	1374.36
1	Autosynchronizer Gen. feedback VT unit	$254.14
19	Autosynchronizer Gen. feedback VT toal	$4,828.66
	total generator system	**$697,719.58**
	Total Expenses	**$102,504,529.58**


Solar Cost comparison
$20,000.00, 0%
$1,032,408.00, 12%
$1,339,650.00, 16%
$4,738,720.00, 54%
$1,337,310.00, 15%
$250,848.00, 3%
solar Panel module 1
solar Panel module 2
solar Panel module 3
solar Panel conv&theater
grid-tie Inverter (solar) total
Module 1&2 Transformer


Battery Cost comparison
$8,814.00, 0%
$279,060.00, 0%
$48,000,000.00, 52%
$44,800,000.00, 48%
Battery bank location 1
Battery bank location 2
grid-tie Inverter (Battery) total
Battery step-up transformer total


Generator cost comparison
$18,000.00, 3%
$205,000.00, 30%
$435,000.00, 63%
$30,000.00, 4%
Diesel to Nutural gas Conv. kit Deconness
Diesel to Nutural gas Conv. kit Shrines
Diesel to Nutural gas Conv. kit Sacred Heart
Autosynchronizer total


Total cost comparison
$697,719.58, 1%
$8,718,936.00, 8%
$93,087,874.00, 91%
total solar system
total battery system
total generator system

APPENDIX C - SOLAR PANELS DATASHEET [13]

Sunmodule® Bisun
SW 330 XL DUO

SOLARWORLD
REAL VALUE

PERFORMANCE UNDER OPTIMIZED CONDITIONS

Energy boost		6 %	10 %	20 %	25%
Maximum power	P_{max}	348 Wp	361 Wp	391 Wp	406 Wp
Open circuit voltage	V_{oc}	46.9 V	46.9 V	46.9 V	46.9 V
Maximum power point voltage	V_{mpp}	38.0 V	34.7 V	38.0 V	34.7 V
Short circuit current	I_{sc}	10.08 A	10.46 A	11.41 A	11.89 A
Maximum power point current	I_{mpp}	9.21 A	9.56 A	10.43 A	10.86 A
Module efficiency	η_m	17.46 %	18.08 %	19.60 %	20.36 %

PERFORMANCE UNDER STANDARD TEST CONDITIONS (STC)*

Maximum power	P_{max}	330 Wp
Open circuit voltage	V_{oc}	46.9 V
Maximum power point voltage	V_{mpp}	38.0 V
Short circuit current	I_{sc}	9.51 A
Maximum power point current	I_{mpp}	8.69 A
Module efficiency	η_m	16.54 %

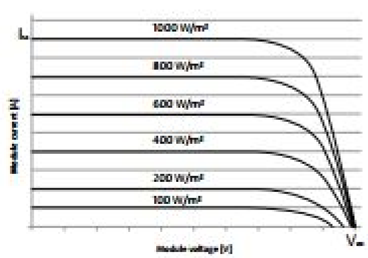
Measuring tolerance (P_{max}) traceable to TUV Rheinland: +/- 2 % (TUV Power controlled)

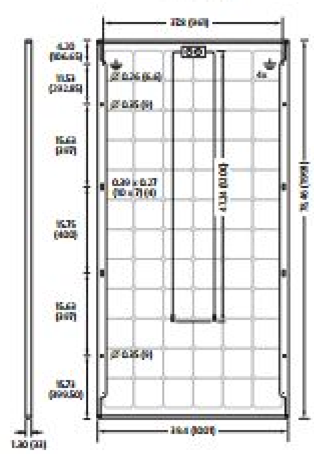
*STC: 1000W/m², 25 °C, AM 1.5

PERFORMANCE AT 800 W/m², NOCT, AM 1.5

Maximum power	P_{max}	246 Wp
Open circuit voltage	V_{oc}	42.9 V
Maximum power point voltage	V_{mpp}	34.7 V
Short circuit current	I_{sc}	7.68 A
Maximum power point current	I_{mpp}	7.02 A
Module efficiency	η_m	12.34 %

Minor reduction in efficiency under partial load conditions at 25 °C: at 200 W/m², 95 % (+/-2%) of the STC efficiency (1000 W/m²) is achieved.





COMPONENT MATERIALS

Cells per module	72
Cell type	bifacial duo
Cell dimensions	6.17 x 6.17 in (156.75 x 156.75 mm)
Front	Tempered safety glass (EN 12150)
Back	transparent backsheet
Frame	clear anodized aluminum
J-Box	IP65
Connector	PV wire per UL4703 with UTX/H4 connectors
Module fire performance	(UL1703) Type 1

DIMENSIONS / WEIGHT

Length	78.46 in (1993 mm)
Width	39.4 in (1001 mm)
Height	1.3 in (33 mm)
Weight	47.6 lbs (21.6 kg)

THERMAL CHARACTERISTICS

NOCT	46 °C
TK I_{sc}	0.042 % / °C
TK V_{oc}	-0.304 % / °C
TK P_{mpp}	-0.43 % / °C

PARAMETERS FOR OPTIMAL SYSTEM INTEGRATION

Power sorting	-0 Wp / +5 Wp
Maximum system voltage NEC	1000 V or 1500 V • *Specify when ordering*
Maximum system voltage SC II	1000 V
Maximum reverse current	25 A
Load / dynamic load	50 / -50 psf (2.4 / -2.4 kN/m²)
Number of bypass diodes	3
Operating range	-40 to +85 °C

INSTALLATION PARAMETERS FOR MAXIMUM YIELD

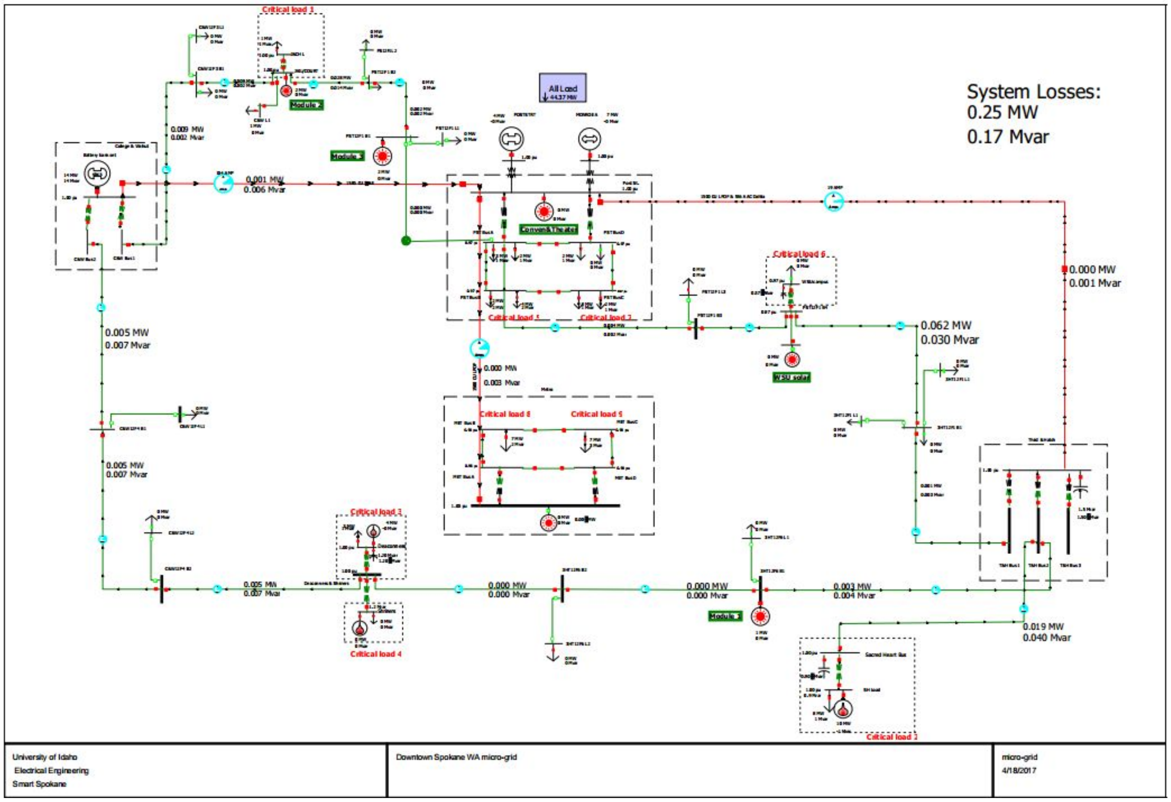
For maximum system yield and optimum performance ratio we recommend the following installation guidelines:

- Highly reflective background surface like white concrete, bright roof covering membrane, trapezoidal roof or limestone ground
- Maximize module distance to ground
- Mounting system with low shading of backside
- Sufficient distance between rows to avoid shading
- Prefer landscape mounting

All units provided are imperial. SI units provided in parentheses.
SolarWorld AG reserves the right to make specification changes without notice.
This data sheet complies with the requirements of EN 50380.

SW-01-7127US 160906

APPENDIX D- POWERWORLD MODEL[8]



APPENDIX E - DIESEL TO NATURAL GAS GENERATOR CONVERSION KIT PRICES [5]

Deaconess			
Manufacturer	**Model/Serial #**	**KW**	**Price Estimate for Conversion**
Silver Eagle	Volvo Penta TD 121 GG	200	$25,000
Caterpillar	1000SC2/CAT00C32AJAZ00218	1000	$40,000
Caterpillar	1000SC2/CAT00C32ESAZ00269	1000	$40,000
Caterpillar	3412 / 00000V9EP00895	750	$35,000
Caterpillar	3412 / 00000V9EP00896	750	$35,000
Onan	Cummins KTTA19G2 / 37130849	500	$30,000
			$205,000
Sacred Heart			
Manufacturer	**Model/Serial #**	**KW**	**Price Estimate for Conversion**
Cummins	Possibly DFLC4961842/G010265453	1250	$45,000
Cummins	Possibly DFLC4961842/G010265453	1250	$45,000
Cummins	Possibly DFLC4961842/G010265453	1250	$45,000
Cummins	Possibly DFLC4961842/G010265453	1250	$45,000
Cummins	Possibly DFLC4961842/G010265453	1250	$45,000
Cummins	Possibly DFLC4961842/G010265453	1250	$45,000
Cummins	Possibly DFLC4961842/G010265453	1250	$45,000
Detroit Diesel	Possibly DFLC4961842/G010265453	750	$35,000
Cummins	Possibly DFLC4961842/G010265453	260	$25,000
Caterpillar	Possibly DFLC4961842/G010265453	35	Not Economical
Caterpillar	Possibly DFLC4961842/G010265453	250	25,000
			$400,000
Shriners			
Manufacturer	**Model/Serial #**	**KW**	**Price Estimate for Conversion**
Caterpillar	3412/81Z09461	500	$30,000
			$30,000
			$635,000