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Pre-feasibility study of stand-alone hybrid energy systems for applications in Newfoundland

M.J. Khan*, M.T. Iqbal[1]

Faculty of Engineering and Applied Science, Memorial University of Newfoundland, St John's, Nfld, Canada A1B3X5

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Abstract

A potential solution for stand-alone power generation is to use a hybrid energy system in parallel with some hydrogen energy storage. In this paper, a pre-feasibility study of using hybrid energy systems with hydrogen as an energy carrier for applications in Newfoundland, Canada is explained. Various renewable and non-renewable energy sources, energy storage methods and their applicability in terms of cost and performance are discussed. HOMER is used as a sizing and optimization tool. Sensitivity analysis with wind speed data, solar radiation level, diesel price and fuel cell cost was done. A remote house having an energy consumption of 25 kW h/d with a 4.73 kW peak power demand was considered as the stand-alone load. It was found that, a wind–diesel–battery hybrid system is the most suitable solution at present. However, with a reduction of fuel cell cost to 15% of its current value, a wind–fuel cell system would become a superior choice. Validity of such projection and economics against conventional power sources were identified. Sizing, performance and various cost indices were also analyzed in this paper.

Keywords: Hybrid energy systems; Wind–fuel cell systems; Wind turbines; Pre-feasibility study; Renewable energy; Sizing hybrid energy systems

* Corresponding author. Tel.: +1 709 737 8809.
E-mail addresses: mjakhan@engr.mun.ca (M.J. Khan), tariq@engr.mun.ca (M.T. Iqbal).
[1] Tel.: +1 709 737 8934.

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1. Introduction

Large-scale grid-connected wind turbines have proven to be economically viable in many parts of the world. However, design of small-scale stand-alone power sources for use in remote or off-grid locations is yet to reach a commercially feasible stage [1]. With expected reduction in the component cost and gain in the system performance, attention towards renewable energy alternatives for electric power generation in stand-alone applications is gaining momentum all over the world. Wind and solar energy technologies are the forerunners amongst various types of renewable sources [2].

One of the major requirements for a hybrid energy system is to ensure continuous power flow by storing excess energy from the renewable source. Although, battery technology has reached a very suppurate stage, size, cost and disposal are the constraining factors for its use in remote stand-alone applications. Battery self discharge is a major issue in cold Canadian environment. Recent advancements in fuel cell and electrolyzer technology have opened up the option for using hydrogen as an energy storage medium. A hybrid energy system based on such alternative technologies operating in parallel with a renewable source may prove to be a solution for small-scale power generation [1,2].

Since the performance of a hybrid energy system is highly dependant on the environmental conditions, a site-specific analysis is required to investigate the associated cost, component size and overall economics. In this paper, a pre-feasibility study is done for St John's, NL, Canada. A search for accurate wind speed and solar irradiation data yielded St John's Airport (47°37′N–52°44′W) region to be an ideal place for investigation. The sub-urban site considered here might not be feasible for a stand-alone system. However, sensitivity analysis is done with the wind and solar data and the output parameters are expressed as functions of these variables. It makes the results suitable for identifying technology alternatives for almost all parts of Newfoundland. Such stand-alone hybrid energy systems may find applications in remote lodges, telecommunication installations, recreational facilities, etc.

National Renewable Energy Laboratory (NREL)'s, Hybrid Optimization Model for Electric Renewables (HOMER version 2.09) has been used as the sizing and optimization software tool. It contains a number of energy component models and evaluates suitable technology options based on cost and availability of resources [4]. Analysis with HOMER requires information on resources, economic constraints, and control methods. It also requires inputs on component types, their numbers, costs, efficiency, longevity, etc. Sensitivity analysis could be done with variables having a range of values instead of a specific number. This allows one to ascertain the effects of change in a certain parameter on the overall system.

Various combinations of diesel generator, wind turbine, PV array, fuel cell, electrolyzer, battery, and power converter modules were taken into account towards identifying an economic solution that would meet a given load. In addition to renewable primary sources (wind and solar), a more conventional fossil fuel based system (diesel generators) was considered. Use of other renewable sources such as, micro-hydro, geothermal, biomass, etc. appeared beyond the scope of this work and left for later analysis. Although mostly unexplored, wind resource in Newfoundland is generally categorized as high [3]. On the other hand, it is expected that fuel cell technology would become cheaper and utile in the near future [1,17]. Therefore, emphases have been given in analyzing the size, cost and performance of a wind–fuel cell hybrid system. To widen the search space, each of these components had provisions to have more than one unit for inclusion in the optimum solution. Along with wind speed and solar irradiation data, fuel cell cost and diesel price were also taken as sensitivity variables. Care has been taken not to consider additional sensitivity variables, as this increases the simulation time in a geometric manner.

It was found that, for St John's, Newfoundland use of wind resource is more economical than solar energy. At present, a wind-diesel-battery hybrid system is the most suitable solution for remote sites (without considering micro-hydro, geothermal, etc.). However, with a reduction of fuel cell cost to 65% of its current value, wind–fuel cell–diesel–battery systems would become a superior choice. Need for diesel generators and batteries could be eliminated and a wind–fuel cell system would be feasible if fuel cell cost reduces to 15% of the present market price. Sizing, performance and various cost indices are also analyzed.

2. Hybrid energy system

A hybrid energy system generally consists of a primary renewable source working in parallel with a standby secondary non-renewable module and storage units. Fig. 1 outlines a general scheme of a stand-alone small power generation system.

Fig. 2 shows the proposed scheme as implemented in the HOMER simulation tool. The hydrogen storage tank is considered within the electrolyzer model. Supply of hydrogen to the fuel cell is set such that stored hydrogen in the tank is used only, without requiring additional fuel supply. Several additional units such as compressors in fuel cell and hydrogen storage, dc–dc converters in PV modules and fuel cell, are assumed lumped within each corresponding model.

The general scheme outlined in Fig. 1 is reflected in the HOMER model (Fig. 2). Additional information for load, resources, etc. are described in the following sections.

2.1. Electrical load

A survey was conducted to identify energy consumption in a typical grid-connected house in Newfoundland against various off-grid installations around Canada [5–9].

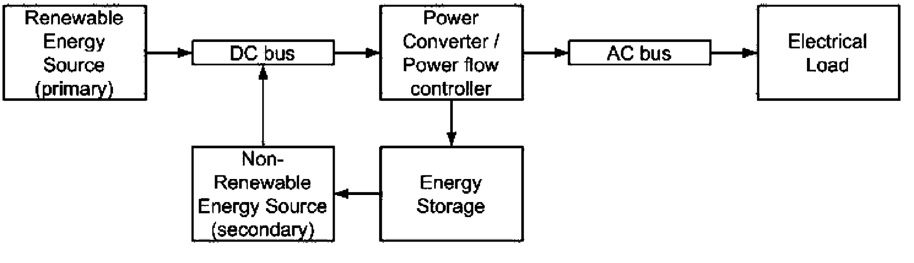


Fig. 1. General scheme of a stand-alone hybrid power system.

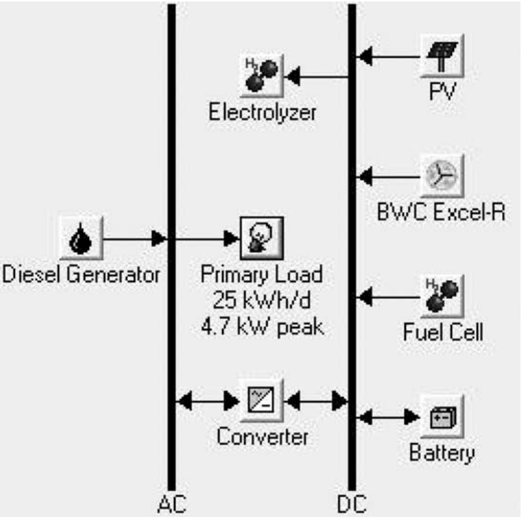


Fig. 2. HOMER implementation of the hybrid energy system.

An ordinary house in St John's, Newfoundland may consume around 50 kW h/d with a peak demand of nearly 11 kW [5]. Meeting such a load by only renewable or hybrid energy source is not practical, especially in a city area. Various energy saving schemes and housing standards [10], need to be considered when building an off-grid house. Remote houses, lodges or resorts built with such attributes may use as low as 10–15 kW h/d with 1–5 kW peak demand [6,7,9]. For a telecommunication installation, 21 kW h/d with 1 kW peak power may prove to be sufficient [8].

A set of energy consumption data for a typical grid-connected house in St John's was collected [11]. This data was sampled every 15 min for 365 days of a year. For this study, the total energy consumption is scaled down to 25 kW h/d (with a 4.73 kW peak) to realize the off-grid nature of a remote house.

For a typical day energy consumption is higher in the morning and evening hours (Fig. 3). On the other hand, winter months (November to March) show an elevated power demand in comparison with the summer months (April to September). For this given load profile, hourly and daily variations are 42.7 and 16.45%, respectively.

2.2. Renewable resources

Wind and solar energy resources of St John's are considered for this study. Sensitivity analysis is done to make the results suitable for other places in Newfoundland.

2.2.1. Wind energy resource

A monthly average wind dataset for St John's Airport (47°37′N–52°44′W) was collected from Environment Canada Climate normals [12]. This is an average of 49 years (from 1942 to 1990) and indicates that annual average wind speed in St John's to be 6.64 m/s.

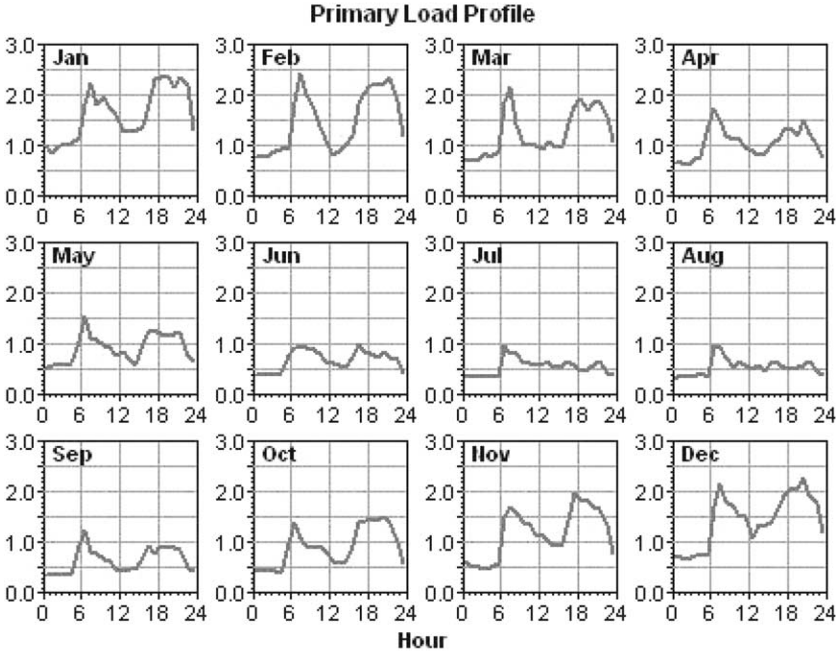


Fig. 3. Daily load profile for a year.

For implementation in HOMER, 8760 data points for each hour in 1 year is required. Therefore, another set of data containing hourly average wind speed for 365 days of a year (1998–1999) was collected from the Environment Canada's Regional office. Proper scaling was done to match the long-term average (Table 1) with this 1-year data.

For this given data, Weibull distribution factor (a measure of the distribution of wind speeds over a year) is 1.961 (Fig. 4). The autocorrelation factor (randomness in wind speed) is found to be 0.86. The diurnal pattern strength (wind speed variation over a day) is 0.07435 and the hours of peak wind speed is 13.

Average wind speed in the winter season is slightly higher than the summer as shown in Fig. 5. For sensitivity analysis, four levels of wind speed data were introduced around the annual average monthly wind speed of 6.64 m/s. These are: 3, 4.5, 6.64, and 8 m/s. This range of variation appeared sufficient to consider wind power classes almost any where in Newfoundland [3].

2.2.2. Solar energy resource

Hourly solar irradiation data for the year 1998–1999 was collected from Environment Canada's regional office. Scaling was done on this data to consider the long-term average annual resource (3.15 kW h/m^2/d) for St John's [12]. HOMER introduces the clearness index from the latitude information of the site under investigation (Fig. 6).

Sensitivity analysis is done with three values around the mean, which are: 1.5, 3.15, and 5.0 kW h/m^2/d.

Table 1
Wind data for St John's Airport

	January	February	March	April	May	June	July	August	September	October	November	December	Year
Speed (m/s)	7.78	7.5	7.22	6.67	6.11	6.11	5.83	5.83	5.83	6.39	6.95	7.5	6.64
Most frequent direction	W	W	W	W	W	SW	SW	SW	W	W	W	W	W

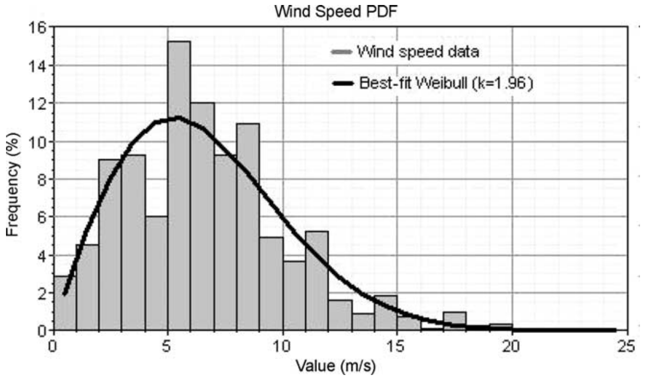


Fig. 4. Wind speed probability distribution function.

2.3. Hybrid system components

The energy system components are diesel generator, PV module, wind turbine, battery, fuel cell, electrolyzer and power converter. Cost, number of units to be used, operating hours, etc. need to be specified in HOMER for each of this equipment. Description of these components is given in the following sections.

2.3.1. Diesel generator

The cost of a commercially available diesel generator may vary from $250 to $500/kW [13]. For larger units per kW cost is lower and smaller units cost more. Since the peak power demand is less than 5 kW, in this analysis diesel generator cost is taken as $450/kW (Fig. 7). Replacement and operational costs are assumed to be $400/kW and $0.150/h, respectively.

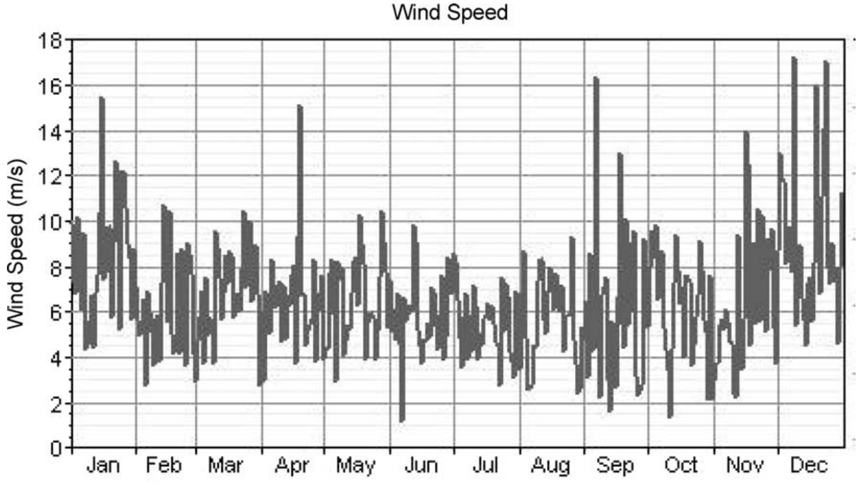


Fig. 5. Average hourly wind speed for 1 year.

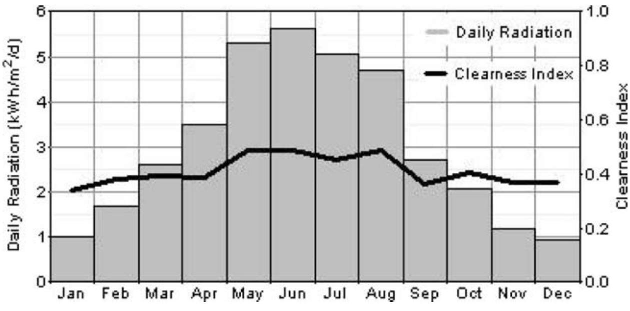


Fig. 6. Average daily radiation.

Options for considering no diesel generator (0 kW) or a 5 kW unit were used in HOMER. Operating lifetime is taken to be 10,000 h [13]. Diesel price is used for sensitivity analysis and three discrete values (0.20, 0.35, and 0.65 $/L) were introduced. At present, diesel price is around 0.35$/L [14] and for a very remote location this could increase up to 0.65$/L [7,8].

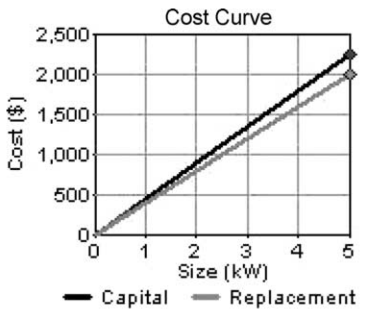


Fig. 7. Diesel generator cost curves.

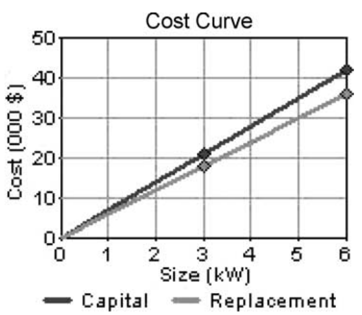


Fig. 8. Cost of photovoltaic units.

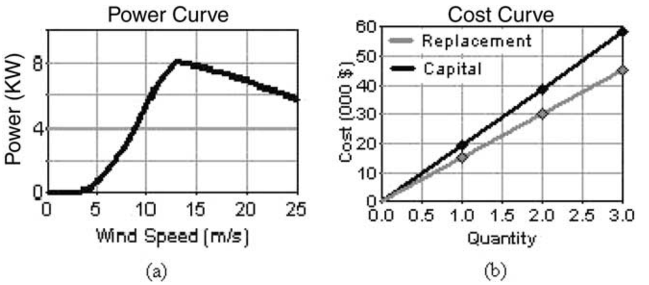


Fig. 9. BWC Excel R/48. (a) Power curve. (b) Cost curve.

2.3.2. Photovoltaic array

The installation cost of PV arrays may vary from \$6.00 to \$10.00/W [13,15]. Considering a more optimistic case [1], a 1 kW solar energy system's installation, and replacement costs are taken as \$7000 and \$6000, respectively [13] (Fig. 8).

Three different sizes are considered, which are 0 (no PV module), 2 and 6 kW. The lifetime of the PV arrays are taken as 20 years and no tracking system is included in the PV system.

2.3.3. Wind energy conversion system (WECS)

Availability of energy from the wind turbine depends greatly on wind variations. Therefore, wind turbine rating is generally much higher compared to the average electrical load. In this analysis, Bergey Wind Power's BWC Excel-R/48 model is considered [16]. It has a rated capacity of 7.5 kW and provides 48 V dc as output.

Cost of one unit is considered to be \$19,400 while replacement and maintenance costs are taken as \$15,000 and \$75/year [16] (Fig. 9). To allow the simulation program find an optimum solution, provision for using 0 (no turbine), 1 or 2 units is given. Lifetime of a turbine is taken to be 20 years.

2.3.4. Fuel cell system

The cost of fuel cell varies greatly depending on type of technology, reformer, auxiliary equipments and power converters. At present, fuel cell costs varies from \$3000 to \$6000/kW [13,17,18]. However, current research and thrust for developing low-cost electric vehicles could reduce the price to \$195–\$325/kW in near future [19]. Considering these factors, the capital, replacement and operational costs are taken as \$3000, \$2500 and \$0.020/h for an 1 kW system, respectively (Fig. 10).

Four different sizes of fuel cells were taken in the search space: 0 (no fuel cell used), 1.5, 3.5, and 5 kW. Fuel cell lifetime and efficiency are considered to be 40,000 h and 50%, respectively. Since the cost of fuel cell is one of the most significant issues in commercializing a hybrid energy system with hydrogen storage, a sensitivity analysis with varying cost is necessary. Here, a set of cost multiplying factors for fuel cell was taken into account (0.05, 0.15, 0.65, and 1.0).

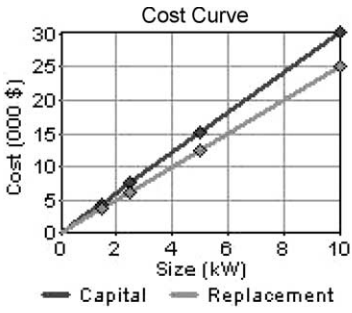


Fig. 10. Fuel cell cost curves.

2.3.5. Electrolyzer

Current production cost of electrolyzers is \$1500–\$3000/kW [13,20]. With improvements in polymer technology, control systems and power electronics it is expected that costs would reduce much in 10 years [13]. In this analysis, a 1 kW system is associated with \$2000 capital, \$1500 replacement and \$20 maintenance cost (Fig. 11).

Different sizes of electrolyzers (0, 2.5, 5, and 7.5 kW) are taken in the model. Lifetime is considered as 25 years with efficiency 75%. Hydrogen storage tanks are also included in the electrolyzer model. Cost of a tank with 1 kg capacity is assumed to be \$1300. The replacement and operational costs are taken as \$1200 and \$15/year [12]. Five different sizes (from 0 to 15 kg) are included, to widen the search space for a cost effective configuration.

2.3.6. Battery

To compare the energy storage capability of the electrolyzer–tank systems, conventional batteries are included in this analysis. Commercially available models, such as Surrette Battery Engineering's Surrette™-6CS25P models (6 V, 1156 Ah, 9645 kW h) are considered in the scheme [21].

Cost of one battery is \$1250 with a replacement cost of \$1100 (Fig. 12). The battery stack may contain a number of batteries (0, 2, 6, 12, or 36).

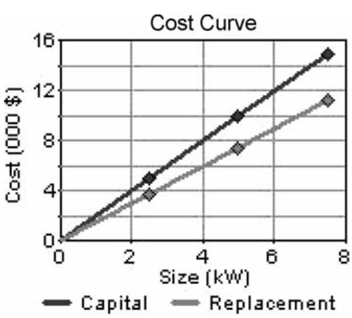


Fig. 11. Electrolyzer cost curves.

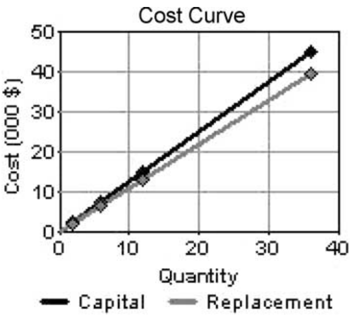


Fig. 12. Cost of battery.

2.3.7. Power converter

A power electronic converter is needed to maintain flow of energy between the ac and dc components. For an 1 kW system the installation and replacement costs are taken as $800 and $750, respectively (Fig. 13).

Three different sizes of converter (1.5, 3.5, and 5.0 kW) are taken in the model. Lifetime of a unit is considered to be 15 years with an efficiency of 90%.

2.4. Economics and constraints

Considering the project lifetime to be 25 years, the annual real interest rate is taken as 8%. For a small sized system, the fixed capital cost is less and it is assumed to be $1500. Since operations and maintenance costs are given in the individual components, a nominal value ($100) is taken for this term. Maximum annual capacity shortage is 1% and operating reserve, as percentage of hourly load is 6.5%. For renewable output, this reserve is 25 and 50% for solar and wind energy, respectively. No cost subsidy available from Canadian government is considered in this study.

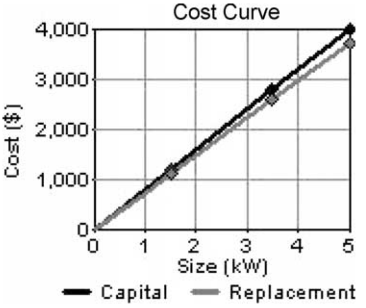


Fig. 13. Converter cost curves.

Table 2
Search space alternatives

	Components						
	PV (kW)	BWC excel R (nos.)	Fuel cell (kW)	Battery (nos.)	Converter (kW)	Electroly-zer (kW)	H_2 tank (kg)
Sizes/numbers	0	0	0	0	1.5	0	0
	2	1	1.5	2	3.5	2.5	2.5
	6	2	3.5	6	5.0	5.0	5.0
			5.0	12		7.5	10
				36			15

3. Sensitivity results

Four sensitivity variables (wind speed, solar irradiation, diesel price and fuel cell cost) are considered in this analysis. To keep provisions for finding suitable system type (combination of technologies) and system configuration (size and numbers of each component), the search space is widened by introducing various alternatives (Table 2).

For each of the sensitivity values HOMER simulates all the systems in their respective search space. An hourly time series simulation for every possible system type and configuration is done for an 1-year period. A feasible system is defined as a solution or hybrid system configuration that is capable of meeting the load. HOMER eliminates all infeasible combinations and ranks the feasible systems according to increasing net present cost. It also allows a number of parameters to be displayed against the sensitivity variables for identifying an optimal system type.

A total of 144 sensitivity cases (product of wind speed (4), solar radiation (3), diesel price (3) and fuel cell cost multipliers (4)) were tested with each of the system configurations. Totally 43,200 systems were simulated for 144 cases and nearly 6.22 million alternatives were examined. Total simulation time was 27 h-12 min on a 2.67 GHz Intel personal computer. Warnings were generated indicating insufficiency in search space for wind turbine, converter, electrolyzer and hydrogen tank. An increase in number of components would have required even longer time without significantly affecting the outcome. Therefore, no further attempts were made to modify the search space.

The optimization results in graphical form are shown in Figs. 14–19. Here, various optimal system types (OST) are displayed as functions of different sensitivity parameters. In Figs. 14–17, these plots are given in terms of wind speed and solar irradiation data. This allows identification of system configuration for various locations around Newfoundland.

Considering present fuel cell cost and diesel price (0.35$/L), a wind/diesel/battery based hybrid system is suitable for stand-alone loads around St John's (Fig. 14). Total net present cost (NPC), Capital cost and cost of energy (COE) for such a system is $48,454, $28,450 and 0.497$/kW h, respectively. For a region with very low wind penetration, a diesel generator/battery system might be suitable. Although the capital cost and NPC are lower for such a system, the COE is much higher ($0.776/kW h).

Fig. 15 represents a scenario where diesel cost is elevated to 0.65$/L, due to remoteness of a site or an unforeseen price hike. Associated costs of hybrid systems are also increased.

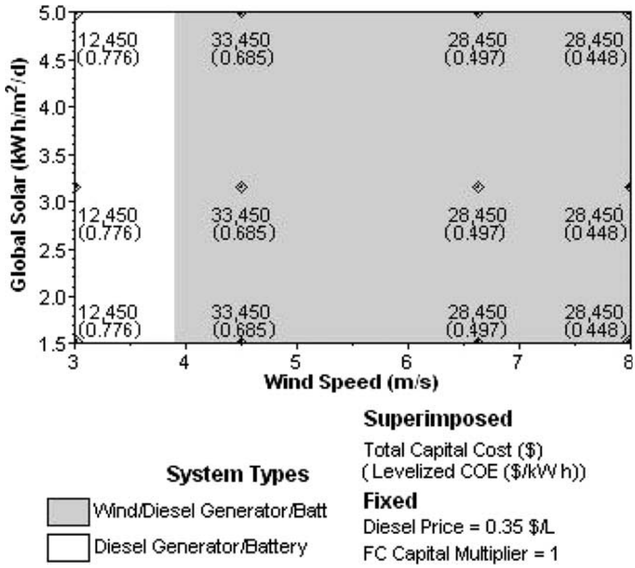


Fig. 14. OST with diesel price = 0.35$/L and FC cost = 100%.

One important observation is that, a photovoltaic based system comes into the picture only when wind resource is very limited, solar energy density is very high and cost of diesel is elevated. For Newfoundland, such a constrained situation is not generally expected. Therefore, utilization of solar energy is not feasible for most remote installations. This observation is reinstated in other OST plots as well (Figs. 14–19). Another conclusion

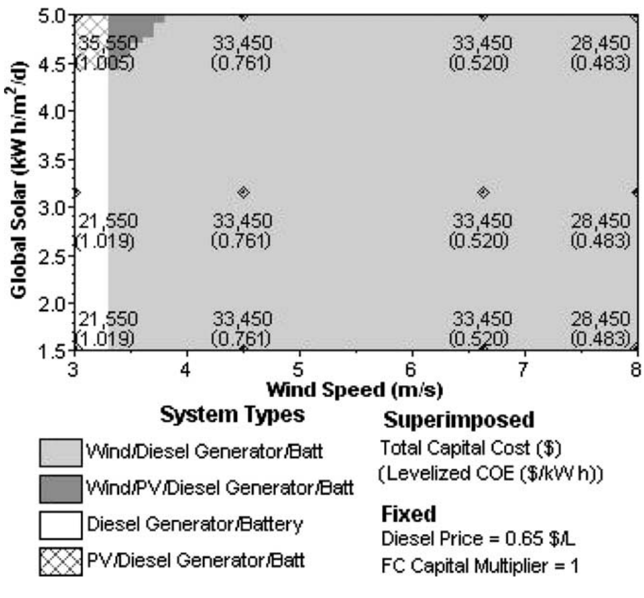


Fig. 15. OST with diesel price = 0.65$/L and FC cost = 100%.

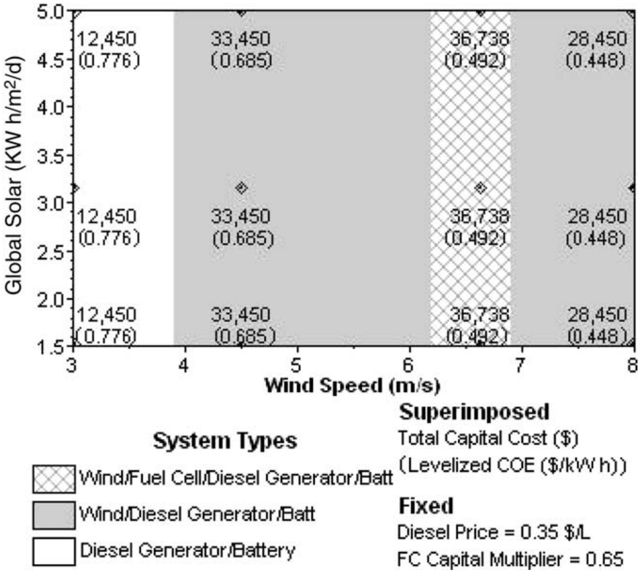


Fig. 16. OST with diesel price = 0.35$/L and FC cost = 65%.

from these figures (Figs. 14 and 15) is that, integration of fuel cells into a hybrid system is not feasible at current market price of the fuel cell systems.

With an expectation that fuel cell costs might reduce in near future [13,19], the observations in Figs. 16 and 17 are done with lower cost levels. A wind/fuel cell/diesel generator/battery system would be preferable for St John's, if the fuel cell cost reduces to

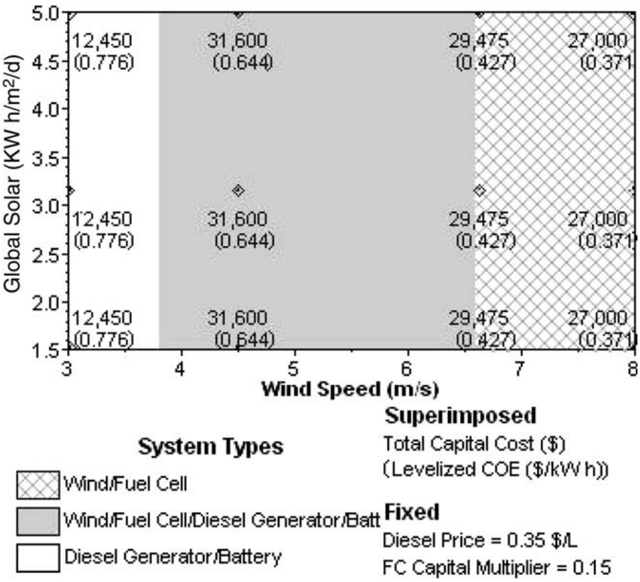


Fig. 17. OST with diesel price = 0.35$/L and FC cost = 15%.

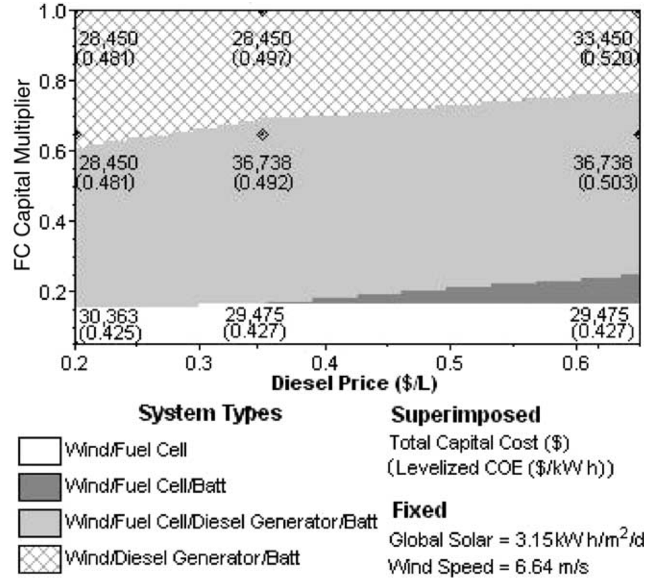


Fig. 18. OST with solar irradiation = 3.15 kW h/m^2/d and wind speed = 6.64 m/s.

65% of its current cost. The capital cost, NPC, and COE for such systems might be around $36,738, $47,910 and $0.492/kW h, respectively.

If the fuel cell cost drops around 15% of its present market price, only a wind/fuel cell system would be sufficient for the remote application being considered in this paper

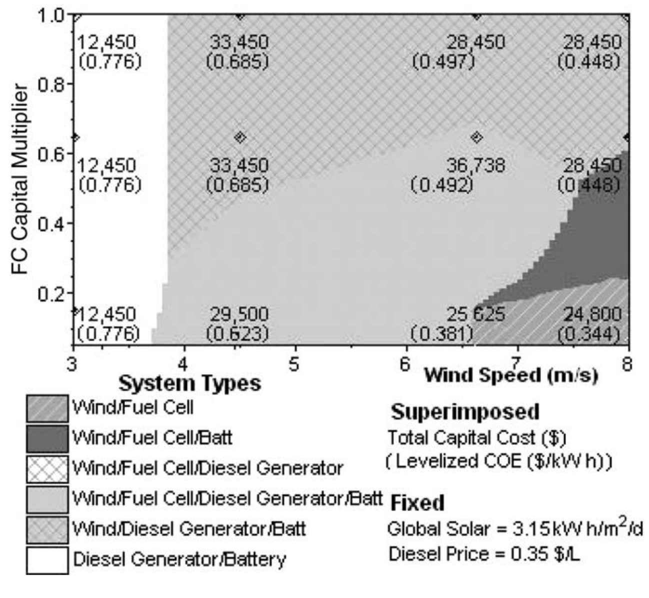


Fig. 19. OST with solar irradiation = 3.15 kW h/m^2/d and diesel price = 0.35$/L.

(Fig. 17). For such a system, the expected capital cost, NPC and COE would be around ($29,475, $41,425, and $0.427/kW h, respectively) depending on the average wind speed.

Selection of an OST is investigated from a different perspective in Fig. 18, where a fixed renewable resource is considered (for St John's only). Diesel price and fuel cell cost multiplier are taken as the sensitivity parameters. Irrespective of diesel price, a wind/fuel cell system would be feasible if the fuel cell cost reduces towards 15% (Fig. 18). This figure stresses the fact that, at present fuel cell cost (65% or above), a wind/diesel generator/battery system is probably the only feasible solution.

In Fig. 19, selection of an OST is outlined as a function of wind speed and fuel cell cost. This allows identification of suitable hybrid systems based on various wind regimes. At lower winds, use of a diesel generator/battery system is the only option. At intermediate wind speeds, a wind turbine or fuel cell could be added to it (depending on fuel cell cost) and reduction in COE could be achieved. On the other hand, at higher wind areas, a wind/fuel cell or wind/fuel cell/battery system might also prove to be feasible if the fuel cell cost drops significantly.

4. Optimization results

In HOMER, the optimization results could be categorized for a particular set of sensitivity parameters. Considering the diesel price fixed at 0.35$/L, the fuel cell cost can be varied to identify an optimal system type (OST) for St John's (wind speed = 6.64 m/s and solar irradiation = 3.15 kW h/m^2/d). This, in other words, implies an optimistic case where the fuel cell cost is expected to reduce.

At present, a wind/diesel generator/battery system is the most suitable solution as the fuel cell cost is very high (Fig. 20). For a remote home (25 kW h/d, 4.73 kW peak), this system might consist of one BWC Excel-R wind turbine, one 5 kW diesel generator, two batteries and a 3.5 kW power converter.

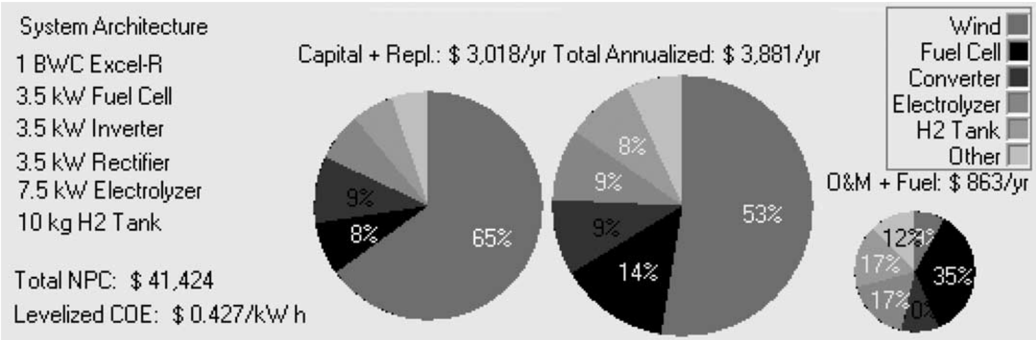
With a reduction in fuel cell cost (cost multiplier = 0.65), a wind/fuel cell/diesel generator/battery system appears as a feasible solution. Considerable reduction in carbon emission, and dependency on fossil fuel could be achieved by replacing the diesel generator with a fuel cell system. System integration issues could also be simplified by eliminating the need for batteries in a wind/fuel cell system. However, such a solution is cost-competitive only when the fuel cell price reduces by 85% or more.

The major obstacle in using hydrogen as a storage medium is the high cost associated with it. However, indications are, cost of the fuel cell may reduce significantly in near future (around year 2010) and reach a level of $300/kW [13,19]. This implies a capital cost multiplier of 0.1 (present cost $3000/kW to future cost $300/kW) is not impractical. Considering a more futuristic scenario, the following discussion focuses on discerning the applicability of a wind–fuel cell hybrid system in Newfoundland.

A wind–fuel cell system for remote homes having an energy rating of 25 kW h/d (4.73 kW peak) should include one 3.5 kW fuel cell, one 3.5 kW converter (inverter and rectifier), one 7.5 kW electrolyzer and a hydrogen tanks with 10 kg capacity. Details of various cost indices are shown in Fig. 21.

FC Capital Multiplier	PV (kW)	XLR	FC (kW)	DG (kW)	Batt.	Conv. (kW)	Elec. (kW)	H2 (kg)	Total Capital	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	FC (hrs)	DG (hrs)
1		1		5	2	3.5			$ 28,450	$ 48,454	0.497	0.93	998		1,041
0.65		1	1.5	5	2	3.5	2.5	2.5	$ 36,738	$ 47,910	0.492	0.93	270	1,401	283
0.15		1	3.5			3.5	7.5	10	$ 29,475	$ 41,424	0.427	0.90		4,286	
0.05		1	3.5			3.5	7.5	10	$ 25,625	$ 36,980	0.381	0.90		4,286	

Fig. 20. Optimization results for wind speed = 6.64 m/s, solar irradiation = 3.15 kW h/m^2/d, and diesel price = 0.35$/L.



Component	Initial Capital ($)	Annualized Capital ($/yr)	Annualized Replacement ($/yr)	Annual O&M ($/yr)	Annual Fuel ($/yr)	Total Annualized ($/yr)
BWC Excel-R	19,400	1,817	148	75	0	2,040
Fuel Cell	1,575	148	83	300	0	531
Converter	2,800	262	26	88	0	376
Electrolyzer	2,250	211	0	150	0	361
Hydrogen Tank	1,950	183	0	150	0	333
Other	1,500	141	0	100	0	241
Totals	29,475	2,761	257	863	0	3,881

Fig. 21. Wind–fuel cell system cost analysis.

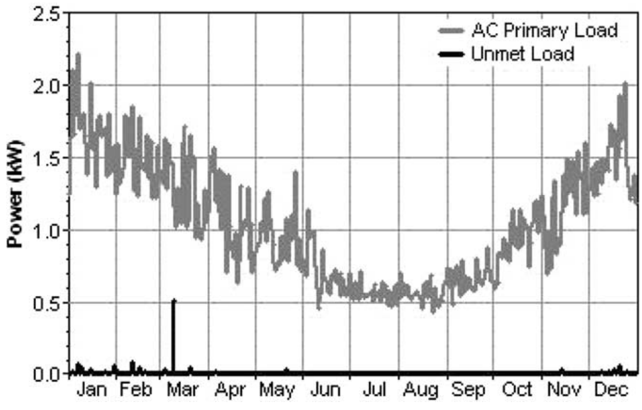


Fig. 22. Primary load and unmet load.

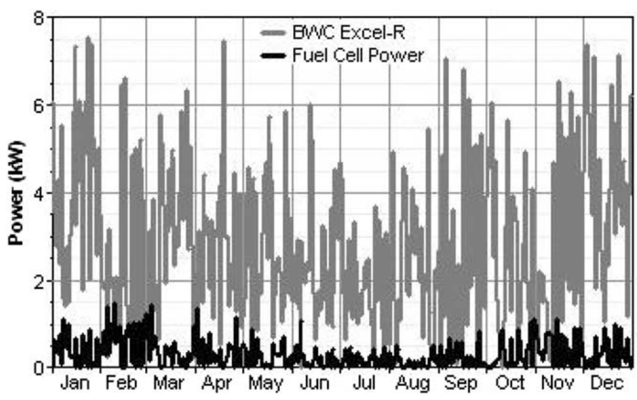


Fig. 23. Wind power and fuel cell power.

Annual extracted wind energy is 25,384 kW h and fuel cell power delivery is 2762 kW h. Therefore, the wind turbine meets 90% demand and remaining 10% is contributed by the fuel cell. Excess electricity, unmet load and capacity shortage are 9328, 32, and 55 kW h, respectively. The fuel cell operates 4268 h in a year and hydrogen usage is 165.7 kg/year (efficiency 50%).

The primary load is served with 9093 kW h and electrolyzer consumes 8716 kW h in a year. Peak unmet load is 0.5 kW (Fig. 22) and excess electricity production is 7650 kW h. With reduced wind speed during the summer months (Fig. 5), wind power production reduces in a proportionate manner (Fig. 23). The fuel cell average power delivery (0.644 kW) is much lower than the rated value of 3.5 kW (Fig. 23). However, it supplies occasional peak load and serves as a secondary power source. The excess electricity, whenever available might be used in water pumping or space heating, which would elevate the overall efficiency.

5. Conclusion

At present, renewable energy based low-emission hybrid energy systems with hydrogen storage are not cost-competitive against conventional fossil fuel based stand-alone or grid interfaced power sources. However, the need for cleaner power and improvements in alternative energy technologies bear good potential for widespread use of such systems. Various energy sources (wind, solar, and diesel generator) and storage systems (battery, and electrolyzer–tank) were considered in this analysis. NREL's optimization tool HOMER was used in identifying probable hybrid configurations and their applicability. Focus has been given on hydrogen-based systems as an emerging technology for use in stand-alone applications in St John', Newfoundland. Following conclusions could be drawn based on this analysis:

- Wind resources in Newfoundland bear excellent potential compared to solar energy and utilization of solar resources might not be cost effective in most cases.
- At present, a wind-diesel-battery system is the most suitable solution for stand-alone applications. Cost of energy for such a small system in St John's (delivering $\sim$25 kW h/d, peak $\sim$5 kW), is around 0.497$/kW h.
- With a reduction of fuel cell cost to 65%, a wind-diesel-fuel cell-battery system would be feasible.
- A wind–fuel cell system would be a more attractive choice if the fuel cell cost reduces to 15% of its present market price. In such a case capital cost, net present cost and cost of energy would be around $29,475, $41,425, and $0.427/kW h, respectively.
- Instead of using single stand-alone units, larger hybrid systems would be cost-competitive for remote communities and the economies of scale might bring down the cost of energy towards the present utility electricity price (0.07$/kW h).
- Significant advancement in small wind turbine technology and fuel cell research is needed before a wind–fuel cell system could be termed as commercially feasible.

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