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Sizing a Hybrid Power 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. Presently, electricity is generated on Battle Harbour using a diesel generator when the island is populated for 3 summer months per year. Due to its remote location, the fuel cost on Battle Harbour is very expensive. In this research we look into on-site renewable energy resources and conduct a feasibility study of a hybrid power system for Battle Harbour. We present one-year recorded power consumption data, wind, solar energy and hydro resources of the island and discuss options for reducing diesel consumption. Two cases are considered, a) load as usual b) load reduced by 50% after energy conservation measures. The sizing of the hybrid power system for both cases is discussed. This feasibility study indicates that by using a hybrid power system the diesel consumption on the island can be reduced to one sixth of its present annual consumption.

Keywords: Renewable Energy, Wind Energy, Hybrid Power Systems, Renewable Resources

1. INTRODUCTION
Battle Harbour is a restored, 19th century fishing community accessed 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 no longer a permanent community. Community residents, under a government-sponsored resettlement program from 1965 to 1970, relocated to nearby Mary's Harbour. This was due to the replacement of salt-fish operations with fresh and frozen fish industries and the decline in the inshore fishery. In 1990, the site was turned over to the Battle Harbour Historic Trust who has restored few buildings and put on display a collection of more than 500 artifacts related to the fishery and everyday life in the past. Presently, Battle Harbour is a national historic site (open only for three summer months a year) 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). Figures 1 and 2 below show the location and a view of Battle Harbour.

Presently, electricity on Battle Harbour is generated using a diesel generator. Diesel costs are expensive on Battle Harbour due to its location. In 2006 the price was C$1.35 per litre. High diesel cost is the major issue for the Battle Harbour. Battle Harbour has many renewable resources that can be exploited to generate electricity and heat water. These resources include, wind, solar irradiation, ocean waves, ocean currents and rainwater coming down from the ponds on the surroundings hills. A hybrid power 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 [1-5]. In this paper we explore the load demand and renewable resources at Battle Harbour and propose a hybrid power system for the island.

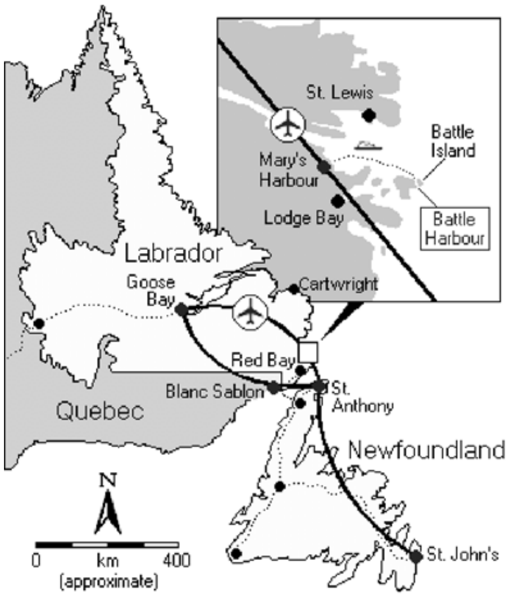

Figure 1. Location of Battle Harbour

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

Battle Harbour's Existing Power System:

Electricity is generated at Battle Harbour using a 75 kW diesel generator. Line to line 600 V from the generator is transmitted to three 25 kVA step down transformers installed close to restored buildings using underground cables. Table 1 below lists some features of the existing power system at Battle Harbour. In summer 2006, another used 60 kW 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 for powering lights and a few appliances used by the employees who live there permanently during the three summer months. Electricity is also used for appliances in the guest residences and to power a few electric heaters if needed. The main heating of all buildings, if needed in the summer, is done using heating oil. Water heating is also done using 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 only. The fuel is transported in barrels and pumped into a larger tank and the cost in Table 1 does not include some of the boat transportation and handling expenses since these are difficult to separate from the overall site 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 75 kW, 3-phase, 1800 rpm, 600 V_{l-l}, Exciter 60 V
Model: B503KY-3M50DC-AM
Three, 25 kVA, 600 V to 120-0-120 V 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.
In the 2006 season, about 2000 people visited the site while 11 employees stayed on the island full time.

Table 2. Data loggers installed on the Island in 2006
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 near the generator room.
2) NRG Systems Wind Explorer with wind speed sensor #40 and a 200 series wind vane is installed at a height of 30 feet on the nearby hilltop. It sampled data every 10s but recorded an average value every 10 minutes.
3) 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.

2. 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 Battle Harbour village. Table 2 lists some details of the installed data loggers. The location and the height of one sensor was selected to be 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 easily come to the island via boats. So movement of the 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. The hub height of most small wind turbines is about 20-30 m, therefore, the anemometer height was selected as 80 feet (24.4 m).

Another anemometer and a wind vane (Wind Explorer) were installed on the top of the hill next to Battle Harbour village. It was installed on an old telecommunications tower at a height of about 10 m 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.

To determine power consumption and its variations an ACR logger with three current probes was installed inside the generator control box. All data loggers were installed in June 2006 and they remained in operation until the middle of July 2007.

3. AVAILABLE RENEWABLE ENERGY RESOURCES:

We collected site data from June 20, 2006 to July 15, 2007. Table 3 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 3.) for 2006-07 indicates a much smaller wind resource near the generator room. NASA predicted yearly average insolation values incident on a horizontal surface of 2.9 kWh/(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 3 and 4. Obviously the hilltop wind speed is greater than wind speed in the village. Note the sudden variations in the wind speed. On the hilltop, on August 7, 2006, the wind speed increased from 7m/s to 17m/s within a few minutes. Many other similar events can be noted in figures 3 and 4. The hilltop anemometer recorded wind speed standard deviation between each 10-minute recording interval. It indicates that the 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 5 to figure 10. The load current data gap in figure 8 is due to the site shut down in winter. The data gap in figure 10 is due to a battery failure.

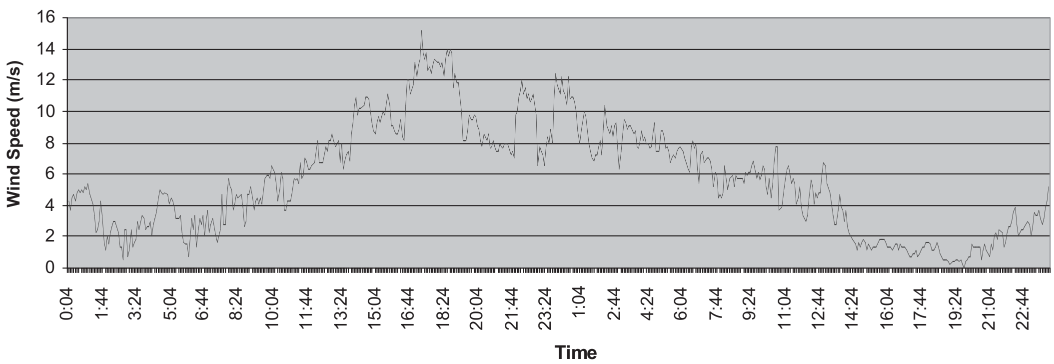

Figure 3. Battle Harbour village wind speed data of August 7 and August 8, 2006

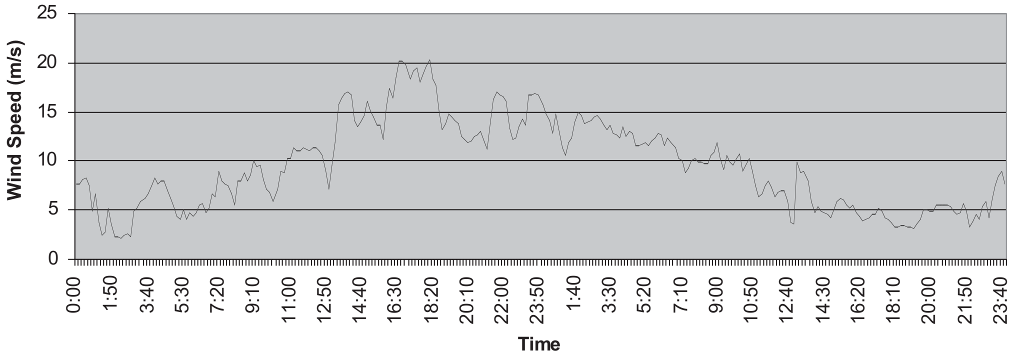

Figure 4. Hilltop wind speed data of August 7 and August 8, 2006

Table 3: A summary of data recorded at Battle Harbour
Average wind speed at a height of 80 feet = 6.0 m/s (sensor accuracy +/- 0.5m/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 m/s
Average hilltop wind speed at a height of 30 feet = 6.8 m/s (missing data)
Hilltop wind speed standard deviation = 4.86 m/s
Maximum Hilltop average wind speed at a height of 30 feet = 26.8 m/s
Annual Average Solar Irradiance = 2.83 kWh/ (m2 day)
Average Solar Radiation = 118 W/m2
Maximum Solar Radiation = 1271.9 W/m2
Average Temperature = 1.4 ˚C
Minimum temperature = -24.3 ˚C
Maximum temperature = 27.1 ˚C
Battle Harbour Average Power Consumption from June 17, 2006 to September 12, 2006 (site open season) = 17.4kW
Maximum Load from June 17, 2006 to September 12, 2006 = 36kW

A summary of load current data is provided in Figure 11. Note that only two phases are being used and the load on the generator is unbalanced. The average current drawn from the generator is about 30A. Therefore the average power consumption at Battle Harbour is about 600Vx30A → 18kW. Presently a 75 kW diesel generator is operating continuously day and night. The maximum current drawn from the diesel generator was almost 60 A. Hence the instantaneous maximum load was about 36 kW. This indicates that most of the 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 [7]. This indicates that the generator being used at Battle Harbour is too large for the site. Figure 12 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.

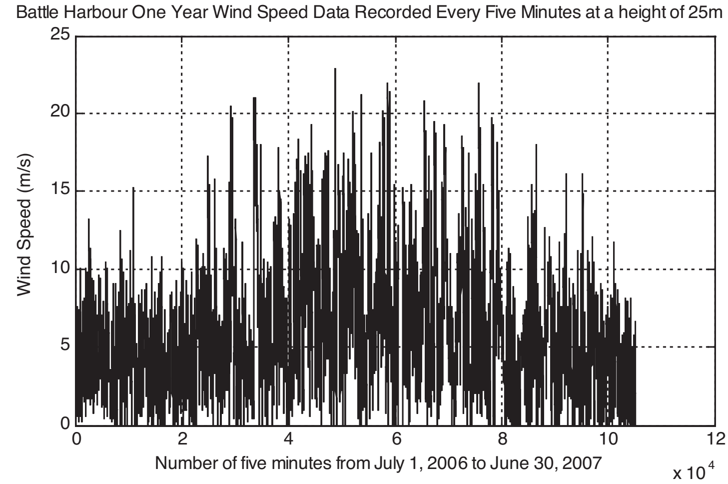

Figure 5. One-year wind speed data in Battle Harbour.

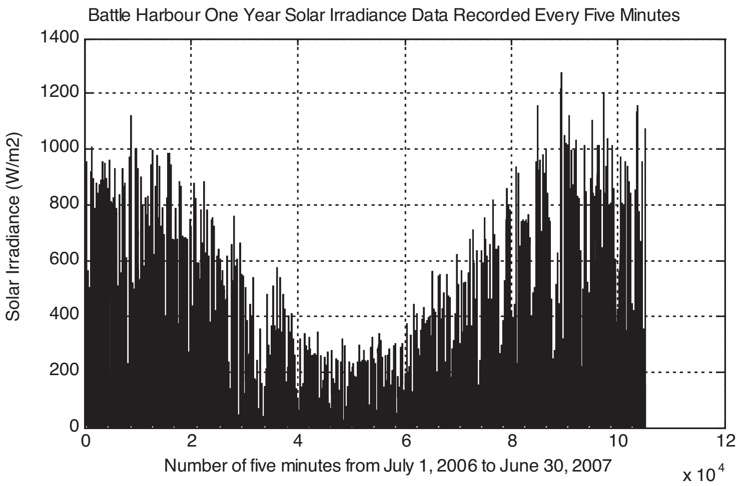

Figure 6. One-year solar radiation data in Battle Harbour.

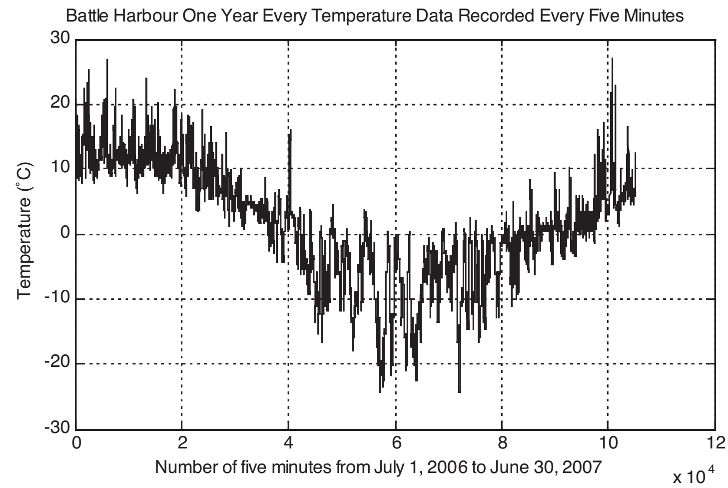

Figure 7. One-year temperature data in Battle Harbour.

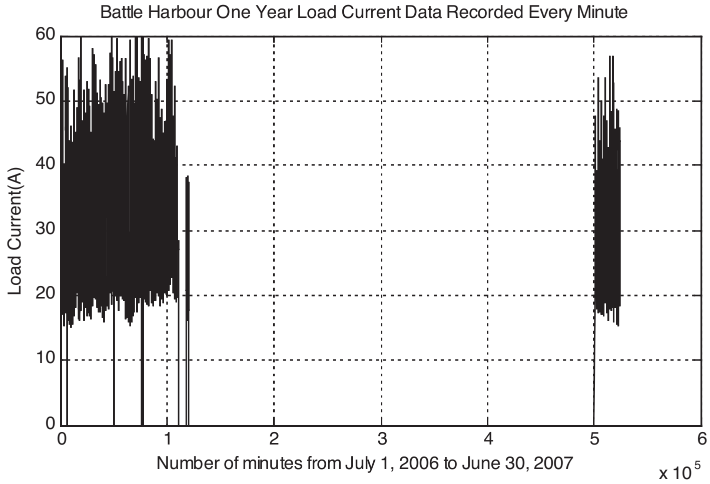

Figure 8. One-year load current data in Battle Harbour.

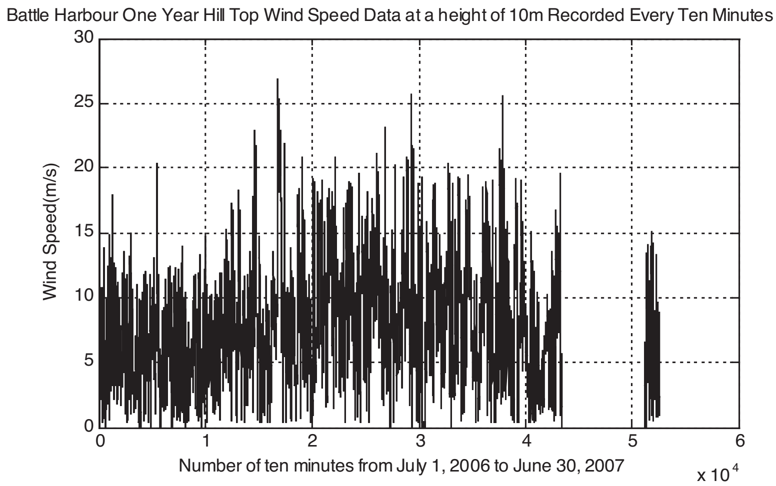

Figure 9. One-year hilltop wind speed data in Battle Harbour. (Missing data is due to a dead battery)

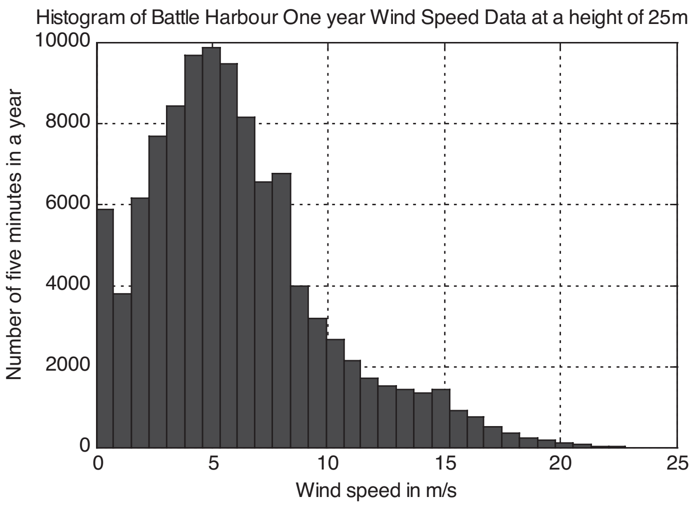

Figure 10. Histogram of one-year wind speed raw data.

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

Description	Low	Mean	High	Range	Units
Temperature	9.85	23.89	35.45	25.60	°C
Phase A	0.00	29.10	59.85	59.85	A
Phase B	0.00	31.22	59.57	59.57	A
Phase C	0.00	3.66	5.80	5.80	A

Figure 11. Generator currents summary for the summer 2006

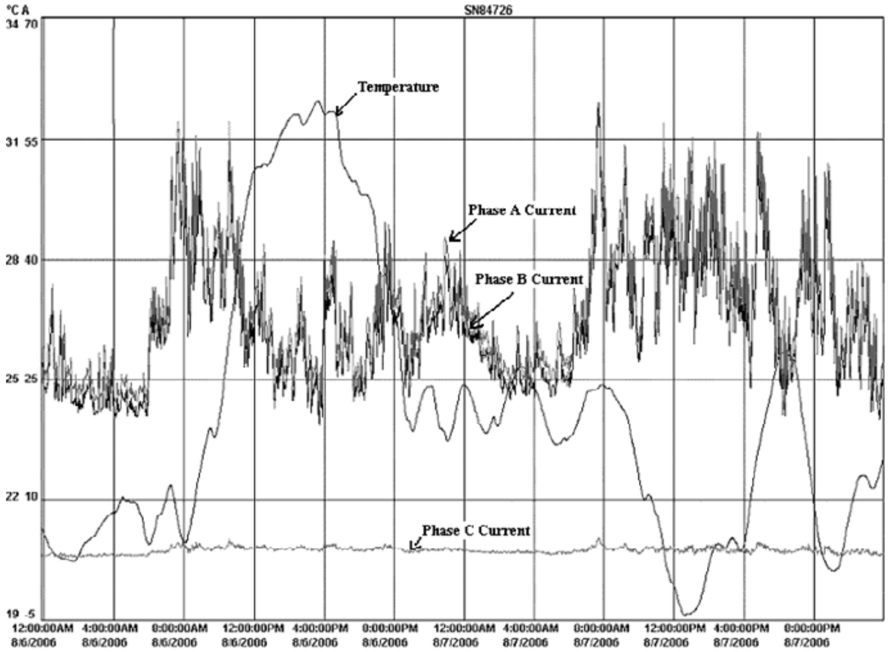

Figure 12. Typical generator current variations during two summer days

Site raw data was formatted such that it starts from January 1 and ends at December 31. Formatting and basic data analysis was done using Matlab. Hourly data averages were calculated so that they could be used in the program HOMER. Homer is a hybrid energy system optimization program developed by National Renewable Energy Laboratory USA [6]. 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 1.5 m/year (assuming the same value as Newfoundland). We explored Battle Harbor and the neighboring Great Caribou Island for possible hydro resources (see figure 13). There are no ponds on Battle Harbour, but there is a large pond on Great Caribou Island. It is at about 50 m height, 600 m meters away from Battle Harbour and is used for drinking water at Battle Harbour. Figure 13 shows a Google satellite photo. The pond is about 200 m long and 100 m 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 65 psi indicating a head of 50 m.

Assuming a mean pond depth of 5 m, 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. A new 4” water pipe could be laid down to run a pico-hydro unit capable of producing about 4 kW. Such a pico-hydro unit would need a flow rate of 10 L/s. The pond could supply this much flow rate for three months of 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. The pico-hydro drain could be used for drinking water on the island. An accurate survey of the pond, the catchment area assessment and rainfall data is needed to confirm these assumptions.

4 PROPOSED HYBRID ENERGY SYSTEM

The above section indicates that the 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 14. Sizing of a hybrid system can be done using Homer [5, 6]. 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. We believe that by replacing all incandescent lighting with compact fluorescent energy saving lights and LEDs, and replacing, or removing, some appliances can make this possible. We also assumed that the existing diesel would be replaced with smaller units.

4.1 Case #1: (No energy conservation measures taken)

It was assumed that a new turgo type stream turbine would be installed on the island and that the flow rate through that turbine would be 10 L/s at a head of 50 m. 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 7.5 kW wind turbines were selected as part of the option. The system component costs were determined from the manufacturers' websites. Figure 14 shows the proposed hybrid energy system for Battle Harbour. Figure 15 shows a part list of various combinations that the Homer software considered.

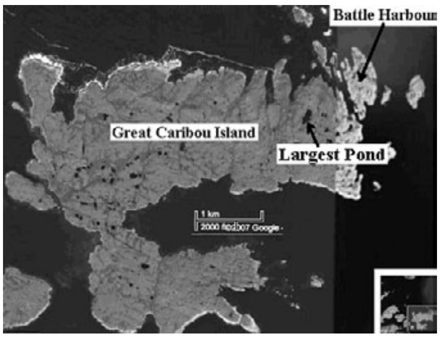

Figure 13. Battle Harbour and nearby Caribou Island

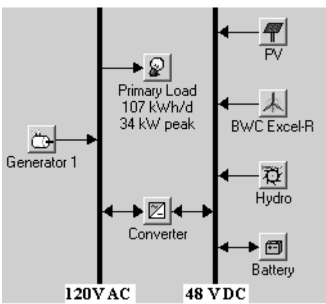

Figure 14. Proposed hybrid energy system

Homer proposed that the hybrid system should consist of two BWC Excel-R wind turbines, a 3.7 kW pico-hydro unit, 13 kW (8kW+5kW) diesel generator, a battery bank consisting of 24 x 6V Trojan L-16 batteries and two 5.5 kW inverters. Initial cost of such a system would be about C$134,000 (In July 2006, Canadian dollars C$1= US $0.97 = Euro 0.70)) and it would result in a renewable energy fraction of 64%. Such a system would reduce diesel consumption from the present level of 30,000 L/year to 13,000 L/year. The expected electrical performance of this system is shown in figure 16. In such a hybrid system the wind turbine contribution would be 50%, hydro contribution 14% and 36% of the electricity would come from the smaller diesel generator. The significant surplus electricity is due to the site shut down. Excess electricity would be about 48%, but could be used beneficially for heating buildings and so maintaining their fabric. The cost of the energy would be C$1.07 per kWh, which is less than the present unit cost. These costs were calculated with an assumption that a 25 year loan would be taken at an interest rate of 8%. Expected daily electrical performance of the designed system is shown in figure 17.

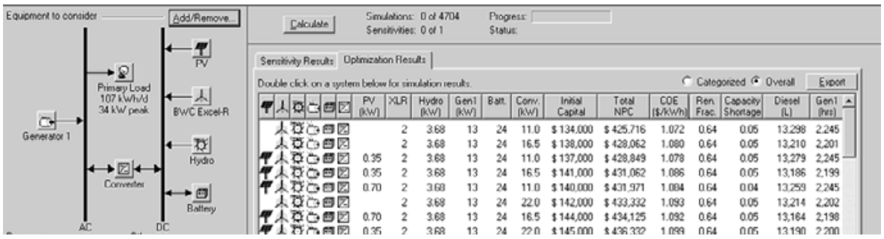

Figure 15. Homer optimization results.

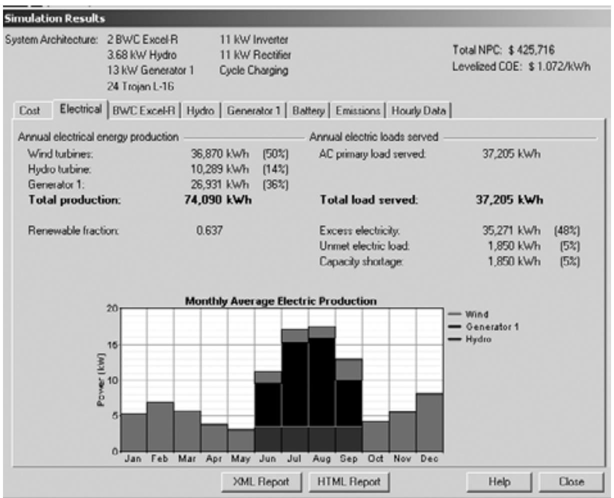

Figure 16. Expected electrical performance of the proposed hybrid energy system for Battle Harbour

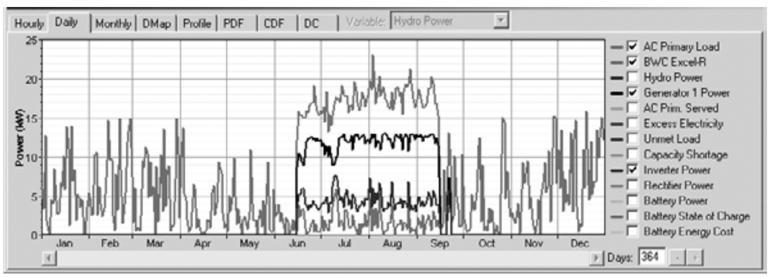

Figure 17. Expected daily electrical performance of the designed hybrid power system for Battle Harbour

4.2 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%. Presently, most of the electricity at Battle Harbour is consumed by the incandescent lamps always kept on in the historic buildings. We noted incandescent lamps are also used in the dinning room, workshop, office, shop, and in guest rooms. The 11 employees of Battle Harbour Trust living on site during the open season also use incandescent lamps at their residences. There is no electricity metering on the island. Other than lighting load, employees have few appliances and electronics. Battle Harbour Management can easily replace all bulbs on the island. We estimate 50% reduction is possible by replacing all light bulbs with compact fluorescent energy saving lamps and LEDs, 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 18 and 19. Homer proposed that the hybrid power system should now consist of one BWC Excel-R wind turbine, a 3.7 kW pico-hydro unit, one 5 kW diesel generator, a battery bank consisting of 12 of 6V Trojan L-16 batteries and one 5.5kW inverter. Initial cost of such a system would be about C$70,000 and it would result in a renewable energy fraction of 74%. Such a system would reduce diesel consumption from the present level of 30,000 L/year to only 5,000 L/year. The expected electrical performance of such a system is shown in Figure 19. 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 5 kW diesel generator. Excess electricity would be about 50%. The cost of energy would be C$0.90 per kWh. Note in figure 17 that, diesel would be running only for three months in a year as needed while renewable energy is not used for 8 months in a year.

The Homer optimization described above shows that installation of a pico-hydro unit is essential, but that use of photovoltaics would not be economical for the Battle Harbour. The site can use other smaller ponds on the nearby Caribou Island to increase its hydro capacity. With a reduced load one small 7.5 kW wind turbine would be needed.

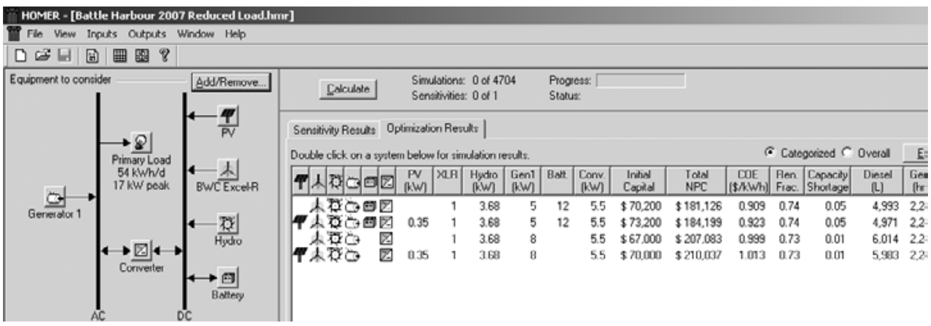

Figure 18. Homer optimization results for the reduced load case.

Data shows that the available wind resource at Battle Harbour 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, a DC wind turbine (such as the Bergey Excel) and a DC micro-hydro are proposed along with a battery bank and the other equipment mentioned in figures 16 and 19.

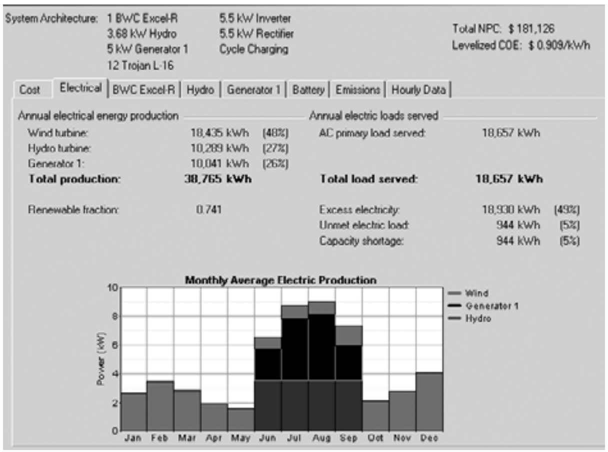

Figure 19. Expected electrical performance of the reduced load hybrid power system.

5 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 the one-year site renewable energy resource data is presented in this paper. The public domain software Homer was used to size a hybrid power system for the Island. Two cases were considered: a) a hybrid power system sizing without any energy conservation, b) a hybrid energy system sizing with 50% reduced load due to the more efficient use of energy. Green house gases emission calculation of the island was not done in this research. This research indicates that the available renewable resources at Battle Harbour are significant and that a hybrid power system 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.

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