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Hybrid Energy System for Battle Harbour Island in Labrador

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Hybrid Energy System for Battle Harbour Island in Labrador

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Abstract: Battle Harbour is a small island in the Labrador Sea just off the South East coast of Labrador. It is a historic site that represents a fascinating era of Labrador history. Presently, electricity is generated on Battle Harbour using a diesel generator. Due to its remote location, the fuel cost on Battle Harbour is very high. In this research we look into on-site renewable energy resources and conduct a feasibility study of a hybrid energy system for Battle Harbour. We present one-year recorded power consumption data, the wind and solar energy resource of the island and discuss options for power generation for Battle Harbour. A hybrid energy system is proposed and a pre-feasibility study of that system is presented in the report. The proposed system, if developed, will not only reduce the high cost of generating electricity to maintain the historic tourist site in an environmentally responsible manner, but will also serve as a test-base for other northern and remote communities in Canada.

Keywords: Renewable Energy, Wind Energy, Hybrid Energy Systems, Wind Resource

Introduction: Battle Harbour is a restored, 19th century fishing community accessible by boat only during the months of mid-June through to late September. It is located on a small island in the Labrador Sea, just north of the Strait of Belle Isle and near to Mary's Harbour. Battle Harbour is a national historic site that is an ideal destination for the adventure tourist interested in history, nature, rugged and spectacular scenery and the annual movements of majestic icebergs down the Labrador coast (www.battleharbour.com). Regarded by generations as the unofficial capital of Labrador, this small, isolated out port is a truly unique destination. The waterfront buildings are reminiscent of an era now past, but retain the sights and smell of years gone by and house an impressive collection of fisheries-related artifacts. Figures 1 and 2 below show the location and a view of Battle Harbour.

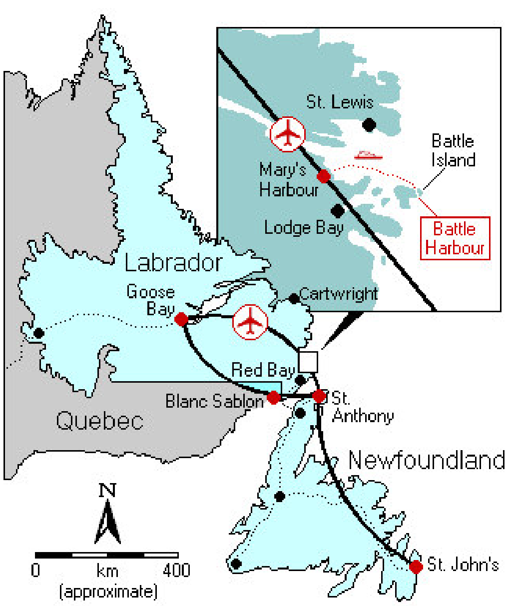


Figure 1: Location of Battle Harbour

Figure 2: A view of Battle Harbour from Great Caribou Island

Presently, electricity on Battle Harbour is generated using a diesel generator. However, Battle Harbour has many renewable resources that can be exploited to generate electricity. These resources include, wind, solar irradiation, ocean waves, ocean currents and rainwater coming down from the ponds on the surroundings hills. A hybrid energy system is needed to use the renewable resources of the island and reduce diesel consumption. Renewable energy resources on many islands in the world have been used to generate electricity for those islands [1-4]. In this report we explore the load demand and renewable resources at Battle Harbour and propose a hybrid energy system for the island. Based on this assessment some recommendations for Battle Harbour are given.

Battle Harbour's Existing Power System:

Electricity is generated at Battle Harbour using a 75kW diesel generator. Line to line 600V from the generator is transmitted to three 25kVA step down transformers installed close to restored buildings using underground cables. Figure 3 shows the existing electrical connections. Note that only one phase is being used i.e. the generator is not loaded evenly. Table 1 below lists some more features of the existing power system at Battle Harbour. Figure 4 shows a photo of the diesel generator. In summer 2006, another used 60kW diesel generator was installed in the same generator room. Operator plans are to use that machine as a back up in future.

Electricity on Battle Harbour is mainly used for lighting in the historic buildings, gift shop, office, dining hall and guest residences as well as powering lights and a few appliances used by the employees who live there permanently during the summer months. Electricity is also used for appliances in the guest residences and to power a few electric heaters. The main heating of all buildings, if needed in the summer, is done using heating oil. Heating oil consumption is minimal since the site is only open during the summer months and heating is required for a few days in a season. In a typical season (mid June to mid September) the Battle Harbour diesel generator consumes 25,000-30,000 L of fuel. Fuel costs are high on Battle Harbour due to its location. In 2006 the price was $1.35 per litre. The fuel is transported in barrels and pumped into a larger tank and this cost does not include some of the boat transportation and handling expenses since these are difficult to separate from the overall operation expenses. Fuel cost is a major issue for the Battle Harbour Trust.

Table 1. Some features of the power system

A Tamper Synchronous Generator 75kW, 3-phase, 1800rpm, 600V_{l-l}, Exciter 60V Model: B503KY-3M50DC-AM
Three, 25kVA, 600V to 120-0-120V transformers
Fuel Consumption during the open session (from June 15, 2006 to September 15, 2006) was 30,000 L Diesel @ C$1.35 per litre
One handy man on site runs and maintains the diesel generator.
Diesel is stored in one large tank but it is transported in barrels and manually pumped into the large tank.
Another old 60kW generator was installed in summer 2006. It is used as a backup generator.
In 2006 site open session, 2000 people visited the site while 11 employees stayed on the island full time.

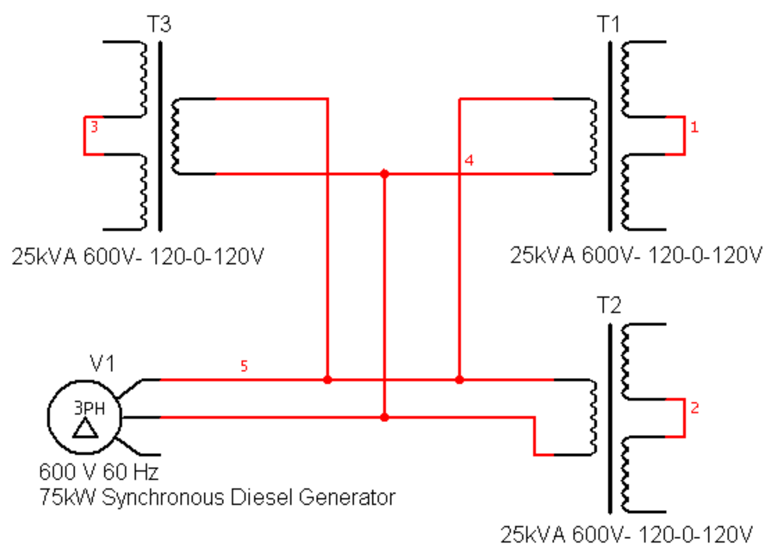


Figure 3: Battle Harbour power system

Installed Data Acquisition Systems: In June 2006 we installed three data loggers and a number of sensors at Battle Harbour. The objective was to monitor the renewable resources at Battle Harbour and determine electrical load of the Battle Harbour village. Figures 5 and 6 show the installed wind equipment. One wind sensor was installed on the top of a building at a height of about 80 feet from the base of the diesel generator room. Location and the height of the sensor were selected about same as the hub height of a small wind turbine that would most likely be installed close to the generator room. There are no roads on the island and the area near the generator room is the only vacant flat patch of land close to the harbor and historic buildings. Heavy machinery and trucks cannot come to the island via boats. So movement of heavy parts of a wind turbine would be limited. Therefore, we assumed that using a small crane and a tractor, parts of a wind turbine could be off loaded and installed on the site close to the generator room. Hub height of most small wind turbines is about 25-30m, therefore, the anemometer height was selected as 80 feet. A HOBO data logger was installed within the dining hall to record wind speed, wind direction, temperature and solar radiation every five minutes. (http://www.microdaq.com/occ/hws/logger.php)

Figure 4: Battle Harbour diesel generator

Figure 5: Installed wind equipment at Battle Harbour

Another anemometer and a wind vane were installed on the top of the hill next to the Battle Harbour village. It was installed on an old telecommunication tower at a height of about 10m from the tower base – this was the left hand tower shown on the hilltop in Figure 2. That site was selected to determine the wind speed and wind turbulence on top of the hill. The hill slope is steep and there is no track going up that can be used by a tractor so the location cannot be used for a wind turbine installation unless it is a very small wind turbine or unless an expensive installation is considered. A Davis Instrument Wind Explorer data logger shown in figure 6 was used to record data at that location.

To determine power consumption and its variations an ACR logger with three current probes was installed inside the generator control box. It recorded generator phase currents data every minute and it had a battery life of 10 years. Figure 7 shows that data logger and the associated current probes. Generator voltage is fixed at 600V, therefore we needed to measure only load currents to determine the total load. Note that, a complete log of the Battle Harbour village power consumption is required to determine the size and configuration of the proposed hybrid energy system. The ACR logger also logs generator room temperature. All data loggers were installed in June 2006 and they remained in operation until the middle of July 2007.

Weather data loggers installed at Battle Harbour

1) H21-001 HOBO weather data logger with wind speed, wind direction, temperature and pyranometer sensor. Sampling every 10-second, but recording every five minutes after averaging. Wind speed sensor is installed at a height of about 80 feet from the ground.

2) NRG Wind Explorer with wind speed sensor #40 and a 200 series wind vane installed at a height of 30 feet on the hilltop. It sampled data every 10s but recorded an average value every 10 minutes.

Figure 6: Wind explorer and HOBO data logger

Battle Harbour Power Consumption Data Logger

SRP-003-1-5M ACR Smart Reader Plus 3, 1.5MB data logger recording room temperature and three phase generator currents every minute. It uses three clamp-on AC current probes (A70FL) installed within the generator control box.

Figure 7: Power data logger

Available Renewable Energy Resources:

We collected site data from June 20, 2006 to July 15, 2007. Table 2 below presents a summary of the data collected. The NASA surface meteorology and solar energy data available at http://eosweb.larc.nasa.gov/sse/ indicates that the 10 year average annual wind speed at the Battle Harbour location at 10m height is 7.64m/s while in the summer months (June to September) it is 6.4m/s. The data we recorded on site (Table 2.) for 2006-07 indicates a similar value at the hill top location, but as expected, a lower wind resource at the lower location near the generator room. Similarly NASA predicted yearly average insolation values incident on a horizontal surface of 2.9 kWhr/m^2 /day; this is about same as we recorded on site. Typical Battle Harbour wind speed data for two stormy summer days are shown in figures 8 and 9. Obviously the hilltop wind speed is higher than wind speed in the village. Note the sudden variations in the wind speed. On August 7, 2006 wind speed increased from 7m/s to 17m/s within a few minutes. Many other similar events can be noted in figures 8 and 9. The hilltop anemometer recorded wind speed standard deviation between each 10-minute recording interval. The standard deviation data is plotted in figure 10. Note the high standard deviation and many spikes in the data. It indicates that wind at Battle Harbour is very gusty and sudden variations are frequent and large. The complete record of raw one-year Battle Harbour data is shown in figure 11 to figure 18. The data gap in figure 14 is due to the site shut down. The data gap in figure 15 is due to the battery. A set of complete data in digital form can be obtained from author Iqbal of this report.

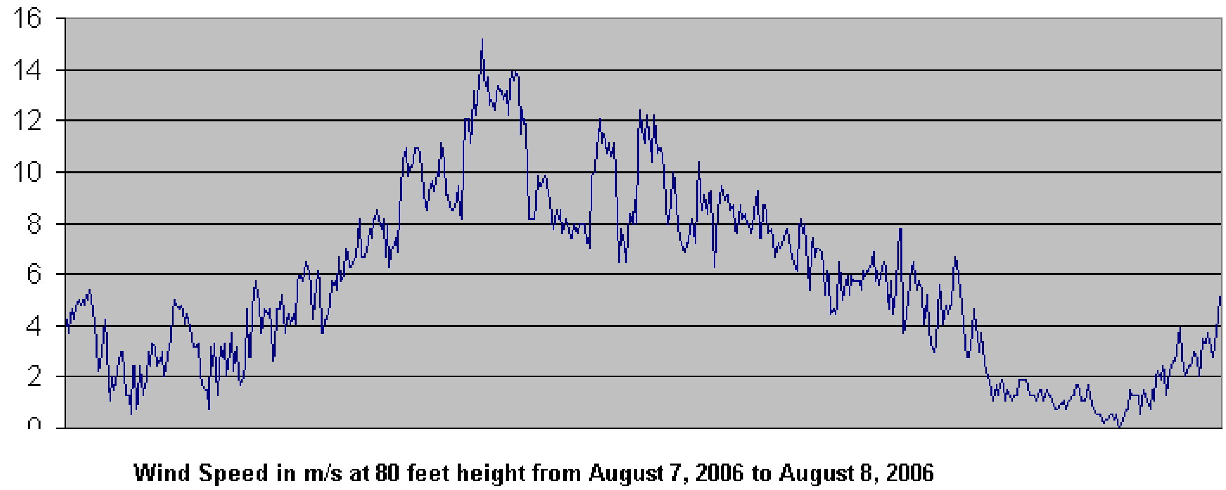


Figure 8: Wind speed data on two stormy days at the Battle Harbour village

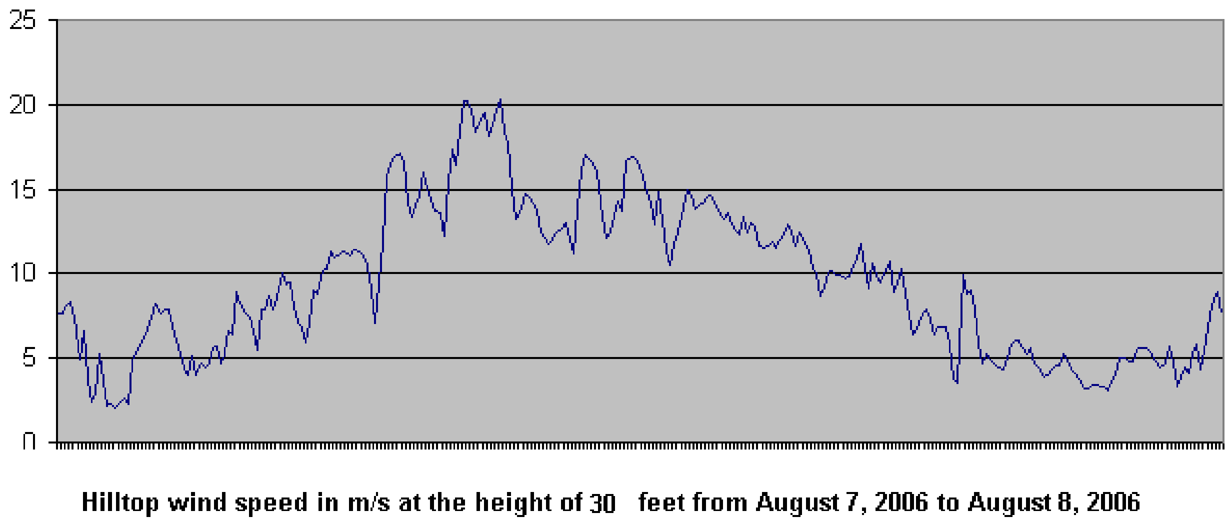


Figure 9: Wind speed data on two stormy days on top of the hill next to Battle Harbour village

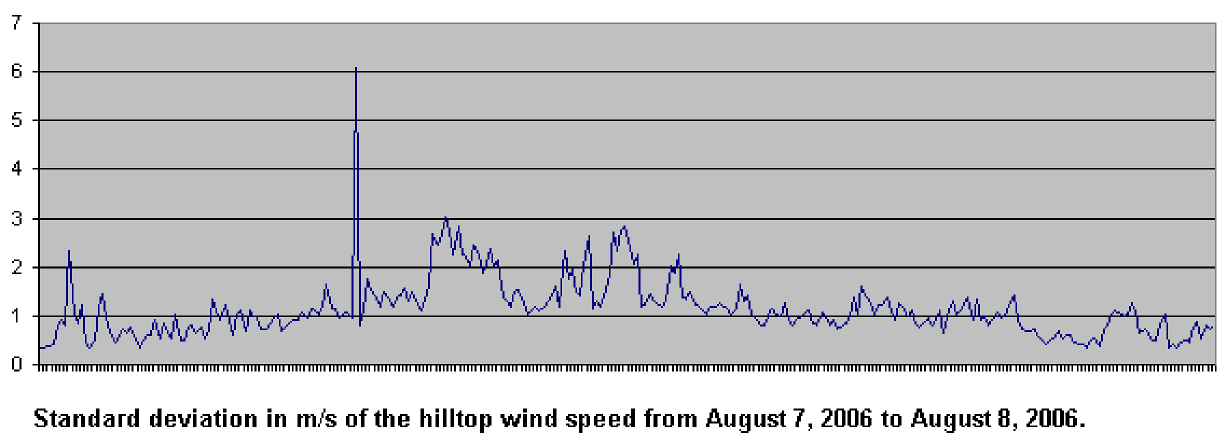


Figure 10: Standard deviation over 10 minutes intervals for the hilltop wind data.

Table 2: A summary of data recorded from July 1,2006 to June 30, 2007

Average wind speed at a height of 80 feet = 6.0056 m/s
Standard deviation of the wind speed at a height of 80 feet = 3.85 m/s
Maximum wind speed at a height of 80 feet = 22.8 m/s
Maximum wind gust recorded at a height of 80 feet = 30.06 m/s
Average hilltop wind speed at a height of 30 feet = 6.8348 m/s (missing data)
Hilltop wind speed standard deviation = 4.86 m/s
Maximum Hilltop wind speed at a height of 30 feet = 26.8 m/s
Annual Average Solar Irradiance = 2.83 kWhr/m^2/day
Average Solar Radiation = 118.05 W/m^2
Maximum Solar Radiation = 1271.9 W/m^2
Average Temperature = 1.4462 °C
Minimum temperature = -24.29 °C
Maximum temperature = 27.12 °C
Battle Harbour Average Power Consumption during from June 17, 2006 to September 12, 2006 = 17.4kW
Maximum Load from June 17, 2006 to September 12, 2006 = 36kW

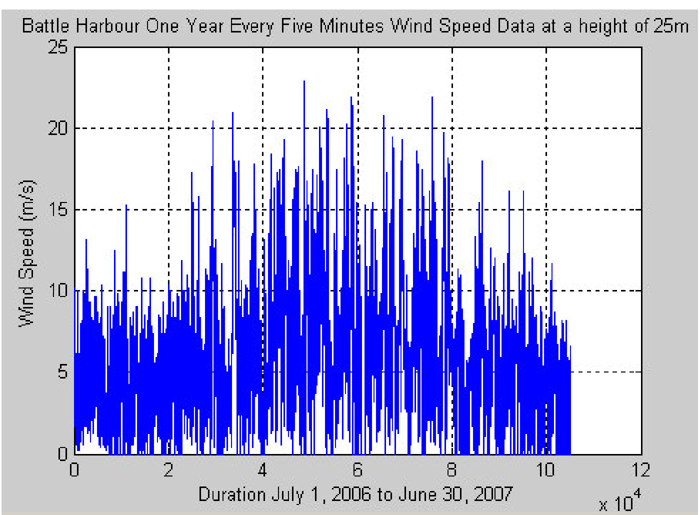


Figure 11. One-year wind speed in Battle Harbour.

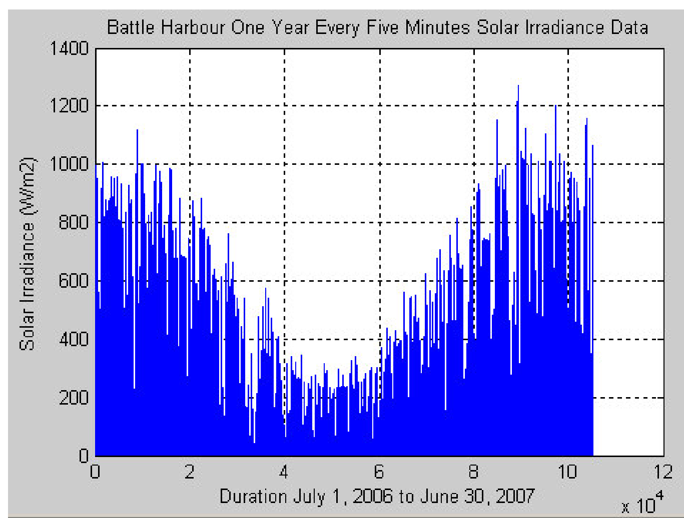


Figure 12. One-year solar radiation data in Battle Harbour.

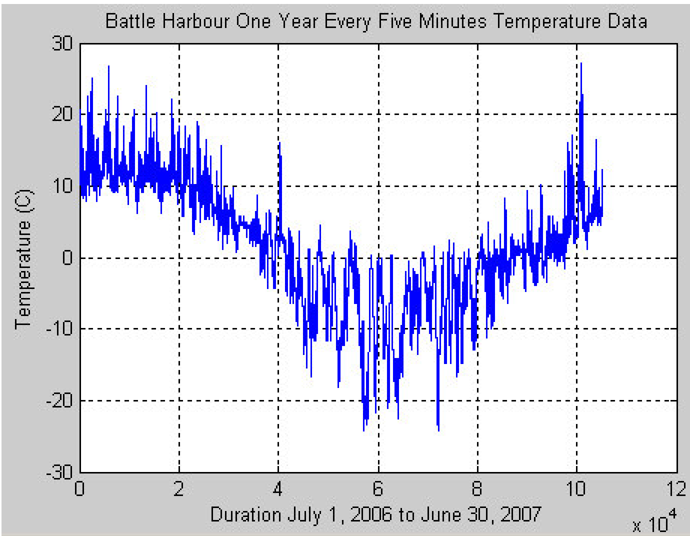


Figure 13. One-year temperature data in Battle Harbour.

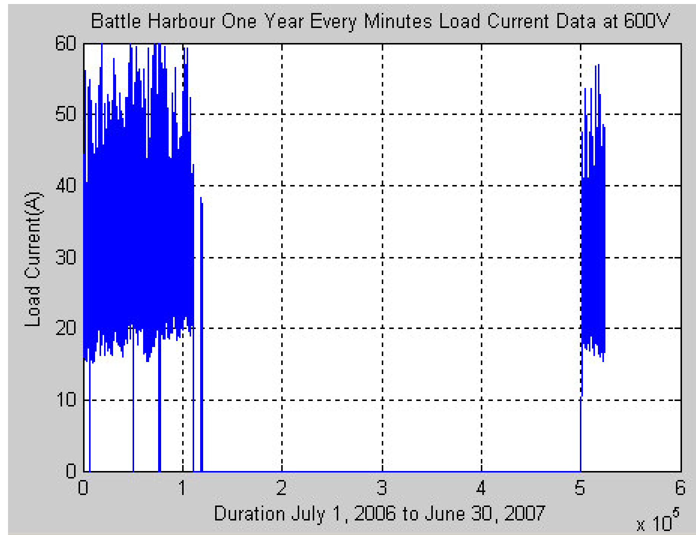


Figure 14. One-year load current data in Battle Harbour.

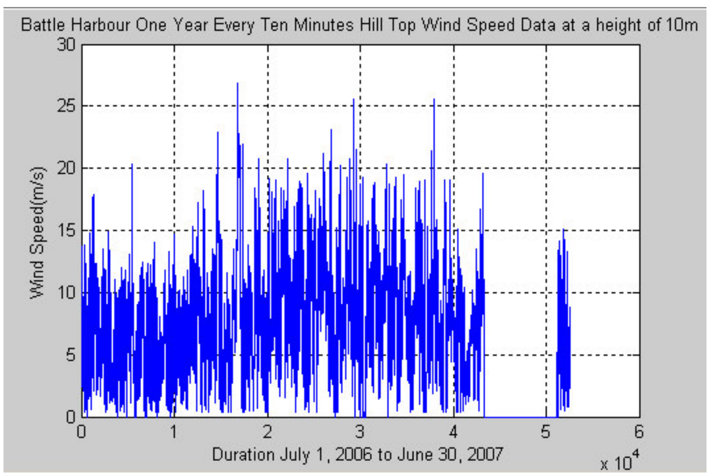


Figure 15. One-year hilltop wind speed data in Battle Harbour. (Missing data is due to a dead battery)

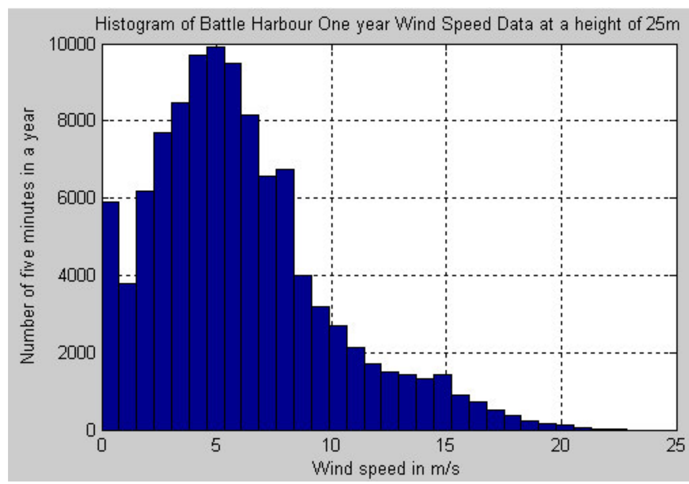


Figure 16. Histogram of one-year wind speed raw data.

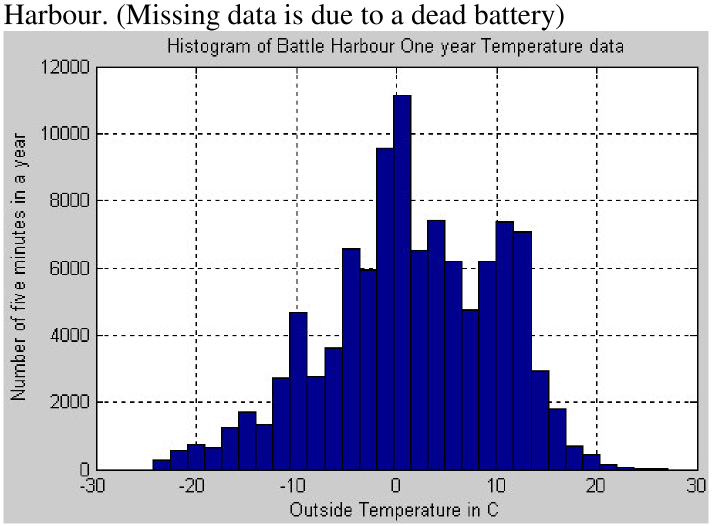


Figure 17. Histogram of one-year temperature raw data.

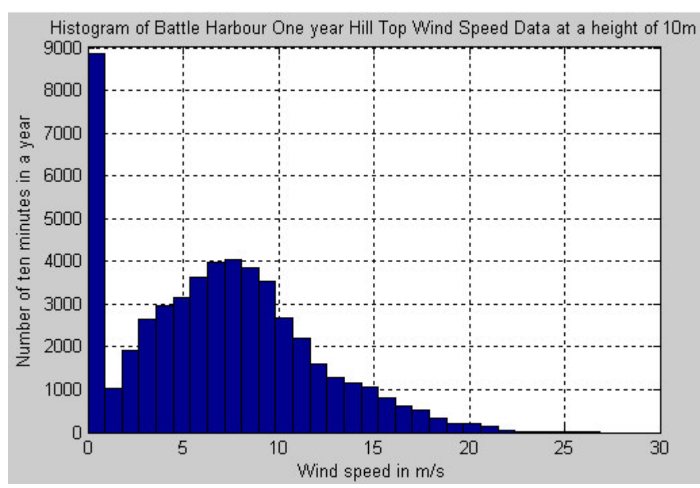


Figure 18. Histogram of one-year Hill top wind speed raw data. (First strip is due to the missing data)

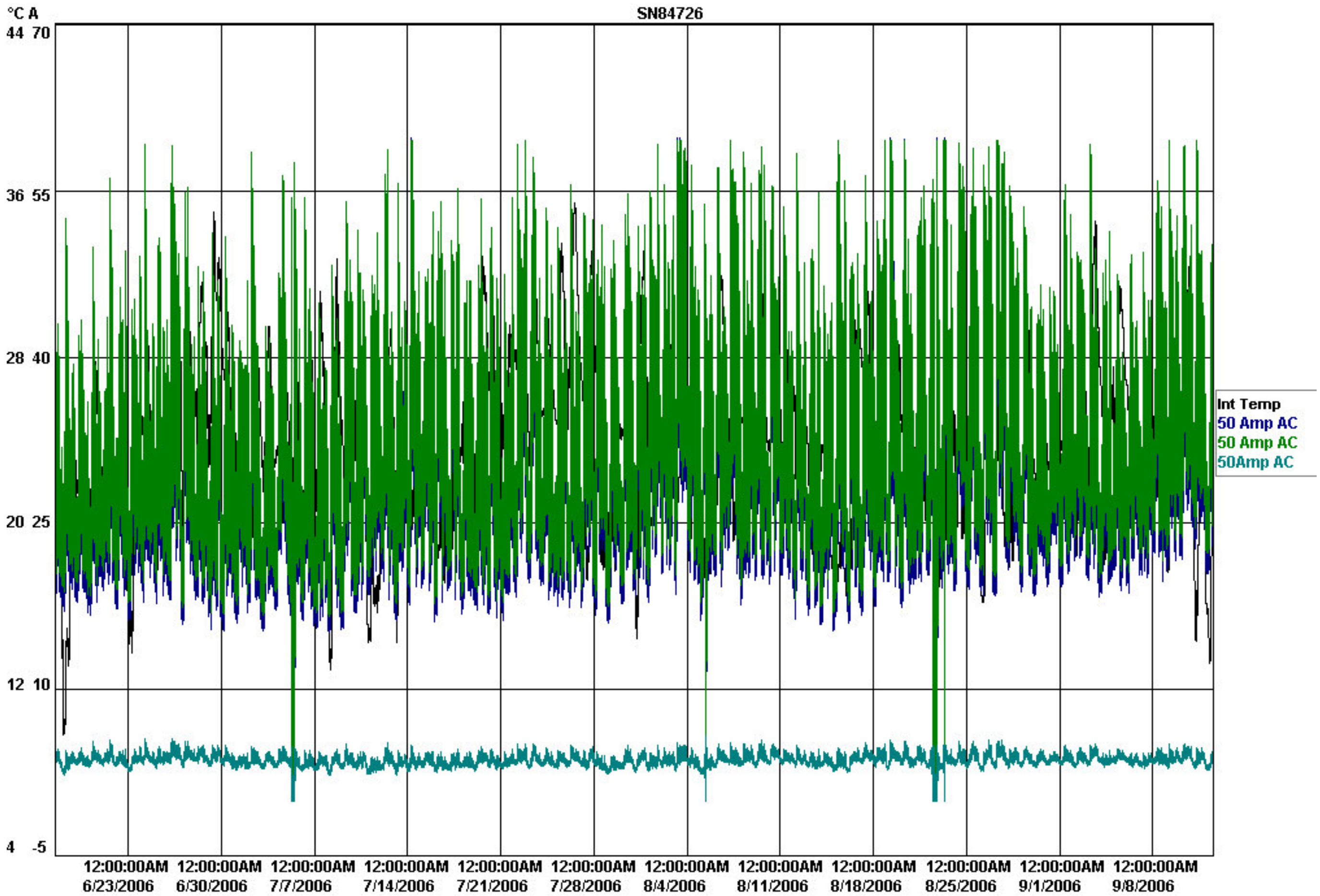


Figure 19: Generator phase currents and generator room temperature from June 20 to Sept. 12, 2006

A selection of load generator load currents data is shown in figure 19. A summary of this data is provided in Figure 20. It indicates that the average current drawn from the generator is about 30A. Therefore the average power consumption at Battle Harbour is about 600Vx18A → 18kW. Presently a 75kW diesel generator is being used 24/7. The maximum current drawn from the diesel generator was almost 60A. Hence instantaneous maximum load was about 36kW. This indicates that, most of time the generator is running at ¼ of its nominal rating and maximum load on the generator is less than half of its full capacity. Running a diesel generator below its rating wastes fuel, is inefficient and leads to higher maintenance costs for the diesel engine. At ¼ of its full load a diesel engine operates in a heavy carbon region (e.g. [7].). This indicates that the generator being used at Battle Harbour is too large for the site. As indicated in figure 3, the generator connections are also incorrect. The second used generator installed on site during summer 2006 is a 60kW unit and this also is too large for the site. Figure 21 shows load current variations on two typical summer days indicating the Battle Harbour daily load cycle. Note that current drawn from the third phase of the generator is about zero since that phase is not being used. Current drawn from other two phases is almost equal.

Site raw data was formatted such that it starts from January 1 and ends at December 31. Hourly data averages were calculated so that they could be used in the program HOMER. Homer is a hybrid energy system optimization program. Formatting and basic analysis was done using Matlab. Formatted hourly site renewable resources and load data is shown in figure 22 to figure 24.

Start Time: Jun/17/2006 2:57:32 PM   End Time: Sep/12/2006 1:07:32 PM

	Description	Rate	Readings	Low	Mean	High	Range	Units
File:	84726C.TRW	60	125171					
0	Int Temp			9.85	23.89	35.45	25.60	°C
3	50 Amp AC			0.00	29.10	59.85	59.85	A
5	50 Amp AC			0.00	31.22	59.57	59.57	A
7	50Amp AC			0.00	3.66	5.80	5.80	A

Figure 20: Generator current summary for the summer 2006

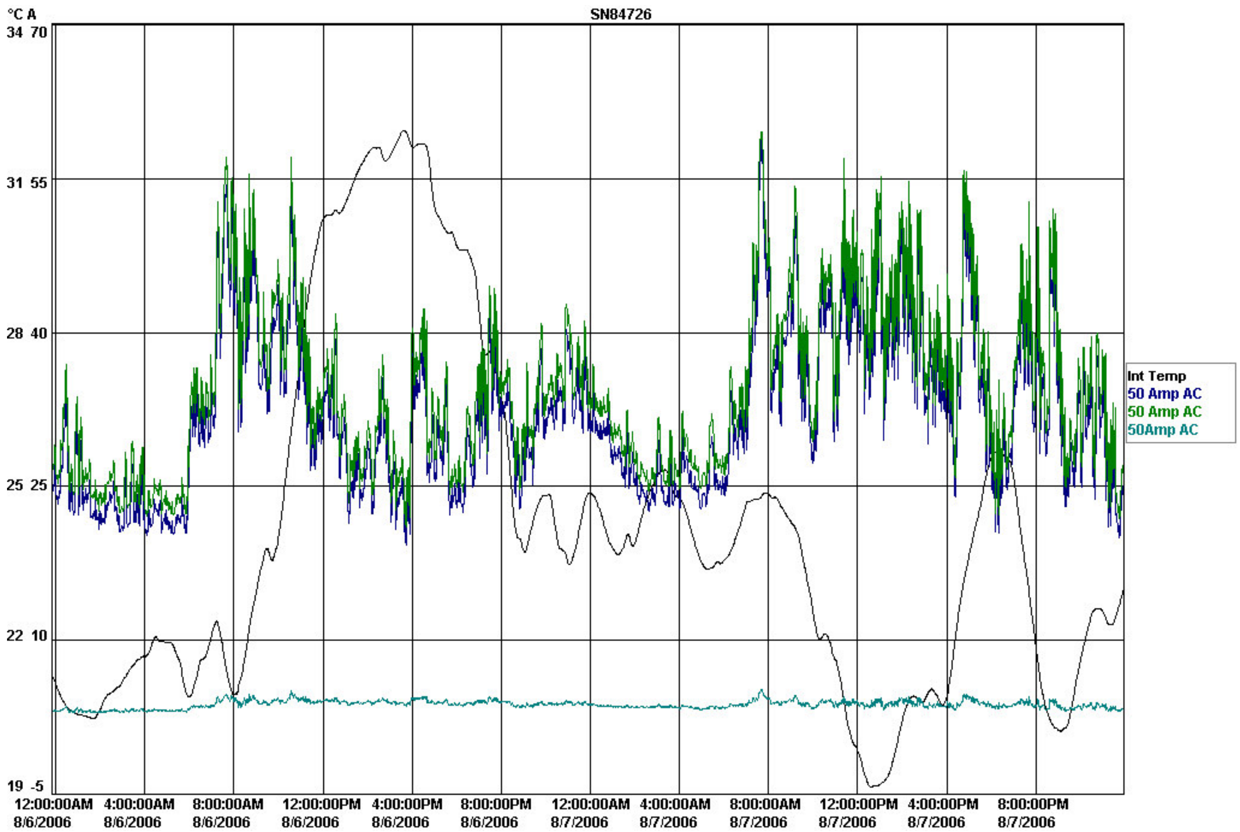


Figure 21: Typical generator current variations during two summer days

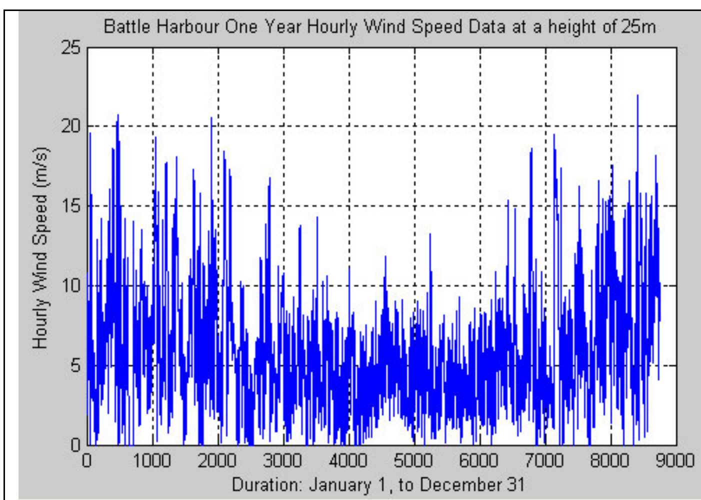


Figure 22: Site formatted hourly wind speed data

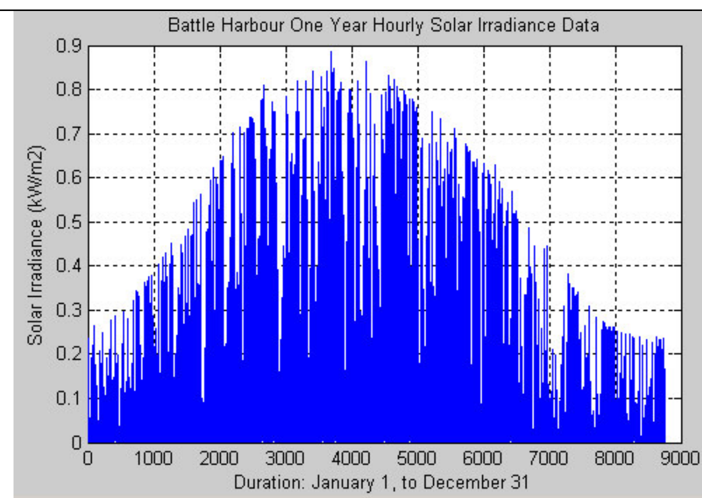


Figure 23a: Site formatted solar radiations data

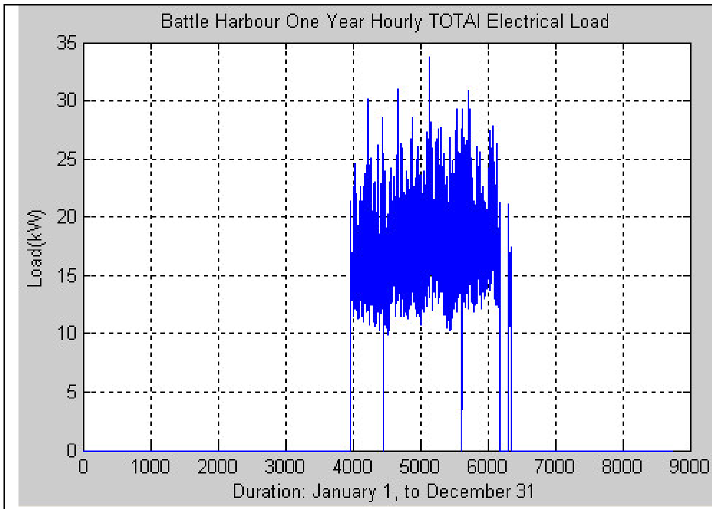


Figure 23b: Site formatted one-year total load data.

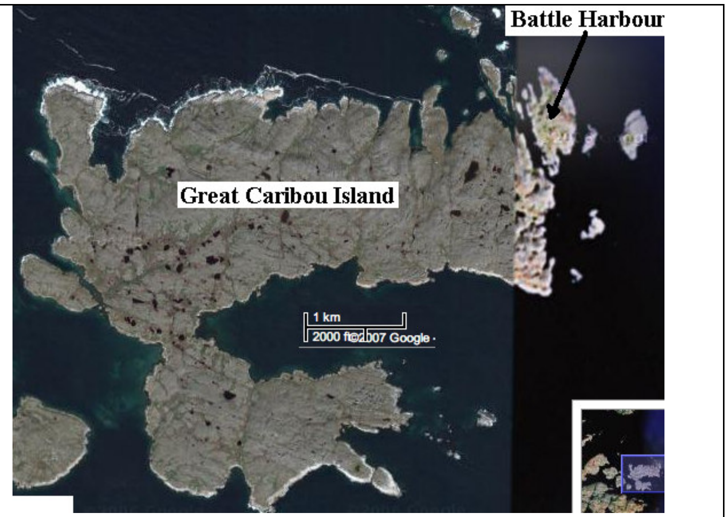


Figure 24: Battle Harbour and nearby Caribou Island

During our visits to Battle Harbour, we started looking at other possible renewable resources. We were not able to measure wave height and tidal current. Battle Harbour may have significant ocean energy resources in the summer, although heavily iced conditions exist in winter. These could be explored in future work. Weather office records exist for rainfall at a number of locations in the province. http://www.weatheroffice.ec.gc.ca/city/pages/nf-29_metric_e.html Records for Battle Harbour or a nearby location do not exist. An estimate of precipitation is about 1.5m/year (assuming the same value as Newfoundland). We explored Battle Harbor and the neighboring Great Caribou Island for possible hydro resources (see figure 24). There are no ponds on Battle Harbour, but there is a large pond on Great Caribou Island. It is at about 50m height, 600m meters from Battle Harbour and is used for drinking water at Battle Harbour. High-resolution google maps of that region confirm that it is the biggest pond on Caribou Island. Figure 25 shows a Google satellite photo. It is about 200m long and 100m wide. There is a 2-inch diameter plastic drinking water grade pipe running from the pond to Battle Harbour. The pressure at the end of this pipe is about 65psi indicating a head of 50m.

Assuming a mean depth of 5m, there is more than 70,000 cu m of water in the pond and it could be used to run a pico-hydro unit at Battle Harbour. The existing water pipe can be used for water supply and to run a pico-hydro unit. A new 4" water pipe could be laid down to run a larger pico-hydro unit capable of producing about 4kW. Such a pico-hydro unit would need a flow rate of 10L/s. That pond could supply this much flow rate for three months in a year. The Battle Harbour site is open for only three months each year. We assumed that during the winter and summer, the pond would refill. An accurate survey of the pond, catchments area assessment and rainfall data is needed to confirm this assumption.

Proposed Hybrid Energy System:

The above section indicates that useable renewable resources at Battle Harbour are wind, solar and hydro. Therefore, a hybrid energy system for the island could consist of wind turbine/s, photovoltaics, a pico-hydro unit and a small diesel. A proposed hybrid energy system is shown in figure 26. Sizing of a hybrid system can be done using Homer [5,6]. Homer needs hourly average one-year resource and load data for the site to determine a suitable hybrid system. Data presented in figure 22 to figure 24 was used for sizing a hybrid system. In the first case we assumed that the load would remain as at present. In the second case we assumed that site would take energy conservation measures and reduce its load by one half. This can be done by replacing all bulbs with energy savers and replacing, or removing, some appliances.

Figure 25: The biggest pond on Great Caribou Island

Case #1: (No energy conservation measures taken)

It was assumed that a new 4" inch diameter pipe would be used to bring the pond water down to Battle Harbour. About a one-inch diameter nozzle would be used to run a stream engine. (http://www.smallhydropower.com/turgo.html) This would result in a constant flow rate of 10L/s for a head of 50m. The site wind resource is significant and it can be used. We also assumed that the existing diesel would be replaced with smaller units. Different types of wind turbines were selected and many sizes of PV, batteries, generators and converter were tried in Homer. Homer produced a feasible system when two or more Bergey Excel 7.5kW wind turbines were selected as part of the option.

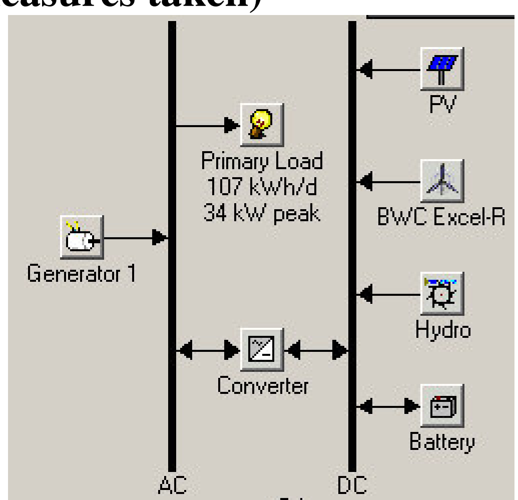


Figure 26: Proposed hybrid energy system

The system component costs were determined from the manufacturers' websites. Figure 26 shows the proposed hybrid energy system for Battle Harbour. Figure 27 shows a list of various combinations that the Homer software considered. Homer suggested the hybrid system should consist of two BWC Excel-R wind turbines, a 3.7kW pico-hydro unit, 13kW (8kW+5kW) diesel generator, a battery bank consisting of 24, 6V Trojan L-16 batteries and two 5.5kW inverters. Initial cost of such a system would be about C$134,000 and it would result in a renewable energy fraction of 64%. Such a system would reduce diesel consumption from the present level of 30,000L/year to 13,000L/year. The expected electrical performance of this system is shown in figure 28. In such a hybrid system the wind turbine contribution would be 50%, hydro contribution 14% and 36% of the electricity will come from the smaller diesel generator. Excess electricity will be about 48% and that might be used for heating buildings. This high excess electricity is due to the site shut down. The cost of the energy will be $1.072 per kWh. That is much lower than the present cost. These costs were calculated with an assumption that a 25year loan would be taken at an interest rate of 8%. Expected daily electrical performance of the proposed system is shown in figure 29. Figure 30 shows expected costs of the system.

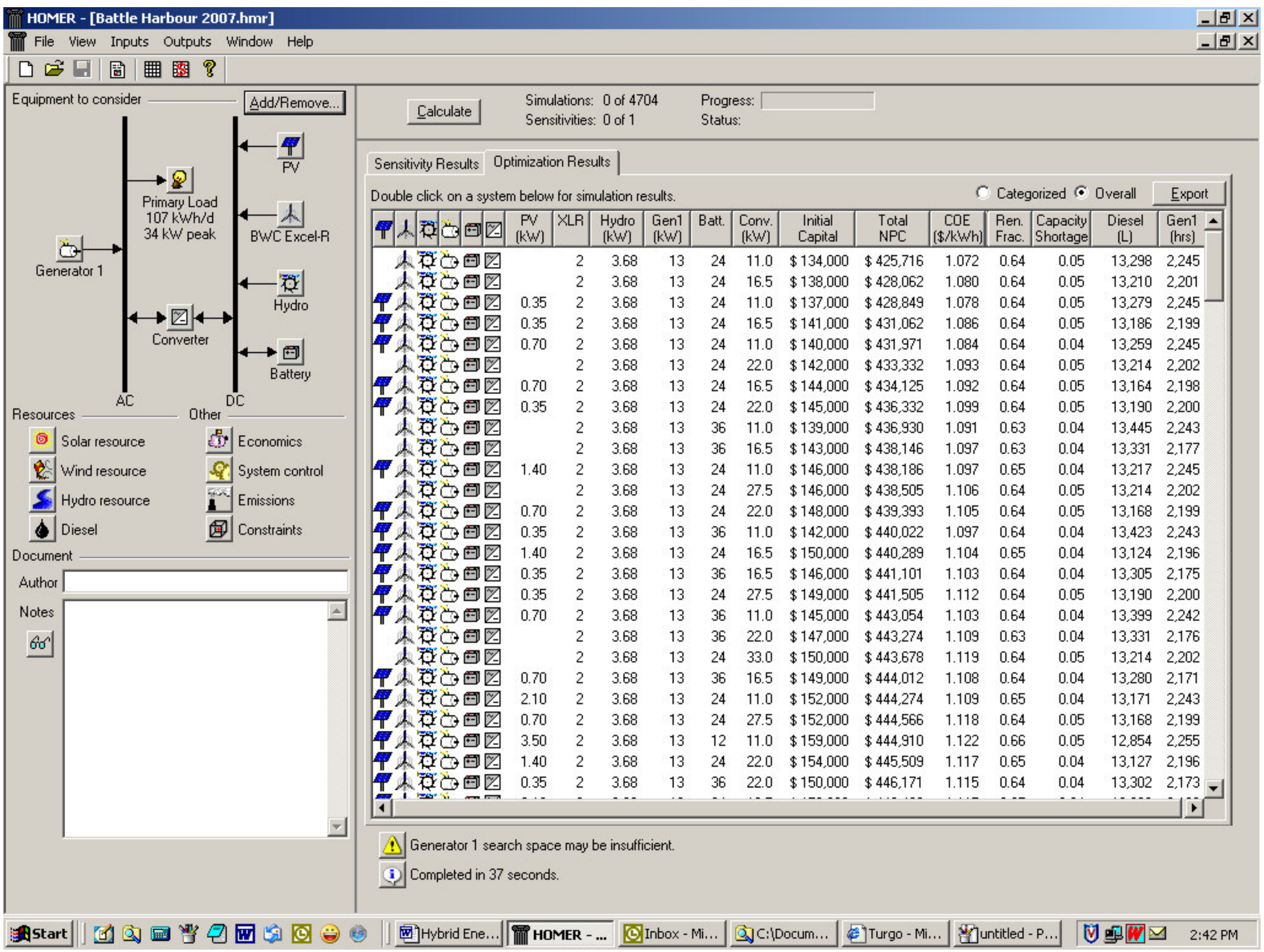


Figure 27: Homer optimization results.

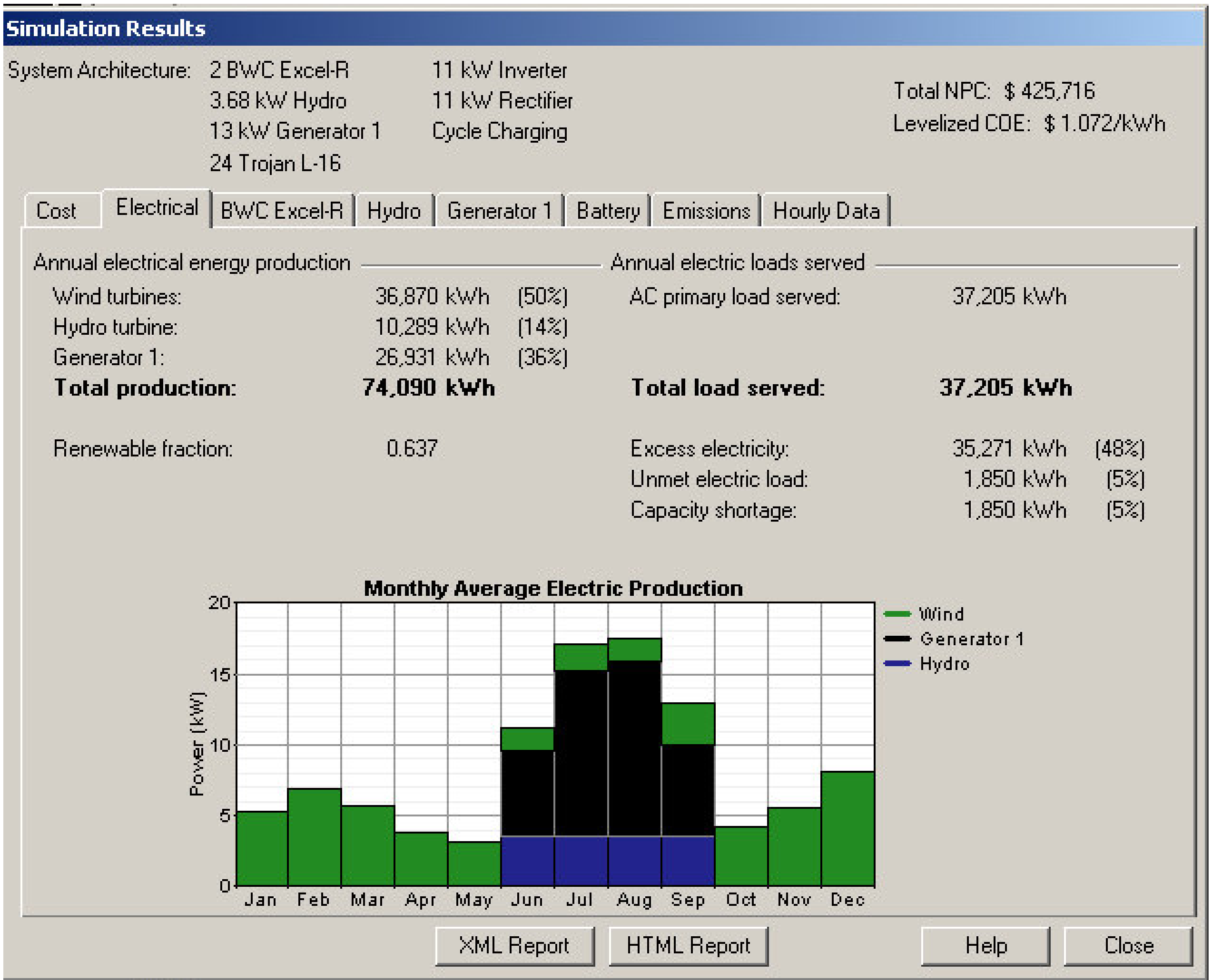


Figure 28: Expected electrical performance of the proposed hybrid energy system for Battle Harbour

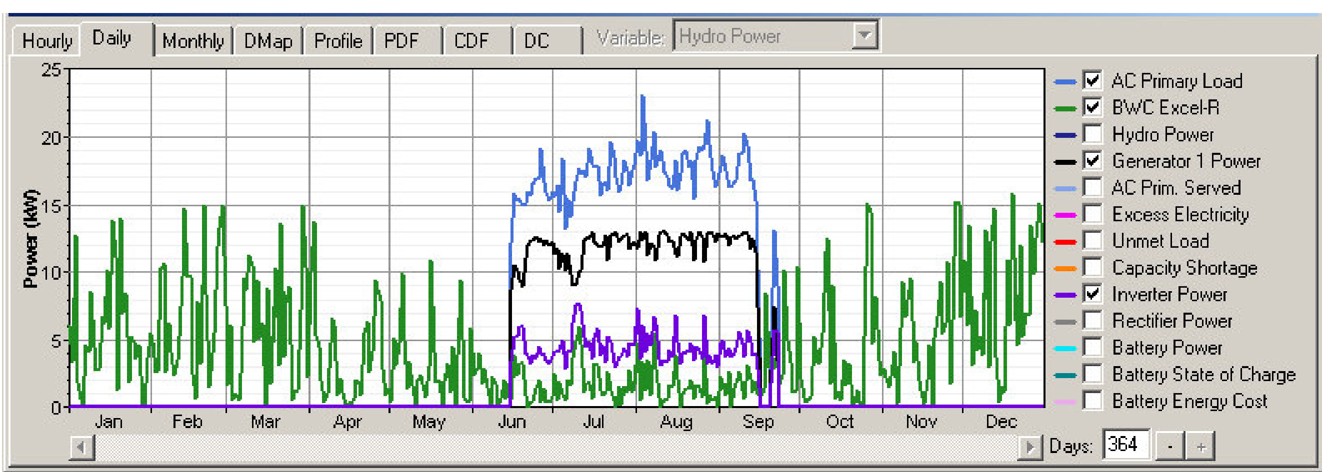
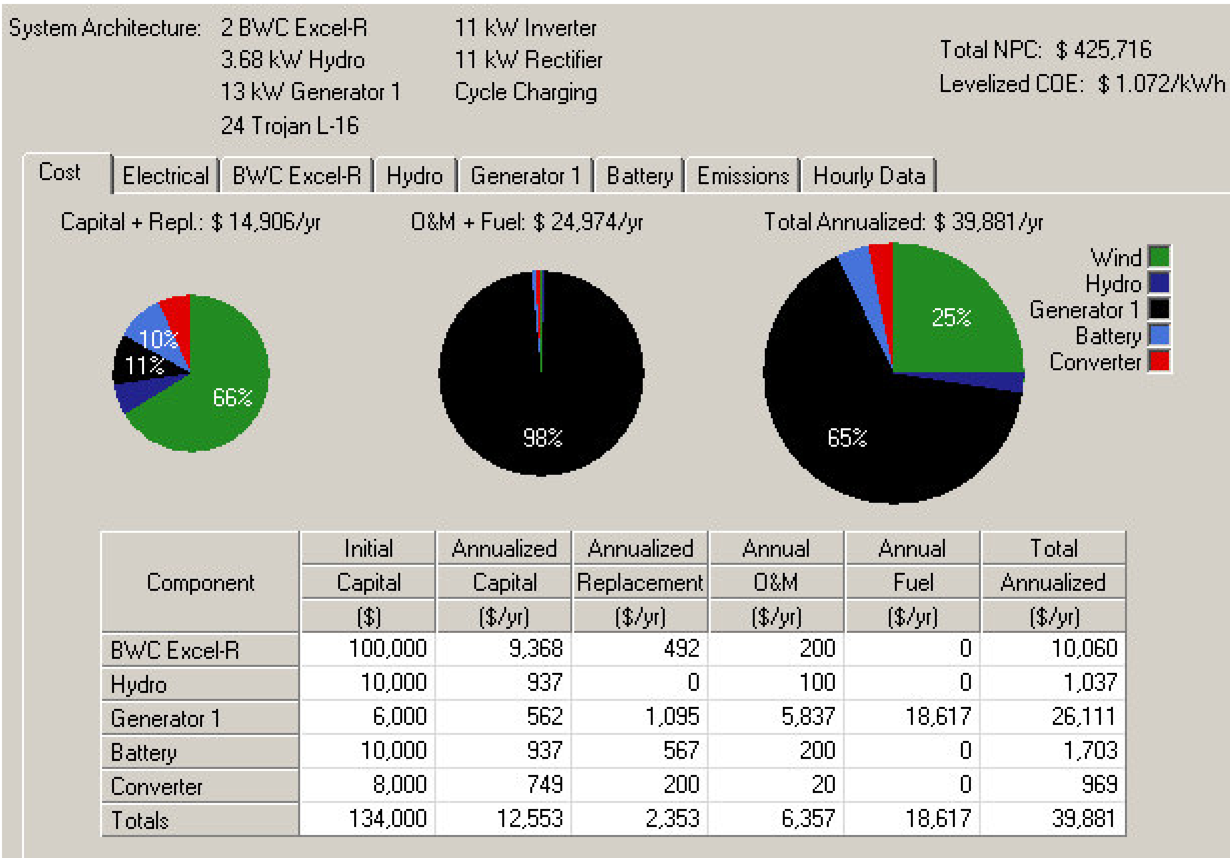


Figure 29: Expected daily electrical performance of the proposed hybrid energy system for Battle Harbour



Component	Initial Capital ($)	Annualized Capital ($/yr)	Annualized Replacement ($/yr)	Annual O&M ($/yr)	Annual Fuel ($/yr)	Total Annualized ($/yr)
BWC Excel-R	100,000	9,368	492	200	0	10,060
Hydro	10,000	937	0	100	0	1,037
Generator 1	6,000	562	1,095	5,837	18,617	26,111
Battery	10,000	937	567	200	0	1,703
Converter	8,000	749	200	20	0	969
Totals	134,000	12,553	2,353	6,357	18,617	39,881

Figure 30: Expected costs of the proposed hybrid energy system for Battle Harbour

Case #2: (Energy conservation measures are taken and load is reduced by 50%)

We believe that with some effort energy consumption at Battle Harbour can be reduced by 50%. As mentioned above thisit can be done by replacing all light bulbs with energy savers and using light sensors and timers to automatically switch off lights when they are not needed. With this assumption the Homer optimization procedure was repeated. Results are shown in figures 31 to 33. Homer suggested the hybrid system should now consist of one BWC Excel-R wind turbines, a 3.7kW pico-hydro unit, one 5kW diesel generator, a battery bank consisting of 12, 6V Trojan L-16 batteries and one 5.5kW inverter. Initial cost of such a system would be about C$70,200 and it would result in a renewable energy fraction of 74%. Such a system would reduce diesel consumption from the present level of 30,000L/year to only 5,000L/year. The expected electrical performance of such a system is shown in Figure 32. In such a hybrid energy system, the wind turbine contribution would be 48%, hydro contribution 27% and 26% of electricity would come from the smaller 5kW diesel generator. Excess electricity would be about 49%. The cost of energy would be $0.909 per kWh. These costs were calculated with an assumption that a 25year loan would be taken at an interest rate of 8%.

The Homer optimization described above shows that installation of a pico-hydro unit is essential, but that use of photovoltaics is not recommended for the Battle Harbour. The site can use other nearby ponds on Caribou Island to increase its hydro capacity. With a reduced load one small 7.5kW wind turbine would be needed. Figure 33 shows the expected cost of a hybrid energy system when load is reduced by 50%.

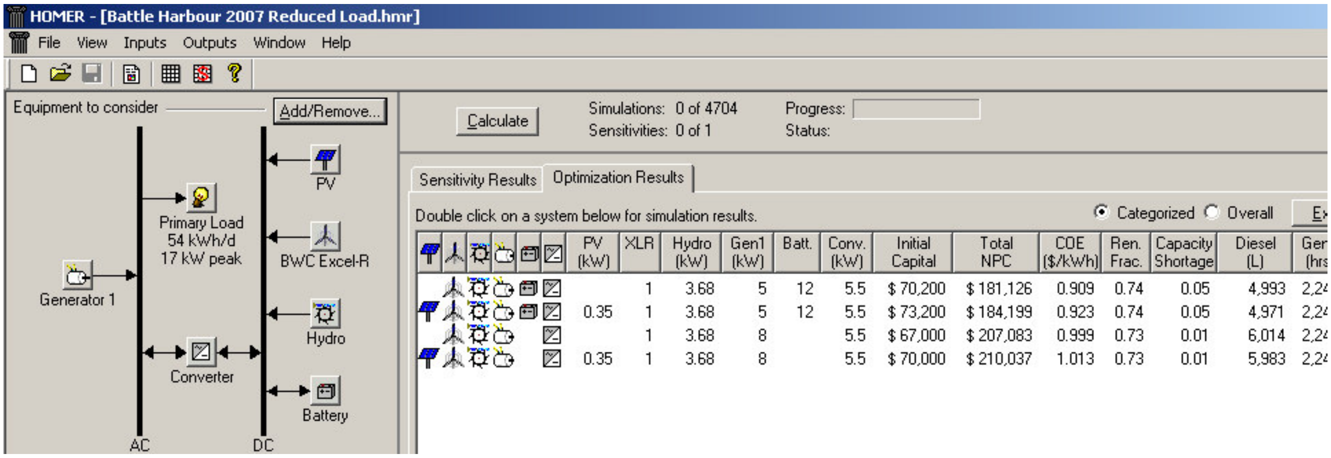


Figure 31: Homer optimization results with a reduced load.

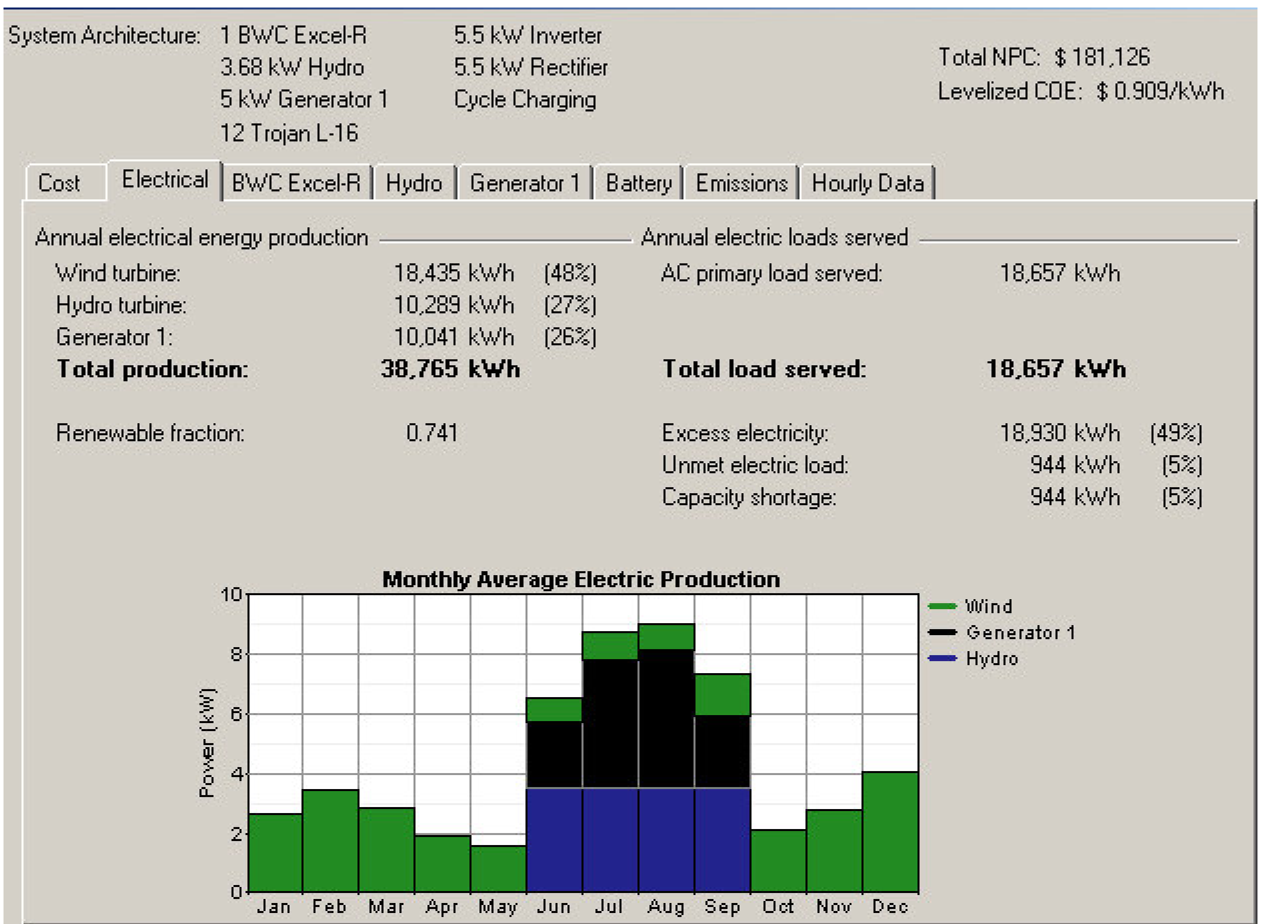
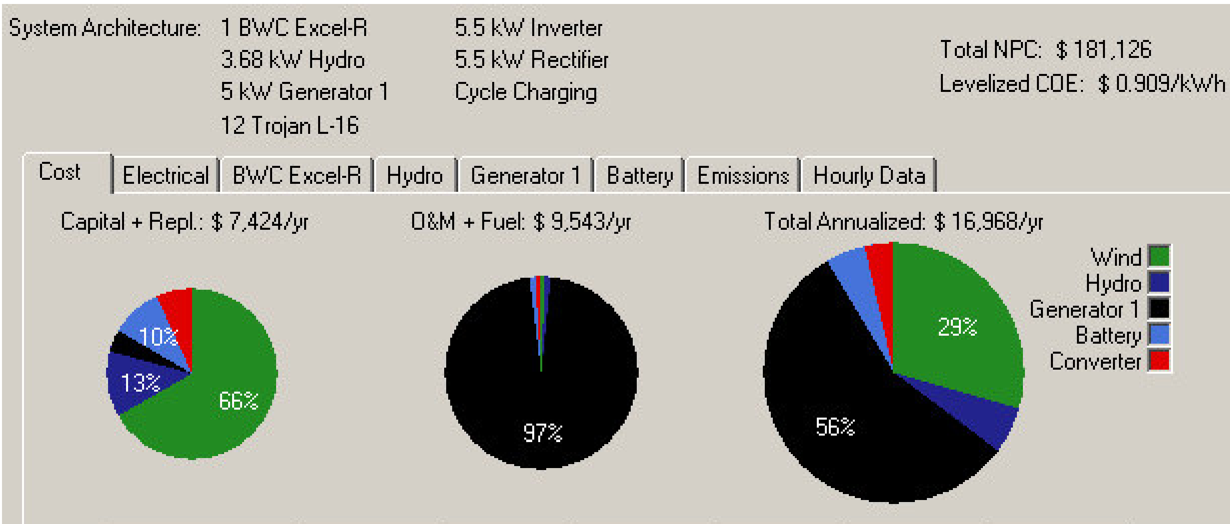


Figure 32: Expected electrical performance of the reduced load hybrid energy system.



Component	Initial Capital ($)	Annualized Capital ($/yr)	Annualized Replacement ($/yr)	Annual O&M ($/yr)	Annual Fuel ($/yr)	Total Annualized ($/yr)
BWC Excel-R	50,000	4,684	246	100	0	5,030
Hydro	10,000	937	0	100	0	1,037
Generator 1	1,200	112	219	2,243	6,990	9,565
Battery	5,000	468	283	100	0	852
Converter	4,000	375	100	10	0	485
Totals	70,200	6,576	848	2,553	6,990	16,968

Figure 33: Expected costs of the proposed reduced load hybrid energy system for Battle Harbour.

Some Recommendations for Battle Harbour:

The above hybrid energy system sizing exercise indicates that a hybrid system is possible for Battle Harbour and it would greatly reduce the diesel consumption. Battle Harbour is open only for a few months in a year to visitors from all across Canada and internationally. Such an investment may attract more visitors to the site. The main issue at Battle Harbour is the high cost of fuel consumed. Many actions could be taken to reduce the Battle Harbor fuel consumption even within the existing system. These actions do not need any large investment and we believe these will result in a large reduction in the fuel cost at Battle Harbour. Based on our observations at Battle Harbour and analysis of the on-site recorded one-year renewable resources data, we have the following comments and suggestions:

- The wind resource at Battle Harbor, at the lower village location, during the summer is significant (annual average 6m/s). On the hilltop location the resource is higher, but there are problems of installation. The available wind resource is very gusty and not good for an AC wind turbine operation that is running in parallel with a diesel generator. Battery charging wind turbines run in variable speed mode with the varying wind speed. Therefore, we do not see any problem if a DC wind turbine is used along with a battery bank and the other equipment mentioned in figure 32. The solar resource at Battle Harbour is low as expected. However, the hydro resource from Caribou Island looks very promising.

- It is suggested to consider reducing the island lighting load by 50% or more. During our visits we noted that incandescent bulbs are used in all buildings and they remain on 100% of the time. These lights are actually needed for only a few hours a day. Energy saver bulbs/ fluorescent lights could replace all incandescent bulbs and many lights could be on timers/light sensitive switches so that they are used only when really needed. Load reduction is essential before going ahead with a hybrid energy system option.

- Energy efficient appliances should be used and it is suggested to remove/ban use of sources of unexpected large loads such as hair dryers, toasters and floodlights. This is after all an island network where visitors come to experience life as it was in a previous era.

- After the replacement of lights and removal of undesired loads, the new power demand of the island should be re-recorded. We believe it can easily be reduced to 54kWh per day. (50% of present value that is 107kWhr per day.

- The available hydro resource at Battle Harbour should be estimated carefully. This may include a detailed survey of the large pond and other small ponds on Great Caribou Island, collection of rain fall data, calculation of the catchments area of each pond and estimation of costs for the required new pipe.

- **A pico-hydro unit, including piping, will cost only a few thousands dollars and consideration should be given to installing such a unit on the island as soon as possible. In addition to that a battery bank, inverter, a small wind turbine and small diesel generator based hybrid energy system as propose in figure 31 to figure 33 could be implemented.**

- If there are no plans to install a hybrid energy system in the near future then at least the existing large diesel generator should be replaced with 1-2 smaller units to be operated as needed.

- It is also recommended to reconnect the diesel generator such that only one 25kVA transformer is connected to each phase of the generator output. Presently, as shown in figure 3, all three transformers are connected to the same phase. This will reduce generator losses and hence the fuel consumption.

Conclusions:

The renewable energy resources of Battle Harbour were recorded over a year in the period 2006-07. The diesel generator load data of Battle Harbour was also recorded for more than a year. Statistical analysis of the data was done and one-year site renewable resource data is presented in this report. The public domain software Homer, developed by the National Renewable Laboratory USA, was used to size a hybrid energy system for the Island. Two cases were considered. a) a hybrid energy system sizing without any energy conservation, b) a hybrid energy system sizing with 50% reduced load. This research indicates that the available renewable resources at Battle Harbour are significant and hybrid energy would be feasible for the site. Such a system would greatly reduce the fuel consumption and it would likely also lead to more visitors to the historic site (to see the energy system in operation). Suggestions for the proposed hybrid energy system are given in the report. We suggest Battle Harbour should consider implementing an approach to conserve its use of electrical energy more in keeping with its role as a site representing life in a previous era and find money to develop a hybrid energy system at Battle Harbour.

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