INTEGRATION OF UNDERGROUND PUMPED HYDRO STORAGE MEMBRANE (UPHSM) SYSTEM WITH HYBRID OF RENEWABLES AND DIESEL GENERATOR IN OFF-GRID REMOTE AREA COMMUNITIES OF ONTARIO

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Abstract

Title: Integration of Underground Pumped Hydro Storage Membrane with Hybrid of Renewables and Diesel Generator in Off-grid Remote Area Communities of Ontario

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Worldwide, off-grid remote areas are facing energy issues. The Canadian remote communities depend on diesel generation posing many issues including high fuel cost and greenhouse gas emissions. The government policy is to connect such communities to electricity grid that requires high cost and long time. In this situation renewable generators, including wind and solar, may be an appropriate solution. However, their intermittent nature is problematic that needs to be addressed.

Therefore, this project investigated the integration of underground pumped hydro storage membrane system (UPHSM) to address the intermittency to provide steady and reliable power supply. A four step systematic methodology is proposed to examine the feasibility of UPHSM in a remote community.

The case study results show an overall 64 percent reduction in diesel consumption and 295696 t in CO_2 emission. The study results also confirmed that the proposed system is a viable solution for off-grid remote areas.

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Glossary of Acronyms and Symbols

EWM	Electrolysis of Water and Methanation
FGs	Fuel Based Generators
GHG	Greenhouse Gasses
HRs	Health Risks
IRENA	International Renewable Energy Agency
OGCs	Off-Grid Communities
PIER	Public Interest Energy Research
PSH	Pumped Storage Hydropower
RE	Renewable Energy
REA	Renewable Energy Alternatives
RES	Renewable Energy Resources
SMES	Superconducting magnetic energy storage
NA	North American
SP	Solar Power
TS	Thermal Storage
UPHSM	Underground Pumped Hydro Storage Membrane
DG	Diesel Generator
RER	Renewable energy Resources
IESO	Independent Electricity Supply Operator
AANDC	Aboriginal Affairs and Northern Development Canada
LTEP	Long Term Energy Plan Ontario (2013)
CAES	Compressed Air Energy Storage
GPM	Gravity Power module
s	Second
h	Hour
k	Kilo
FIT	Feed in Tariff
BESS	Battery Energy Storage System
W	Watt
OFAT	Ontario Flow Assessment Tool
NGO	Non-Government Organization
GUC	Government Utility and Community
IRR	Internal Rate of Return
LIO	Land Information Ontario
HORCI	Hydro One Remote Community Incorporation
O&M	Operation and Maintenance
RRRP	Remote or Rural Electricity Rate Protection
AFC	Avoided Fuel Cost

1 Introduction

1.1 Background

The global technological advancements along with continuous increase in population and industrialization have resulted in increasing the energy demand (Sadorsky 2013) that has lead the power industry towards higher energy production to meet the long term energy requirements. The non-renewable energy resources resulted in many issues such as the adverse effect on climate change, depletion of fossil fuel resources with increased prices and greenhouse gas (GHG) emissions. The global attention has therefore diverted towards the renewable energy resources, especially wind and solar. However, these resources possess certain stochastic issues that need to be addressed for producing reliable and sustainable energy supplies. The wind and solar may fit into a specific application due to their specific properties as an additional advantage (Wadud et al. 2013). The integration of renewable energy, particularly wind and solar, with fuel-based energy power generation besides the energy storages, creates hybrid renewable energy systems (Bahramara et al. 2016) which may be attractive for remote communities. The placement of energy storage with this system can further enhance the utilization of renewable energy resources.

Many remote populated areas of world rely entirely on off-grid electricity supply. Efforts to connect such remote areas with reliable power grids can potentially improve the situation but it involves a high cost. Presently, most of these off-grid population is using diesel generators (DGs) involving a high fuel cost and excessive GHG emissions (Wilke et al. 2012). In Canada, there exist about 175 off-grid communities with population in excess of 100,000 people, out of which only 35 communities are using supply-mix electricity. The remaining 140 communities are entirely dependent on diesel generation (Arriaga et al. 2013). Further, Arriaga et al (Arriaga et al. 2013) stated that about 31 scattered remote settlements in Ontario with a total population of 15,000 have a high electricity cost that ranges from \$0.4 to \$1.2 per kWh (Arriaga et al. 2013). Moreover, the situation is worst in some community areas which are not well connected with the cities by road and hence, the fuel is transported by air to these areas, which is an additional burden of the fuel costs (Karanasios and Parker 2016).

The above situation needs to be addressed by exploring alternative arrangements for providing clean, reliable, inexpensive and sustainable energy production in off-grid remote community areas. Considering these important energy characteristics, the renewable energy resources have become the point of concentration, particularly for clean and inexpensive energy quality (Weis and Ilinca 2010) that can provide economical and sustainable energy in remote areas (National Renewable Energy Laboratory 2004). A literature review presented later in this report shows that this arrangement is still not applied to meet the instant power demand of the communities, and also reveals that the integration of energy storage is an appropriate solution to the problem. Discussing the case of wind and solar, the distributed integration of these renewables overcomes the losses of long distance transmission which is a prominent benefit of utilizing the renewable energy resources (RER). However, the intermittent nature of the wind and solar considerably affects the power production reliability (Weis and Ilinca 2010). Also, the imbalance between power production and energy demand may lead the setup towards system failure or instability (National Renewable Energy Laboratory 2001). Therefore the intermittent nature of the RER needs to be properly addressed to avoid any sort of probable imbalance between power production and energy demand that can be swiftly handled by integration of adequate storage unit to the established RER power unit.

The integration of energy storage system for managing a greater penetration of wind and solar is still needed to address the power quality and to cover maximum electricity load of the system. Therefore the integration of energy storage system with wind, solar and diesel power generators has been focused on providing large energy storage potential to generate a steady and reliable power supply in off-grid remote areas. Among various available energy storage options, a newly introduced underground pumped hydro storage membrane (UPHSM) system has been considered in this study being a simple, easily deployable and cost-effective system for remote areas. Most of the off-grid remote communities in Ontario are settled in the vicinity of the natural water bodies that is an additional benefit to develop the UPHSM system.

The above situation suggests evaluating the integration of UPHSM system with a hybrid of wind, solar and diesel generator in the off-grid remote area communities. Additionally the optimization of UPHSM scheduling followed by an economic analysis would be helpful to test the viability of the UPHSM system.

1.2 Project Problem and Objectives

1.2.1 Problem Statement

In order to provide the clean energy to remote areas the renewables such as wind and solar are needed to associate with diesel generators. However the wind and solar are neither available at the right time of energy demand nor constantly providing the energy generation for a particular time period of electricity demand.

In order to address the above issues, this study proposed the integration of UPHSM system with existing wind, solar and diesel generators and focused on the exploration of optimal solution to mitigate the uncertainty and intermittency of wind and solar power for providing a steady, reliable, demand oriented, and sustainable power supply to the off-grid remote settlements.

Amongst the developed countries, Canada has the same situation with its remote communities particularly in northern areas, from Yukon to Newfoundland. There are various problems which have been faced by remote area communities due to diesel power generation as identified by AANDC in 2010 under their study of ecoENERGY for Aboriginal and Northern Communities Program Overview (Indigenous Affairs and Northern Development Canada 2010). The main concerns are highlighted below:

- Considerable GHG emissions as a result of diesel fuel combustion;
- Long distances for fuel transportation by vehicles are also responsible and adding GHG emissions;
- Fuel becomes expensive due to additional transportation costs by road and air;
- Fuel spills during transportation is wastage ;
- Fuel spills at storage place create environmental issues;
- Generator noise cause disruption, especially in calm and quite remote vicinities;
- The breakdown of DG generally results in black-outs which are highly dangerous in extreme cold weathers;
- High diesel and heating fuel demand, especially in cold weather, adds to high energy expenditure; and
- High power price in off-grid remotes generally discourages the establishment of new businesses, ultimately limiting the future growth opportunities of the communities.

The above issues have invited the attention of this study to provide a feasible solution. In LTEP 2013, the Ontario's Ministry of Energy is intended to connect the remote communities with the grid power on priority basis (Ministry of Energy of Ontario 2013). It was further stated that all possible efforts would be worked out with the Federal Government to connect the remote Frist Nation communities to electricity grid or to find the alternatives where it is not economically feasible. This study has therefore selected Fort Severn community which is situated in far north of Ontario as a case study. The possibility of reaching the electricity grid to this area is highly difficult and uneconomical. Therefore, the proposed solution is to establish an energy storage system like UPHSM system which is simple, easily adoptable within a relatively short time period. Keeping in view the proposed system, this study has set the objectives as given in the following section.

1.2.2 Project Objectives

In order to address the above issues, the specific objectives of this project are as follows:

- To develop a mathematical model for scheduling of underground pumped hydro storage membrane (UPHSM) system for utilizing the available renewable energy resources in combination with existing diesel power generator in off-grid remote areas;
- To establish a UPHSM system based on available renewable energy resources to integrate with wind and solar power generation to become a part of power-mix system with existing diesel generation in off-grid remote areas;
- To apply optimization model and established UPHSM system on a case study in a remote area community; and
- To perform a financial analysis for life-period of UPSHM system.

2 Literature Review

2.1 Energy Storage Technologies

The energy storage plays an important role with renewable energies like wind and solar to control plant output and provide ancillary services to the utility operators. There are numerous energy storage technologies and new concepts are continually being developed. Díaz-González et al. (Díaz-González et al. 2012) provided an overview of different types of energy storages being utilized throughout the world along with their respective technologies.as listed below:

- Gravitational Potential Energy with Water Reservoirs
  - Pumped Hydro Storage (PHS)
- Compressed Air Energy
  - Compressed Air Energy Storage (CAES)
- Electrochemical Energy in Batteries and Flow Batteries
  - Lead-Acid Battery
  - Nickel-Cadmium Battery
  - Sodium-Sulfur Battery
  - Lithium-Ion Battery
  - Vanadium Redox Flow Battery
  - Zinc-Bromine Battery
  - Polysulfide-Bromide Flow Battery
- Chemical Energy in Fuel Cells
  - Hydrogen Based Energy Storage System
- Kinetic Energy in Flywheels
  - Flywheel Energy Storage System
- Magnetic Field in Inductors
  - Superconducting Magnetic Energy Storage
- Electric Field in Capacitors
  - Super-capacitor Energy Storage System

The details of the above technologies can be viewed in various studies including Agrawal et al. (Agrawal et al. 2011), Beaudin et al. (2010), and Pickard et al (Pickard et al. 2009) . This study has focused on pumped hydro storage technology which is widely used for integration with wind and solar energy generation. There are three main types of pumped hydro storage technologies:

- On-Ground Pumped Hydro Energy Storage (PHES)Technology
    - Conventional Pumped Hydro Storage System
- In-Ground Pumped Hydro storage Technology
    - Gravity Power Module (GPM) System
- Underground Pumped Hydro Storage (UPHS) Technology
    - Underground Pumped Hydro Storage Membrane (UPHSM) System

This study focused on "Underground Pumped Hydro Storage Membrane (UPHSM) System

2.2 Rationales of Selecting UPHSM System

The rationales of selecting UPHSM system are as follows:

Conventional PHES technology requires two reservoirs with a high elevation difference. For this purpose the favorable topologies rarely exist that makes difficult to identify the feasible sites. Additionally, this technology involves very high cost and lengthy construction time. With regard to GPM technology, deep excavation is required which is also very expensive. This technology has high operation and maintenance cost after commissioning of the project.

The UPHSM facility does not require any complex topology to find a feasible site and it does not need deep excavations as well. It is less costly as compared to both conventional and GPM technologies. The construction of UPHSM facility is also simple since it involves shallow excavations just below the ground. The operation and maintenance of this system is relatively easy and inexpensive. The energy storage capacity under this technology can easily be adjusted according to the requirement of the power demand of the remote areas. The construction components of UPHSM technology like soil transportation, providing penstock, pump turbine unit, and storage membrane are easy to manage in the remote area conditions. Additionally, the cost of this technology is comparatively less than the other technologies and the construction labor is relatively basic.

2.3 Review of UPHSM Technology

The underground pumped hydro storage (UPHS) technology is a well-established energy storage system. Following the principle of UPHS, Olsen et al. (2015) introduced a novel concept of using a membrane to store the water which is named as Underground Pumped Hydro Storage Membrane (UPHSM). The energy is stored by elevating a mass of dart or soil through water being pumped into a below-ground readily constructed cavity. The cavity is composed of two impervious water-proof flexible membranes properly sealed along the edges. The schematic diagram of the UPHSM system is presented in Figure 2-1

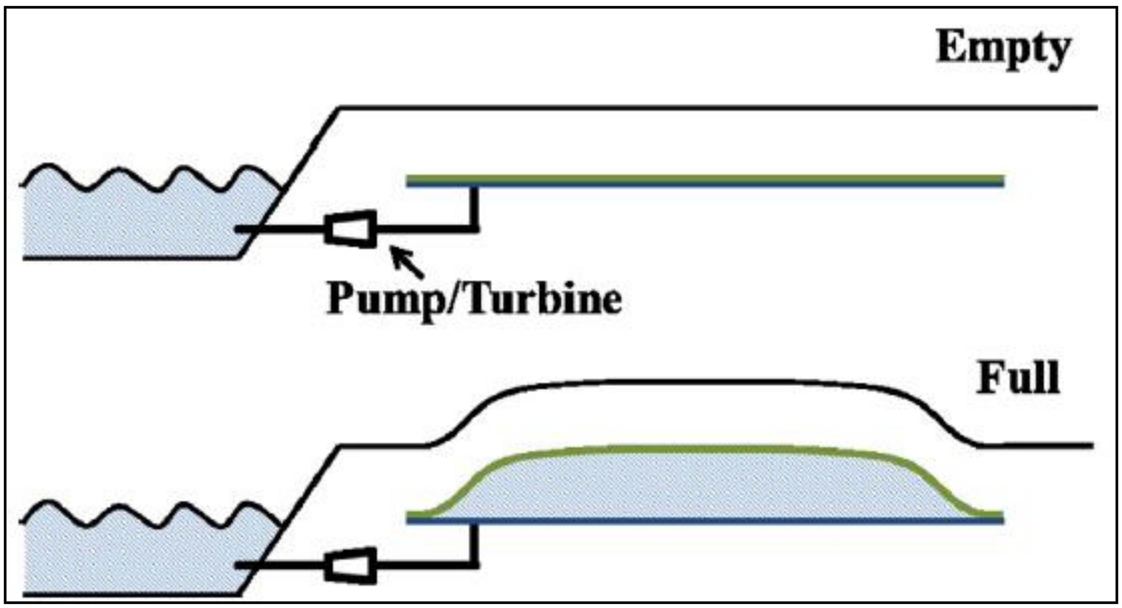


Figure 2-1 Schematic diagram of PHSM system
Source: Olsen et al. (2015)

One of the basic requirements for pumped hydro storage (PHS) is that there should be an elevation difference to create a head difference between the two water reservoirs. The force conveyed for power generation is provided from the hydrostatic pressure obtained from the head level difference of the two reservoirs. The new concept of UPHSM suggested a solution for the circumstances where this kind of elevation difference is not possible due to unfavorable topographic conditions. The conventional concept here is to facilitate the elevation difference by employing the upper reservoir in a below-ground cavity.

The important feature of this concept is the fairly price efficient design where the main cost component is required for movement of the soil. The cost analysis indicated that a full-scale system will be economically viable when associated to the remote area power grid where the income can be generated by providing the daily power demand as well as marketing ancillary services, (Olsen et al. 2015). Figure 2-2 shows the schematic diagram of Longitudinal and Cross Sectional views of UPHSM system. The different parts of this system have been indicated using alphabetical letters as given below:

A: Inflatable Cavity	F: Lower Membrane
B: Connecting Pipe	G: Top Soil
C: Pump System	H: Level Metre
D: Water Reservoir	I: Pressure Gauge
E: Strainer	J: Flow Metre

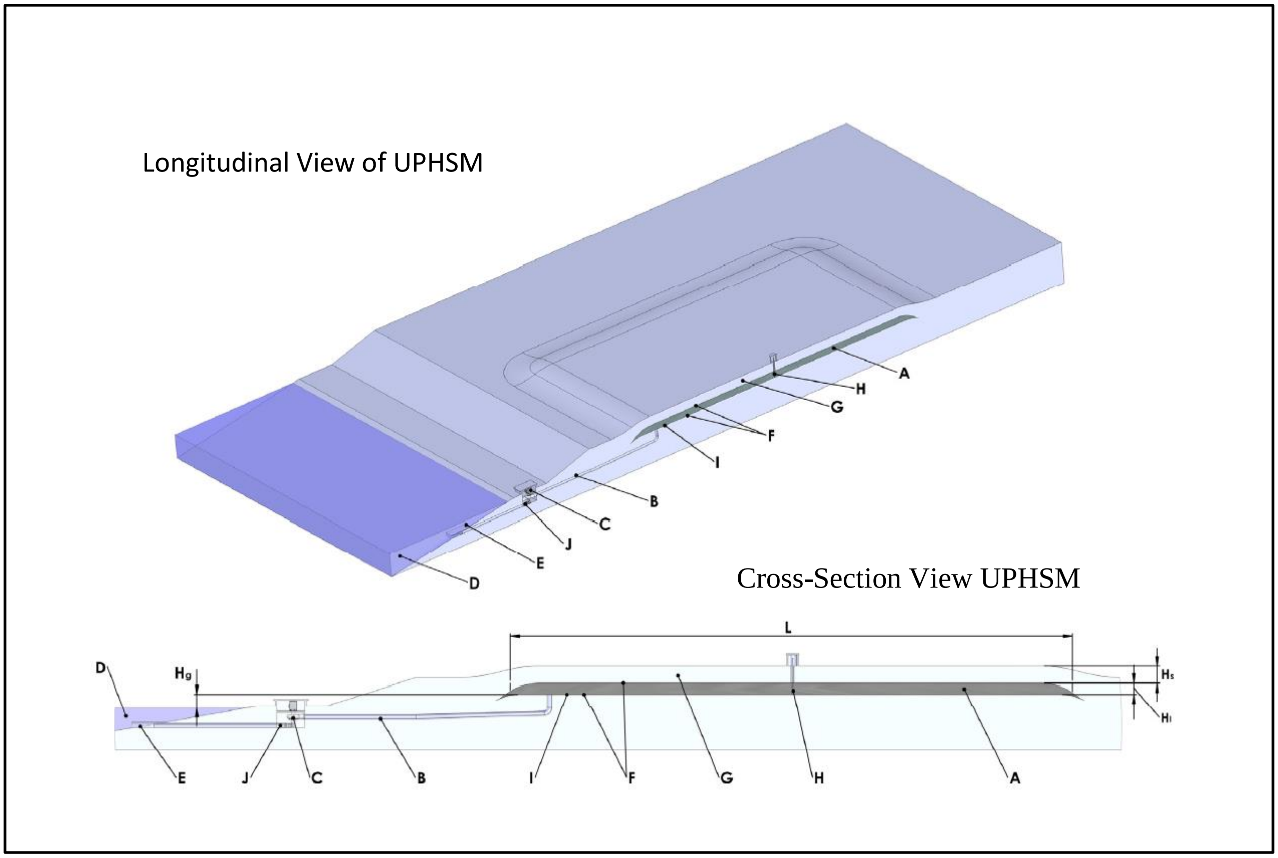


Figure 2-2 Schematic diagram showing longitudinal and cross sectional views of UPHSM system
Source: Olsen et al. (2015)

It is assumed that the hydrostatic pressure in the membrane cavity, hydrodynamic losses, and the possible effects of energy stored in the soil edge zone are negligible. Therefore, the total stored energy (E) assuming the square dimensions of a square membrane cavity (length = width = L) can be calculated by the formula given in Equation 2.1.

$$E = g\,\rho_s H_s L^2 H_l \eta / 3600 \text{ kWh} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2.1)}$$

where, E = Energy (kWh)

If, L = Edge length of the membrane (m)
H_s = Soil layer thickness (m)
H_l = Maximum lift height (m)
g = Gravitational acceleration (m/s^2)
η = Efficiency of pump-turbine unit
ρ_s = Soil density (kg/m^3)

In addition to the above technological details, Olsen et al. (2015) provided the values of design parameters at three experiment levels including lab test, field test, and full scale plant as given in Table 2-1.

Table 2-1 Values of design parameters based on different experiments

No	**Parameters**	**Parameter Values**		
		Lab Test (5 m x 5 m)	**Field Test (50 m x 50 m)**	**Full Scale Plant (500 m x 500 m)**
1	Pump-turbine power	N/A	11 kW/5.5 kW	30 MW
2	Underground Storage Size	25 m^2	2500 m^2	250000 m^2
3	Lifting height of soil layer	10 cm	0.6 m	10 m
4	Soil layer thickness	50 cm	3 m	25 m
5	Soil layer density	1.5 t/m^3	2.0 t/m^3	2.0 t/m^3
6	Soil layer weight	17 t	15,000 t	10,000,000 t
7	Storage volume	1.5 m^3	1500 m^3	1,500,000 m^3
8	Storage pressure	0.07 bar	0.6 bar	5 bar
9	Stored energy	3 kWh	25 kWh	200 MWh
10	Pipe diameter	20 mm	0.3 m	4 m
11	Pipe length	5 m	50 m	300 m
12	Volume flow through turbine	0.5 m^3/h	320 m^3/h	230,000 m^3/h
13	System efficiency	N/A	30%	>80%
14	Energy loss in soil layer	5%	0.4–1.2%	<0.1%

Source: Olsen et al. (2015)

2.4 Review of Electricity System in Off-Grid Remote Areas

The study of Kartsounesl and Ahrens (1979) discussed two types of storages including compressed air energy storage (CAES) and underground pumped hydro energy storage (UPHES). This study compared the characteristics of both storages and evaluated their potential impacts. Accordingly, it was concluded that although UPHES system needs a large underground reservoir and longer construction period, it is technically simple and its overall efficiency is high.

The study of Martin (2007) discussed a new concept for underground pumped hydroelectric energy storage system. This study recommended that this system may prove to be a suitable and promising system for pumped hydro energy storage in agriculture environment. The study also recommended the future work to improve the technology for obtaining better socioeconomic and environmental benefits.

The study by Maine (2009) presented the riverbank power generation technology and described its working principle to store energy from excess or surplus energy at grid level during off-peak hours and emission-free generation during peak periods of about six hours. In this study, the basic technology concept was provided and the details of Diversion River Bank Wiscasset Energy Centre and closed loop riverbank Sparta Energy Centre were briefly discussed**.**

The study by Al-Awami et al. (2009) discussed the stochastic nature of wind power and debated on the predictions of wind. The study discussed various aspects of wind power installation. This study has not discussed the solutions for intermittencies and uncertainties of wind.

The study by Weis (Weis and Ilinca 2010) discussed and validated the potential for a wind–diesel production incentive intended for remote communities of Canada. This study stated that about 300 remote communities are suffering with high energy costs, yet Canada has attained partial success in mounting remote wind energy projects. Most of Canada’s large-scale wind power generation is a direct result of a Federal Government incentive introduced in 2002. This study determined how the deployment of an incentive can be customized for remote wind power to potentially improve the situation in remote areas. This study also emphasized on the implementation of customized energy solutions for Canadian remotes.

Pejovic (Pejovic 2011) studied the energy resources which are environment friendly including the hydro storages as prospective means to store the excess energy produced by wind, solar, nuclear and run-of-river using pumped hydro energy storage system. This study explained that although the nuclear and gas power plants possess the potential of higher energy production to meet power demand, but with high maintenance costs associated with the environmental concerns. This study proposed that the cost of a high head pumped storage plant can be recovered within 5 to 10 years using moderate or average revenue and the surface plants cost can be recovered even in 4 to 6 years.

The study by PIER (2011) presented energy storage strategies that can be implemented in California by 2020. The report discussed and analyzed various available energy storage technologies and policies affecting their implementation in California. The report also discussed critical gaps in technology and proposed policy reform and future research requirements.

Various energy storage technologies were studied by Agrawal et al. (Agrawal et al. 2011) and an assessment of technological readiness and economic feasibilities were conducted to facilitate their implementation. Though the study work has not mentioned the off-grid remote areas, it offers various energy storage options which can be deployed in off-grid remote environment and opens a vast door for future studies.

addressed the prevailing power situation in Bangladesh and discussed the power supply demand ratio. This study addressed the potential of various renewable resources to utilize as an alternate power resource in the country scenario and analyzed how far the renewable energy can be treated as an ideal solution in the economic development of the country. This research did not address the wind and solar intermittency solutions.

Arriaga et al. (Arriaga et al. 2013) studied the renewable energy option to reduce the diesel fuel dependency for remote communities in northern Ontario and conducted the detailed analysis of various scenarios with low renewable energy penetration (7%) and high renewable energy penetration (18%). The proposed system proved the positive impact in reducing the fuel consumption, operating cost and GHG emissions. However, this study did not propose the solution to address the intermittency of renewable energies.

The study of Martin (2015) discussed the long-term renewable energy generation planning for off-grid remote communities. This study has not addressed energy storage options so as to store the redundant energy of renewable units to utilize their full potential.

The study of Cordero (2015) developed systematic approach for optimal design of hybrid renewable energy systems at micro-grids for remote communities to overcome the use of diesel generator which is uneconomical and environmentally untenable for the remote communities. The study also addressed the environmental and economic issues to diesel power generation and proposed a hybrid renewable energy system. However, the integration of energy storage was not discussed which is needed to enhance of sustainability of hybrid system and utilize the full potential of renewable energy.

The study by Alharbi (2015) established a multi-year operational planning model to define battery energy storage system (BESS) for optimal power rating and energy capacity in coordination with year of installation. Several scenarios of ownership were studied for different BESS technologies to estimate the optimal planning decisions. This study potentially addressed the uncertainty of solar and wind. Several micro-grid operational situations were created and studied. To decide the optimal BSS size, a stochastic optimization model was created including different year state of uncertain micro-grid variables.

The study by Wang et al. (2016) focused on the battery energy storage system for wind-diesel off-grid power system located in a Quebec community in Canada. The study proposed an optimal planning model to optimize the economic environmental gains and system dependability. The battery energy capacity and rated converter capacity were synchronized to optimal variables. Several possible scenarios were studied and analyzed in this study. The study resulted in the optimal design of a BE storage unit enhanced the dependability of the wind-diesel system and improved the environmental and economic benefits.

It is important to note that the study by Alharbi (Alharbi 2015) and Wang et al. (Wang et al. 2016) have utilized the battery storage to address the uncertainty of renewables and enhance the dependability of the system. However, the battery storage duration limitation was an issue. It was recommended that a smaller-scale unit may give better results. However, the large-scale energy storage system still needs to be tested at the community area power demand.

The study by Liu et al. (2016) focused on optimization of energy capacity at micro-grid level and proposed a planning strategy of integrating the battery energy storage with wind and solar energy. He has classified micro grid loads in to three categories. Level 1 load is the load that must be supplied without interruption, level 2 load is the load that should be supplied with minimal interruption and level 3 load can be interrupted if necessary. The superconductor was used only for the fast response at level 1 load. Li-ion & Lead Acid batteries were used mainly for the medium response at level 2 load but it can be used for level 1 load if required. Similarly diesel generator (DG) was mainly considered for level 3 load and it can also be used as a back-up source for level 1 and level 2 loads. These storage devices possess the storage capacity and time limit issues. It is important to note that the study result shows that three storages used are still insufficient to meet the power demand and backup of diesel generation was required. This situation confirmed that this study did not employ the high capacity energy storage to utilize the maximum potential of wind and solar.

The study by Boute (2016) revealed that electricity supply in Russian remotes was heavily dependent on diesel generators that imposed critical socio-economic burden on the residents, besides the adverse environmental impact due to greenhouse gas emissions and oil spills. The substitution of renewable energy minimized the prevailing costs of electricity supply of Russian remote areas. This study also reviewed Russia's off-grid renewable energy policy concentrating on the up gradation of wind- and solar-diesel hybrid energy modules in the Russian Arctic. This study also discussed the possibility to adopt the FIT program of Canada, the options of avoided cost energy tariff, and transfer of subsidies from diesel generation to RES for establishing the renewable energy production in remote areas. However, this study has not addressed the integration of energy storage to mitigate the intermittency of renewable energy.

The study by Arriaga et al. (2016) worked on long-term planning model of renewable energies to present the capital costs per unit of installed capacity of renewable energy. It was claimed that the presented model was capable of evaluating various renewable energy projects through years for long-term renewable energy development programs. The results have shown that the proposed model was suitable to get feasible renewable energy plans.

As discussed above, various studies have worked on renewable energy and diesel power generation and addressed multi-significant off-grid remote issues including economic, environmental and social aspects. However, the suitable option of energy storage in remote areas was rarely discussed. This study has therefore focused on the option of energy storage that can have a greater storage capacity to address the intermittent nature of wind and solar power generation. In this regard, the UPHSM system as a novel energy storage technology is considered to integrate with wind, solar and diesel power generators and to find the optimal solution of utilizing the system for producing reliable power supply to off-grid remote settlements. Additionally, most of the off-grid Canadian remotes communities are located near water bodies which provide an advantage of utilizing the nearby water to establish a UPHSM system.

This study has therefore selected the case study of Fort Severn community located near Severn River. A report by Karanasios and Parker (2016) discussd the recent developments of renewable energy in remote aboriginal communities of Ontario and reported that only 20 kW solar power potential is existed whereas 300 kW solar potential is expected to be available by 2016 at Fort Severn community area. This report has not provided any detail of existing wind potential in this community. Therefore, keeping in view the future electricity requirement of Fort Severn community, this project study assumed 4000 kW wind power potential for this area to provide wind power to the proposed UPHSM system.

3 Methodology

3.1 General Approach

The overall approach is to develop a methodology for integration of UPHSM system with diesel generator using wind and solar for their maximum utilization to meet the power demand of off-grid remote area communities. The wind and solar generation cannot be instantly utilized at all the times due to their uncertain nature. There are possibilities that renewable power generation is available when the electricity is not required and similarly, the renewable power is not available when the electricity is needed. Additionally, the fluctuating power is not reliable in the electricity market and, hence, the full electricity generation of wind and solar cannot be utilized. The solution of all these situations is the energy storage with compatible energy capacity so that the maximum generation can be stored for use when it is needed. Therefore, the capacity of energy storage is dependent on the available power potential of renewables which include the existing and proposed wind and solar potential to supply the electricity for the concerned community area.

This study has therefore selected the UPHSM system for integrating with wind and solar in combination with diesel generator which is the basic power producing source in remote area. The systematic approach of this methodology includes the following steps:

- Developing optimization model for scheduling of UPHSM in combination with diesel generation by utilizing renewable energy potential;
- Establishing UPHSM unit based on available renewable energy potential;
- Applying optimization model on a case study; and
- Performing financial analysis of UPHSM system.

The methodological process for the above steps is explained in the following sections.

3.2 Developing Optimization Model for Scheduling of UPHSM System

In order to utilize the optimal power discharged by UPHSM unit at different demand hours (off, mid and peak) in combination with exiting DG, an optimization model is developed. The steps to developing the optimization model have been described in the following sub-sections.

3.2.1 Data Sheet

The Data required to develop optimization mode is provided in Table 3-1

Table 3-1 Data required for developing optimization model

No.	Parameters	Symbol	Unit
	Actual and Assumed Parameters		
1	Life period of UPHSM unit	Y	Years
2	Existing population of the community	N	Number
3	Yearly population increase rate of the community	i	%
4	Average yearly energy inflation rate	m	%
5	Existing daily per capita energy demand	E_t	kWh/day/capita
6	Rate for purchase of power by UPHSM	CA	C$/kWh
7	Rate for sale of power by UPHSM/ diesel generator	BA	C$/kWh
8	Existing daily power demand (daily load)	P_t	kWh
9	Maximum limit of energy to be provided by UPHSM	Ayt	% kWh
10	Unit capital cost of UPHSM	f_u	C$/kWh
11	Yearly O&M cost of UPHSM as percentage of capital cost	p	%
12	Yearly inflation rate for increase in O&M cost of UPHSM	q	%
13	Minimum acceptable rate of return (MARR)	r	%
14	Pump-turbine efficiency of UPHSM unit	η	%
15	Residual value of UPHSM plant at the end of plant life (percentage of capital cost)	v	%
16	Energy storage capacity of UPHSM unit	C	kWh
17	Maximum limit of energy to be provided by UPHSM	$PSU_{max,t}$	% kWh
18	Available solar power potential	PSU_S	kWh
19	Available wind power potential	PSU_W	kWh
20	Unit capital cost of solar installations	f_S	C$ Per kW
21	Unit capital cost of Wind farms	f_w	C$ Per kW
Decision Variables			
1	Power supply by UPHSM (off-peak)	PSU_{off}	kWh
2	Power supply by UPHSM (mid-peak)	PSU_{mid}	kWh
3	Power supply by UPHSM (on-peak)	PSU_{on}	kWh
4	Power supply by diesel generator (off-peak)	PSD_{off}	kWh
5	Power supply by diesel generator (mid-peak)	PSD_{mid}	kWh
6	Power supply by diesel generator (on-peak)	PSD_{on}	kWh

3.2.2 Model Operating Principles

The stakeholders of the electricity generation and supply to the remote area community include the government, the utility operator, renewable energy providers and the community as electricity consumers. This study assumes that the cooperation and inter-relationship among the stakeholders is a main driving force to establish the UPHSM system. Therefore, this study proposed a cooperative association to represent the stakeholders which is named as UPHSM cooperative association (UCA). This association is responsible to run the whole UPHSM system.

The basic principle of the system is that UCA purchases power from renewable generators during off-peak period to store water in the storage to discharge it to the consumer during mid-peak and on-peak periods. The balance demand of the consumers is met by the Diesel Generator being operated by the existing utility operator.

3.2.3 Problem Formulation

It is assumed that the optimization period is the life period of UPHSM unit and each year having nS seasons in nD days in one season. The operating cycle of UPHSM system is assumed as one day of nT hours. The model optimizes total power produced by diesel generator and UPHSM system in one cycle period that is divided in three components including off-peak, mid-peak and on-peak hours. The model variables are the energy supplied by UPHSM and diesel generator in the off-peak, mid-peak and on-peak hours in a day.

Objective Function

The model maximizes the revenue generated by sales and purchases of energy by UPHSM and diesel generator in a year minus yearly O&M cost of UPHSM system. For simplification of this problem, the yearly expense OMC_y of UCA includes the yearly O&M cost and admin fee of UCA.

Let the energy sales by UPHSM arePSU_{off}, PSU_{mid} and PSU_{on} in off-peak, mid-peak and on-peak hours respectively. Similarly, the components of energy sales by diesel generator are PSD_{off}, $PSD_{mid}$and PSD_{on} in off, mid and on-peak hours respectively.

Let the components of energy purchase by UPHSM arePBU_{off}, PBU_{mid} and PBU_{on} in off, mid and on-peak hours respectively. Similarly, the components of energy purchase by diesel generator are PBU_{off}, $PBD_{mid}$and PBD_{on} in off, mid and on-peak hours respectively.

Let the rate for sale of energy is BA which is same for both UPHSM and diesel generator in all energy sale periods. The rate for purchase of energy by diesel generator is same as the rate for sale of power while the rate for purchase of energy by UPHSM is assumed as CA. Therefore, objective function can be written as follows:

Maximize the net profit of UCA

= Yearly revenue generated by UPHSM and diesel generator – yearly expense of UCA.

$$= \sum_{s}^{nS}\sum_{d}^{nD}\sum_{t}^{nT}\left((PSU_{s,d,t} + PSD_{s,d,t}) \times BA_{s,d,t}\right) - \sum_{s}^{nS}\sum_{d}^{nD}\sum_{t}^{nT}\left(\frac{1}{\eta} PBU_{s,d,t} \times CA_{s,d,t}\right)$$

$$- \sum_{s}^{nS}\sum_{d}^{nD}\sum_{t}^{nT}\left(PBD_{s,d,t} \times BA_{s,d,t}\right) - OMC_{y}$$

The system constraints are as follows:

1. Total energy supply from UPHSM and diesel generator should be equal to the total system demand

   $PSU_{s,d,t} + PSD_{s,d,t} = P_{s,d,t}$ ....(1)

   Where, $PSU_{s,d,t} = PSU_{off_{s,d,t}} + PSU_{mid_{s,d,t}} + PSU_{on_{s,d,t}}$

   and $PSD_{s,d,t} = PSD_{off_{s,d,t}} + PSD_{mid_{s,d,t}} + PSD_{on_{s,d,t}}$
2. UPHSM system can supply maximum power up to 90% of the system demand because (i) it purchases power in off-peak period and (ii) to utilize the diesel generator in the system

   $PSU_{s,d,t} \leq 0.90\ P_{s,d,t}$ ....(2)
3. Power sale by diesel generator is same as the power purchase by diesel generator

   $PSD_{s,d,t} = PBD_{s,d,t}$..(3)
4. Power sale by UPHSM is less than power purchase by UPHSM because the UPHSM system is not fully efficient, and therefore the power sale is equal to the power purchase times the efficiency.

$$\sum_{s}^{nS}\sum_{d}^{nD}\sum_{t}^{nT}\mathrm{PSU}_{s,d,t}=\eta\sum_{s}^{nS}\sum_{d}^{nD}\sum_{t}^{nT}\mathrm{PBU}_{s,d,t} \quad \text{(4)}$$

5. Total sale of power by UPHSM and diesel generator in respective period of off, mid and on-peak hours are equal to the respective system demands in these periods.

$$\mathrm{PSU}_{\mathrm{off}_{s,d,t}}+\mathrm{PSD}_{\mathrm{off}_{s,d,t}}=\mathrm{P}_{\mathrm{off}_{s,d,t}} \quad \text{(5)}$$

$$\mathrm{PUS}_{\mathrm{mid}_{s,d,t}}+\mathrm{PSD}_{\mathrm{mid}_{s,d,t}}=\mathrm{P}_{\mathrm{mid}_{s,d,t}} \quad \text{(6)}$$

$$\mathrm{PUS}_{\mathrm{on}_{s,d,t}}+\mathrm{PSD}_{\mathrm{on}_{s,d,t}}=\mathrm{P}_{\mathrm{on}_{s,d,t}} \quad \text{(7)}$$

6. The energy sale by UPHSM in off-peak period does not include the wind energy part of UPHSM. Similarly, the combined energy sale by UPHSM in mid and on-peak period does not include solar energy part of UPHSM.

$$\mathrm{PSU}_{\mathrm{off}}\leq(\mathrm{PSU}_{\mathrm{p}}-\mathrm{PSU}_{\mathrm{W}_{off}}) \quad \text{(8)}$$

$$(\mathrm{PSU}_{\mathrm{mid}}+\mathrm{PSU}_{\mathrm{on}})\leq\{\mathrm{PSU}_{\mathrm{p}}-(\mathrm{PSU}_{\mathrm{S}_{\mathrm{mid}}}+\mathrm{PSU}_{\mathrm{S}_{\mathrm{on}}})\} \quad \text{(9)}$$

7. Yearly cost of UPHSM is a fixed percentage of total capital cost of UPHSM plant

$$\mathrm{OMC}_{\mathrm{y}}=\mathrm{k}\times\mathrm{f}\times(\text{unit capital cost of UPHSM plant}) \quad \text{(10)}$$

8. Non-negativity conditions

$$\mathrm{PSU}_{\mathrm{off}_{s,d,t}},\mathrm{PSU}_{\mathrm{mid}_{s,d,t}},\mathrm{PSU}_{\mathrm{on}_{s,d,t}},\mathrm{PSD}_{\mathrm{off}_{s,d,t}},\mathrm{PSD}_{\mathrm{mid}_{s,d,t}},\text{ and }\mathrm{PSD}_{\mathrm{on}_{s,d,t}}\geq 0$$

Where,

$\mathrm{PSU}_{\mathrm{off}_{s,d,t}}$ = Energy supply by UPHSM in off-peak hours

$\mathrm{PSU}_{\mathrm{mid}_{s,d,t}}$ = Energy supply by UPHSM in mid-peak hours

$\mathrm{PSU}_{\mathrm{on}_{s,d,t}}$ = Energy supply by UPHSM in on-peak hours

$\mathrm{PSD}_{\mathrm{off}_{s,d,t}}$ = Energy supply by diesel generator in off-peak hours

$\mathrm{PSD}_{\mathrm{mid}_{s,d,t}}$ = Energy supply by diesel generator in mid-peak hours

$\mathrm{PSD}_{\mathrm{on}_{s,d,t}}$ = Energy supply by diesel generator in on-peak hours

$\mathrm{PSU}_{\mathrm{max},t}$= Maximum energy supply limit of UPHSM

$\mathrm{BA}_{s,d,t}$= Rate of selling energy by UPHSM and diesel generator

$\mathrm{CA}_{s,d,t}$= Rate of purchasing energy by UPHSM

nT= Total number of hours

nD= Total number of days

nS= Total number of seasons

t= Any hour of a day

d= Any day of a season

s= Any season of a year

f= Unit capital cost of UPHSM plant

k= Percentage of capital cost of UPHSM plant

η= Efficiency of pump-turbine unit

The optimization problem was solved using LINGO software (version 17).

3.3 Establishing UPHSM System

3.3.1 Estimating Component Sizes of UPHSM Unit

The power to be stored by UPHSM unit is entirely dependent on available renewable potential of the community. Therefore storage capacity of UPHSM unit can be estimated from available renewable potential. After estimating the UPHSM storage capacity, the component sizes of UPHSM plant are determine appropriately considering the optimal capacity. The necessary components of UPHSM system are given in Table 3-2.

Table 3-2 Component sizes of UPHSM plant

No.	Component	Size	Unit
1	UPHSM membrane for underground storage	Area	meter square
2	Lift height of soil layer	Height	Meter
3	Soil layer placed over membrane	Thickness	Meter
4	Pump-turbine power potential	Power	Watt
5	Efficiency of pump-turbine	-	percentage

The size of UPHSM membrane, lifting height and thickness of soil layer need to suitably selected using the energy formula to satisfy the optimal storage capacity of the UPHSM system given in Equation 2-1

The life period of UPHSM system and efficiency of pump-turbine are selected using the data available in past studies.

3.3.2 Identifying Suitable UPHSM Site

The suitable sites should qualify the minimum area of the designed storage capacity of the UPHSM system which is based on the optimization results. Additionally, the selected site should be free from environmental constraints and it should be located near the existing wind farm and solar installations and in the proximity of existing DG.

3.3.3 Locating Waterbody

In order to develop the UPHSM system, a water body satisfying the minimum required volume of water is needed. The water bodies commonly include lakes, rivers and reservoirs. In addition to these water bodies sea water may also be used for this energy storage (Olsen et al. 2015).

3.4 Performing Financial Analysis of UPHSM System

The financial analysis of UPHSM system involves the following financial indicators:

- Minimum acceptable rate of return (MARR)
- Net present value (NPV)
- Internal rate of return (IRR)
- Payback period

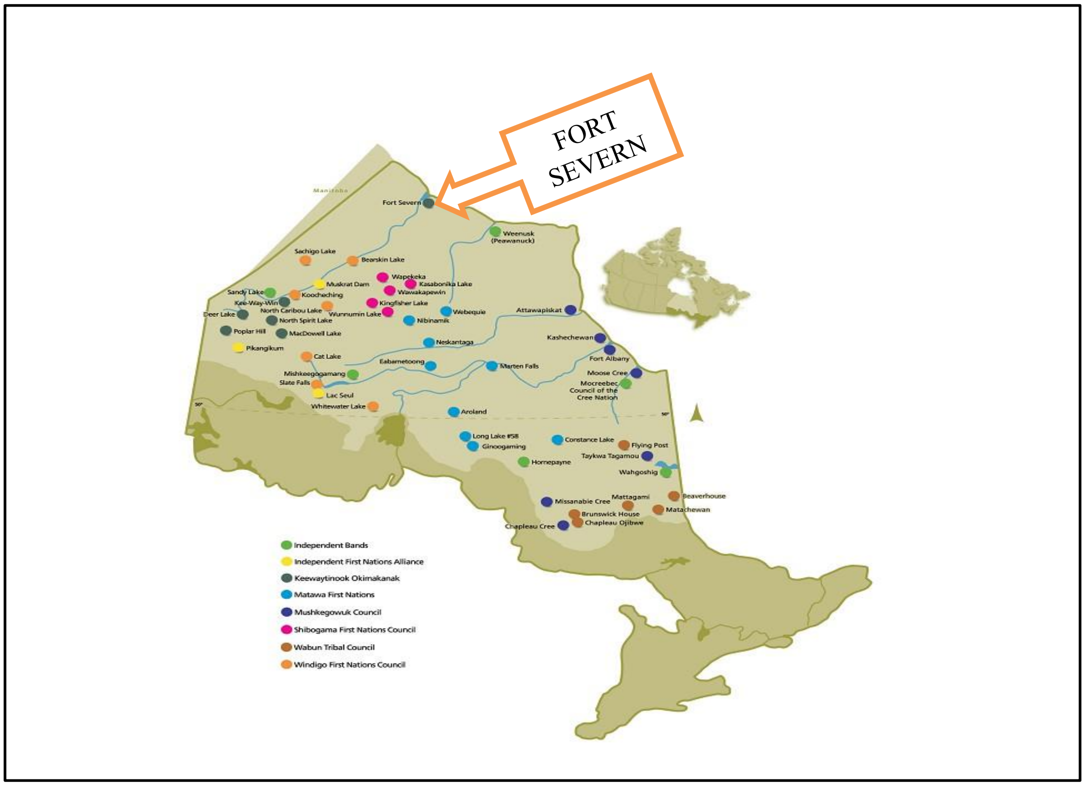
The above indicators are to be computed using their respective formulae available in the literature.

4 Case Study

4.1 Description of Case Study

This case study is concerned with Fort Severn a remote Aboriginal First Nations community in the province of Ontario (Figure 4-1). According to Indigenous and Northern Affairs Canada (2013) there is no road access to this community that imposes higher transportation costs of goods in this community. The total registered population for Fort Severn community is around 635 people (Indigenous and Northern Affairs Canada 2013).

Figure 4-1 Location map of Forte Severn community, Ontario



Source: Nishnawbe Aski Nation (2017)

Population Growth of Fort Severn Community Area

Statics Canada (2015) reported that the total aboriginal population growth rate for ten years period from 1996 to 2006 is 45% as given in Figure 4-3. This data estimates annual growth rate as 4% for combined population growth of total aboriginal and non-aboriginal population.

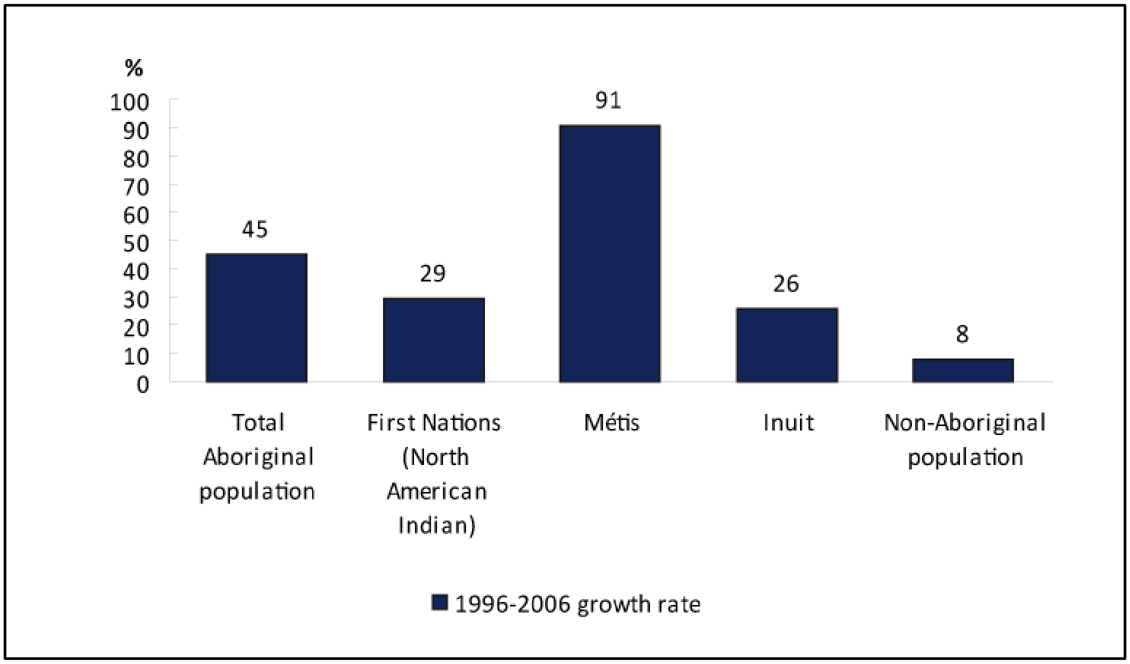


Figure 4-2 Population growth of different communities settled in Fort Severn area
Source: Statics Canada (2015)

Existing Electricity System

Karanasios and Paul (2016) stated that present power demand of the Fort Severn community is managed by diesel power generation. A diesel generated power plant of 550 kW capacity is supplying power to meet the community demand.

Issues of Existing System

Indigenous Affairs and Northern Development Canada (2010) discussed the issues of all the relevant community including Fort Severn community. The issues include GHG emissions from power generation and vehicles. Additionally, the transportation costs by road and air results in increase of fuel costs. The fuel spills during its transportation and at the storage areas are causing environmental issues. Generator noise is a big disruption in quite remote conditions. The breakdown in diesel power generating unit also results in black-outs. High electricity rates in off-grid remote areas generally discourage the establishment of new businesses that ultimately limits the future development growth opportunities in the communities.

Possible Solutions

Fort Severn off-grid community is situated in far north of Ontario and connectivity to Ontario power grid is not only expensive, it is also not feasible (Ontario Ministry of Energy, 2013). This situation suggests the establishment of renewable power generation like wind and solar generation. However, wind and solar energy are uncertain and intermittent in nature. This problem can be mitigated by integrating the energy storage with renewables. It is important to note that for meeting emergencies and supply option in case of unavailability of wind and solar at night, the DG cannot be fully eliminated. Therefore supply mix is the possible options in this area. However, the use of DG can be minimized by utilizing the renewable energy supply.

Therefore, this project proposed a hybrid system model of supply-mix power using the wind, solar and available DG resources. Energy storage of UPHSM system has been integrated with wind and solar to overcome their intermittencies and uncertainties as well as to provide reliable supply.

The proposed hybrid system minimizes the diesel energy generation, resulting in reduced GHG emissions. It is expected that the proposed UPHSM system would also result in providing indirect benefits to the community and the Government such as reliable and sustainable power production to meet the present and future electricity demands of the community. As a result, there will be improvement in existing business, encouragement for new businesses and development of welfare facilities such as schools, hospital, shopping malls, gas stations, fire stations that may result to attract new settlers. Therefore, the proposed solution can contribute in long-term development of the community.

4.1.1 Stakeholders of Fort Severn Electricity System

The stake holders for the electricity generation in remote community areas of Ontario are as follows:

- Provincial Government – Ontario Government
- Utility Operator - Hydro One Remote Community Inc. (HORCI)
- Fuel Suppliers –local community members
- Consumers – Fort Severn community

The government of Ontario through the Ontario Energy Board applies the regulations to provide funding for the electricity generation projects and to provide subsidy on electricity supply to the remote area communities. The government of Ontario also provides subsidy to the customers under the Remote or Rural Electricity Rate Protection (RRRP-Govt. of Ontario 1998).

HORCI is a non-for-government entity that works province-wide for not to generate any profit. The HORCI is responsible to purchase the diesel from the local community sources.

The community is responsible to secure the funding provided by the provincial government for the electricity generation projects. In planning and installation phase of the project, total funding is provided by provincial government. After commissioning of the project, two third cost is provided by the government in subsidy form and remaining one third part of O&M cost is covered from the consumers by sale of electricity. Figure 4-3 shows the stakeholders participation in electricity generation activities of remote area communities in Ontario.

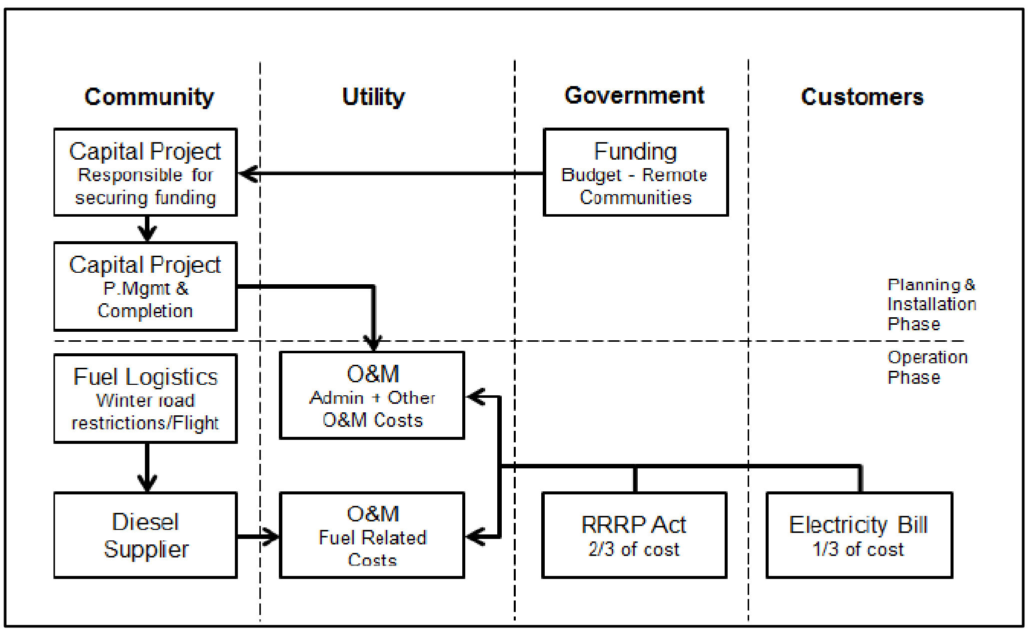


Figure 4-3 Stakeholders participation in electricity generation of remote areas, Ontario
Source: Arriaga et al. (2013)

4.1.2 Existing Electricity Rates and Subsidy Policies

Arriaga et al (Arriaga et al. 2016) provided the electricity rates and subsidies in remote area communities. The applicable electricity rates in remote area communities of Canada are classified as follows:

Unsubsidized Customers: These customers pay the actual electricity cost. These rates mainly applied to the federal government clients and some community owned buildings. These customers are, therefore, allowed to install their own RE equipment for self-consumption purpose. It is important to note that there is no subsidy for the government clients and the community owned buildings (Arriaga et al. 2013).

Subsidized Customers: These customers pay electricity rates matching the electricity rates of southern locations of the provinces. In general these rates are applied to residential customers. These electricity rates are 10% to 20% of the actual electricity cost. The utility operator charges subsidized electricity rate of $0.13/kWh following the residential electricity customer rate effective from Jan 1, 2012 (Hydro One 2012).

Avoided Fuel Cost (AFC) Customers: This is not an electricity rate. This is a fuel displacement cost resulting from renewable electricity generation and the diesel generation including administration and transportation costs. The AFC ultimately represent the energy cost to compete the RE project against DG. Under the AFC, a power purchase agreement can be established with the utility to export RE power to the micro-grid by fixing the rate to AFC.

UPHSM System Impact on Subsidy

It can be observed that the cost of DG power in off-grid communities is very high than grid power. Therefore, to match the power supply rate of off-grid communities with grid power, the Government of Canada has to bear a high financial cost in terms of subsidies and rebates as explained above. UPHSM can decrease the power production cost in off-grid location and the load of subsidy could also be reduced. Accordingly, the proposed UPHSM system could be a useful step if potential savings in diesel consumption are achieved.

4.2 Applying Optimization for Combined Scheduling of UPHSM and Diesel Generation

The optimization model used the proposed capacity of the storage which is based on available data of the case study. The methodological process provided in chapter 3 was applied for establishing the UPHSM system in the case study area with the following assumptions:

1. The "UPHSM system" is existed in the case study area.
2. The renewable generators including wind and solar are existed and provide supply for pumping operation of UPHSM system.
3. As such the hybrid system comprising UPHSM unit, DG, and renewable energy generators is fully operative and capable to meet the power demand of the case study area.

4.2.1 Data Sheet

The model parameters used in optimization process and their values are provided in Table 4-1.

Table 4-1 Input Data and Decision Variables

No.	Parameters	Symbol	Unit	Value	Source
	Actual and Assumed Parameters				
1	Life period of UPHSM Unit	Y	Years	50	1
2	Existing population of the community (year 2017)	N	Number	743	2
3	Yearly population increase rate of the community	I	%	4	3
4	Average yearly energy inflation rate	M	%	2.65	4
5	Existing daily energy demand/ capita/ day	E_t	kWh	20.88	5
6	Rate for purchase of Power by UPHSM (year 2017)	CA	C$/kWh	0.0196	Assumed
7	Rate for Sale of Power by UPHSM/ diesel generator (year 2017)	BA	C$/kWh	0.098	6
8	Existing daily power demand (year 2017)	P_t	kWh	15514	7
9	Capital cost of UPHSM	F	C$/kWh	358	8
10	First year O&M cost of UPHSM as percentage of capital cost	K	%	0.35	9
11	Yearly inflation rate for increase in O&M cost of UPHSM	Q	%	1.55	10
12	Minimum acceptable rate of return (MARR)	R	%	3.33	Assumed
13	Pump-turbine efficiency of UPHSM unit	H	%	80%	11
14	Residual value of UPHSM plant at the end of plant life (% of capital cost)	V	%	15%	12
15	Energy storage capacity of UPHSM unit i. Existing solar installation = 20 kW (for max 9Hrs) ii. Proposed solar installation = 300 kW (for max 9Hrs) iii. Assumed wind power = 4000 kW (for max 12 hrs).	C	kWh	51840	13
16	Maximum limit of Energy to be provided by UPHSM	PSU_{max}	kWh	90 % of max load	

17	Available Solar Power Potential	PSU_S	kW	320	14
18	Available Wind Power Potential	PSU_W	kW	4000	Assumed
19	Unit capital cost of Solar Installation	f_S	C$/kW	2700	15
20	Unit Capital cost of Wind farm	f_w	C$/kW	2000	16
Decision Variables					
1	Energy supply by UPHSM (off-peak)	PSU_{off}	kWh	-	-
2	Energy supply by UPHSM (mid-peak)	PSU_{mid}	kWh	-	-
3	Energy supply by UPHSM (on-peak)	PSU_{on}	kWh	-	-
4	Energy supply by diesel generator (off-peak)	PSD_{off}	kWh	-	-
5	Energy supply by diesel generator (mid-peak)	PSD_{mid}	kWh	-	-
6	Energy supply by diesel generator (on-peak)	PSD_{on}	kWh	-	-

Sources:

1. Zach et. al (2012), Mooney, D.(2015)
2. Indigenous and Northern Affairs Canada (2013)
3. Projections of the Aboriginal population and households in Canada, Stats Canada (2015)
4. Statistics Canada, Government of Canada - Consumer Price Index by Province (Ontario)(https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1810000413)
5. Karanasios, K., and Parker, P. (2016)
6. Karanasios, K., and Parker, P. (2016)
7. Karanasios, K., and Parker, P. (2016)
8. (Olsen et al. 2015)
9. Galvan-Lopez (2014)
10. Statistics Canada (2018)
11. (Olsen et al. 2015)
12. Guzman (2010)
13. Karanasios, K., and Parker, P.(2016)
14. Karanasios, K., and Parker, P.(2016)
15. https://solarpanelpower.ca/cost-solar-panels-canada/
16. Affordable Power - Canadian Wind Energy Association (https://canwea.ca/wind-facts/affordable-power/)

4.2.2 Problem Solution

The values of known parameter were provided in the system constraints to solve the problem. The problem was solved using two seasons of winter and summer in each year for the life period of UPHSM Unit. In each season, the unit cost of energy sale and purchase were estimated for one day cycle operation to apply those as average values for the whole season. The winter and summer seasons consists of 181 and 184 days respectively. Accordingly, the objective function and system constraints were defined in the LINGO software (version 17) to solve the problem as given below.

Objective Function:

$$\text{Maximize} \quad \left[181\left\{\sum_{t}^{nT}\left((PSU_t + PSD_t) \times BA_t\right) - \sum_{t}^{nT}\left(\frac{1}{\eta} PSU_t \times CA_t\right) - \sum_{t}^{nT}(PSD_t \times BA_t)\right\}\right.$$

$$\left. + \; 184\left\{\sum_{t}^{nT}\left((PSU_t + PSD_t) \times BA_t\right) - \sum_{t}^{nT}\left(\frac{1}{\eta} PSU_t \times CA_t\right) - \sum_{t}^{nT}(PSD_t \times BA_t)\right\}\right]$$

$$-(1 + q) \times p \times f \times C$$

Subject to the following constraints:

$$PSU_{off} + PSD_{off} \le P_{off}$$

$$PSU_{on} + PSD_{on} \le P_{on}$$

$$PSU_{mid} + PSD_{mid} \le P_{mid}$$

$$PSU_{off} + PSU_{on} + PSU_{on} \le 0.90 \times (P_{off} + P_{mid} + P_{on})$$

$$(PSD_{off} + PSD_{on} + PSD_{on}) + (PSU_{off} + PSU_{on} + PSU_{on}) \le P_{off} + P_{on} + P_{mid}$$

$$PSU_{off} \le (PSU_P - PSU_W)$$

$$(PSU_{mid} + PSU_{on}) \le (PSU_P - PSU_S)$$

$$PSU_{off}, PSU_{on}, PSU_{on}, PSD_{off}, PSD_{on} \text{ and } PSD_{on} \ge 0$$

Model Input Data

The season-wise energy rates for off, mid and on-peak hours are provided in Table 4.2 as projected values for each year of UPHSM life-period.

Table 4-2 Projected values of season-wise energy rates for off, mid and on-peak hours

YEAR	Winter Season (JAN TO APRIL and NOV to DEC)				Summer Season (MAY TO OCT)			
	*Average Yearly Energy Inflation Rate (2.65%)			CA= 0.20 OFF	*Average Yearly Energy Inflation Rate (2.65%)			CA= 0.20 OFF
	OFF	MID	ON		OFF	MID	ON	
2017	0.98	0.98	0.98	0.196	0.98	0.98	0.98	0.20
2018	1.01	1.01	1.01	0.201	1.01	1.01	1.01	0.20
2019	1.03	1.03	1.03	0.207	1.03	1.03	1.03	0.21
2020	1.06	1.06	1.06	0.212	1.06	1.06	1.06	0.21
2021	1.09	1.09	1.09	0.218	1.09	1.09	1.09	0.22
2022	1.12	1.12	1.12	0.223	1.12	1.12	1.12	0.22
2023	1.15	1.15	1.15	0.229	1.15	1.15	1.15	0.23
2024	1.18	1.18	1.18	0.235	1.18	1.18	1.18	0.24
2025	1.21	1.21	1.21	0.242	1.21	1.21	1.21	0.24
2026	1.24	1.24	1.24	0.248	1.24	1.24	1.24	0.25
2027	1.27	1.27	1.27	0.255	1.27	1.27	1.27	0.25
2028	1.31	1.31	1.31	0.261	1.31	1.31	1.31	0.26
2029	1.34	1.34	1.34	0.268	1.34	1.34	1.34	0.27
2030	1.38	1.38	1.38	0.275	1.38	1.38	1.38	0.28
2031	1.41	1.41	1.41	0.283	1.41	1.41	1.41	0.28
2032	1.45	1.45	1.45	0.290	1.45	1.45	1.45	0.29
2033	1.49	1.49	1.49	0.298	1.49	1.49	1.49	0.30
2034	1.53	1.53	1.53	0.306	1.53	1.53	1.53	0.31
2035	1.57	1.57	1.57	0.314	1.57	1.57	1.57	0.31
2036	1.61	1.61	1.61	0.322	1.61	1.61	1.61	0.32
2037	1.65	1.65	1.65	0.331	1.65	1.65	1.65	0.33
2038	1.70	1.70	1.70	0.339	1.70	1.70	1.70	0.34
2039	1.74	1.74	1.74	0.348	1.74	1.74	1.74	0.35
2040	1.79	1.79	1.79	0.358	1.79	1.79	1.79	0.36
2041	1.84	1.84	1.84	0.367	1.84	1.84	1.84	0.37
2042	1.88	1.88	1.88	0.377	1.88	1.88	1.88	0.38
2043	1.93	1.93	1.93	0.387	1.93	1.93	1.93	0.39
2044	1.99	1.99	1.99	0.397	1.99	1.99	1.99	0.40
2045	2.04	2.04	2.04	0.408	2.04	2.04	2.04	0.41
2046	2.09	2.09	2.09	0.418	2.09	2.09	2.09	0.42
2047	2.15	2.15	2.15	0.430	2.15	2.15	2.15	0.43
2048	2.20	2.20	2.20	0.441	2.20	2.20	2.20	0.44
2049	2.26	2.26	2.26	0.453	2.26	2.26	2.26	0.45
2050	2.32	2.32	2.32	0.465	2.32	2.32	2.32	0.46
2051	2.38	2.38	2.38	0.477	2.38	2.38	2.38	0.48
2052	2.45	2.45	2.45	0.490	2.45	2.45	2.45	0.49
2053	2.51	2.51	2.51	0.503	2.51	2.51	2.51	0.50
2054	2.58	2.58	2.58	0.516	2.58	2.58	2.58	0.52
2055	2.65	2.65	2.65	0.530	2.65	2.65	2.65	0.53
2056	2.72	2.72	2.72	0.544	2.72	2.72	2.72	0.54
2057	2.79	2.79	2.79	0.558	2.79	2.79	2.79	0.56
2058	2.86	2.86	2.86	0.573	2.86	2.86	2.86	0.57
2059	2.94	2.94	2.94	0.588	2.94	2.94	2.94	0.59
2060	3.02	3.02	3.02	0.604	3.02	3.02	3.02	0.60
2061	3.10	3.10	3.10	0.620	3.10	3.10	3.10	0.62
2062	3.18	3.18	3.18	0.636	3.18	3.18	3.18	0.64
2063	3.26	3.26	3.26	0.653	3.26	3.26	3.26	0.65
2064	3.35	3.35	3.35	0.670	3.35	3.35	3.35	0.67
2065	3.44	3.44	3.44	0.688	3.44	3.44	3.44	0.69
2066	3.53	3.53	3.53	0.706	3.53	3.53	3.53	0.71

CA=Power Purchase Price by UPHSM

* Source: Statistics Canada, Government of Canada - Consumer Price Index by Province (Ontario)

Season-wise data is provided in Table 4-3.

Table 4-3 Season-wise data

Season	**Days** (No)	**PSU_{Solar}**(kWh)	**PSU_{Wind}** (kWh)	**PSU_{Total}** (kWh)
Winter	181	980	38400	39380
Summer	184	3328	38400	41728

The season-wise daily power demand projected for life period of UPHSM system has been provided in Table 4-4 below.

Table 4-4 Season-wise daily power demand

Year	Population	Energy Demand/ Day/ Capita (kWh/ Day/ Capita)	Energy Demand/ Day (kWh/ Day)	Winter Power Demand/ Day (P_{tw}) Off-Peak 24% (kWh)	Mid-Peak 34% (kWh)	On-Peak 42% (kWh)	Total 100% (kWh)	Summer Power Demand/ Day (P_{ts}) Off-Peak 21% (kWh)	Mid-Peak 36% (kWh)	On-Peak 43% (kWh)	Total 100% (kWh)
2017	743	20.88	15514	4245	6013	7428	17686	2802	4803	5737	13342
2018	773	20.88	16140	4416	6256	7728	18400	2915	4997	5969	13881
2019	804	20.88	16788	4593	6507	8038	19138	3032	5197	6208	14437
2020	837	20.88	17477	4782	6774	8368	19923	3156	5411	6463	15030
2021	871	20.88	18186	4976	7049	8708	20733	3284	5631	6725	15640
2022	906	20.88	18917	5176	7332	9058	21566	3416	5857	6996	16269
2023	943	20.88	19690	5387	7632	9427	22446	3556	6096	7281	16933
2024	981	20.88	20483	5604	7939	9807	23351	3699	6342	7575	17616
2025	1021	20.88	21318	5833	8263	10207	24303	3850	6600	7884	18334
2026	1062	20.88	22175	6067	8595	10617	25279	4005	6865	8200	19070
2027	1105	20.88	23072	6313	8943	11047	26303	4167	7143	8532	19842
2028	1150	20.88	24012	6570	9307	11497	27374	4337	7434	8880	20650
2029	1196	20.88	24972	6832	9679	11957	28469	4510	7731	9235	21476
2030	1244	20.88	25975	7107	10068	12437	29611	4691	8042	9605	22338
2031	1294	20.88	27019	7392	10472	12937	30801	4880	8365	9992	23236
2032	1346	20.88	28104	7689	10893	13456	32039	5076	8701	10393	24170
2033	1400	20.88	29232	7998	11330	13996	33324	5279	9050	10810	25140
2034	1456	20.88	30401	8318	11784	14556	34657	5490	9412	11242	26145
2035	1515	20.88	31633	8655	12261	15146	36062	5713	9794	11698	27205
2036	1576	20.88	32907	9003	12755	15756	37514	5943	10188	12169	28300
2037	1640	20.88	34243	9369	13273	16396	39037	6184	10602	12663	29449
2038	1706	20.88	35621	9746	13807	17055	40608	6433	11028	13173	30634
2039	1775	20.88	37062	10140	14365	17745	42251	6693	11474	13706	31873
2040	1846	20.88	38544	10546	14940	18455	43941	6961	11933	14254	33148
2041	1920	20.88	40090	10969	15539	19195	45702	7240	12412	14825	34477
2042	1997	20.88	41697	11408	16162	19965	47535	7531	12910	15420	35860
2043	2077	20.88	43368	11865	16809	20764	49439	7832	13427	16037	37296
2044	2161	20.88	45122	12345	17489	21604	51439	8149	13970	16686	38805
2045	2248	20.88	46938	12842	18193	22474	53510	8477	14532	17358	40367
2046	2338	20.88	48817	13356	18922	23374	55652	8816	15114	18053	41983
2047	2432	20.88	50780	13893	19682	24314	57889	9171	15722	18779	43671
2048	2530	20.88	52826	14453	20476	25293	60222	9540	16355	19535	45431
2049	2632	20.88	54956	15036	21301	26313	62650	9925	17014	20323	47262
2050	2738	20.88	57169	15642	22159	27373	65173	10325	17700	21141	49166
2051	2848	20.88	59466	16270	23049	28472	67792	10740	18411	21991	51141
2052	2962	20.88	61847	16921	23972	29612	70505	11169	19148	22871	53188
2053	3081	20.88	64331	17601	24935	30802	73338	11618	19917	23790	55325
2054	3205	20.88	66920	18309	25938	32041	76289	12086	20719	24747	57552
2055	3334	20.88	69614	19046	26982	33331	79360	12572	21552	25743	59868
2056	3468	20.88	72412	19812	28067	34671	82549	13078	22419	26778	62274
2057	3607	20.88	75314	20606	29192	36060	85858	13602	23317	27851	64770
2058	3752	20.88	78342	21434	30365	37510	89310	14149	24255	28971	67374
2059	3903	20.88	81495	22297	31587	39020	92904	14718	25231	30137	70085
2060	4060	20.88	84773	23194	32858	40589	96641	15310	26246	31349	72905
2061	4223	20.88	88176	24125	34177	42219	100521	15925	27299	32608	75832
2062	4392	20.88	91705	25090	35545	43908	104544	16562	28392	33912	78866
2063	4568	20.88	95380	26096	36969	45668	108733	17226	29530	35271	82027
2064	4751	20.88	99201	27141	38450	47497	113089	17916	30713	36684	85313
2065	4942	20.88	103189	28232	39996	49407	117635	18636	31947	38159	88743
2066	5140	20.88	107323	29364	41598	51386	122348	19383	33227	39688	92298

4.3 Establishing UPHSM System Using Optimal Storage Capacity

Considering the available renewable potential in the Fort Severn community area, storage capacity of the UPHSM system is 41,728 kWh. Accordingly, the component sizes have been appropriately adjusted to satisfy the available storage capacity using the UPHSM energy formula as given below.

$$E = g\,\rho_s H_s L^2 H_l\, \eta/3600 \text{ kWh}$$

The following result satisfied the available energy capacity:

$$E = (9.81\text{m/sec}^2 \times 2000 \text{ kg/m}^3 \times 10\text{m} \times 250\text{m} \times 250\text{m} \times 15.31\text{m} \times 0.8) / 1000 \times 3600$$

$$\mathbf{= 41{,}728 \text{ kWh}}$$

Accordingly, Table 4-5 was prepared to provide the component sizes of the proposed UPHSM system.

Table 4-5 Component sizes of UPHSM system

No.	Component sizes	Unit	Value
1	Size of UPHSM membrane for underground storage	m^2	250 x 250
2	Lift height of soil layer	m	10
3	Thickness of soil layer	m	15.31
4	Efficiency of pump-turbine	%	80%

Therefore, the above component sizes are the UPHSM system design parameters of this study project.

Minimum Water Flow Rate to Fill the UPHSM Water Storage Chamber

Volume of the chamber = 250m x 250m x 10m = 625000 m^3

Proposed operational pumping hours in one cycle = 12hrs = 43200 sec.

Flow = 625000 m^3/43200 sec = 14.47 m^3/sec

Assuming 100% allowance on the flow rate, the required minimum water flow rate in the river should be 28.9 m^3/sec

4.3.1 Identifying Suitable UPHSM Site

In order to identify a suitable site for establishing UPHSM system in Forte Severn community, the shape file of Fort Severn area was downloaded from Ryerson Geospatial Map & Data Centre (https://library.ryerson.ca/gmdc/madar/geo-data/search). The Fort Severn polygon was extracted from ‘Census Subdivision Boundary File’ (Statistics Canada 2014) using Select tool in ArcGIS as shown in Figure 4-4.

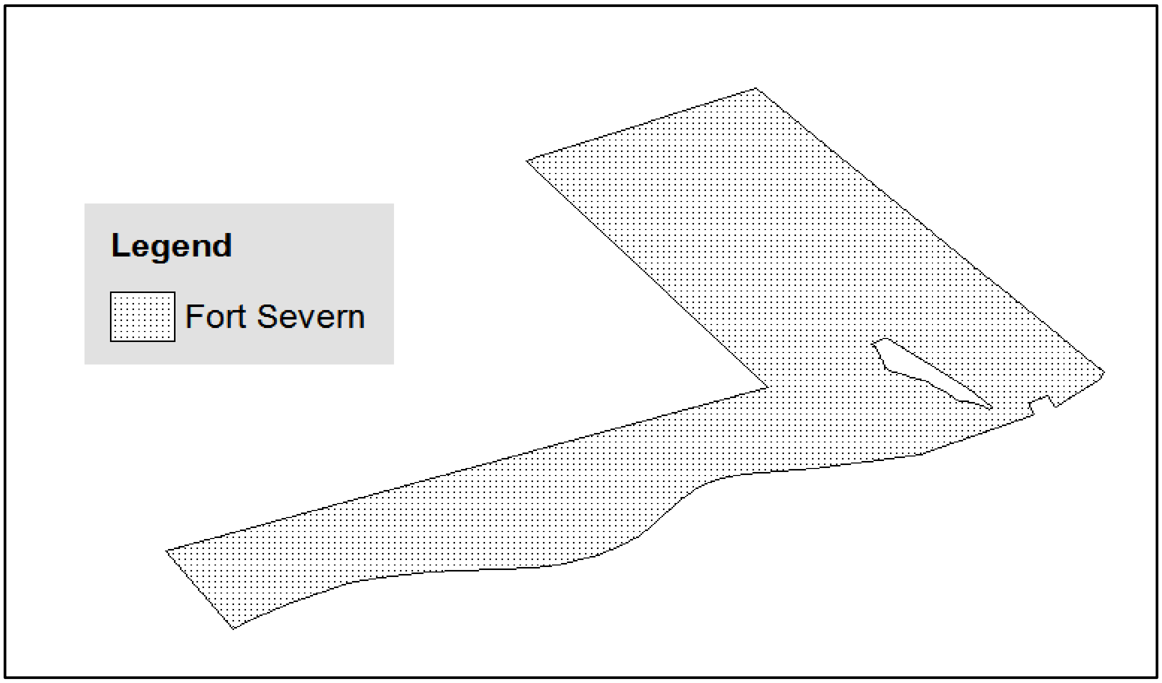


Figure 4-4 Shape file of Fort Severn community area

The possible areas were identified using GIS tools in ArcGIS software. The following layers were used for screening purpose to identify the feasible sites:

- Built-up areas (Ontario Ministry of Natural Resources 2006);
- Existing local infrastructure other than residential area (Ontario Ministry of Natural Resources 2012);
- Provincial parks (Ontario Ministry of Natural Resources 2008);
- National wild life area (Ontario Ministry of Natural Resources 2005);
- NGO natural reserves (Ontario Ministry of Natural Resources 2009);
- Wetland (Ontario Ministry of Natural Resources 2011);

Each layer was erased from the Fort Severn shape one by one to get the area free from any constraint. Figure 4-4 shows the available constraints free areas.

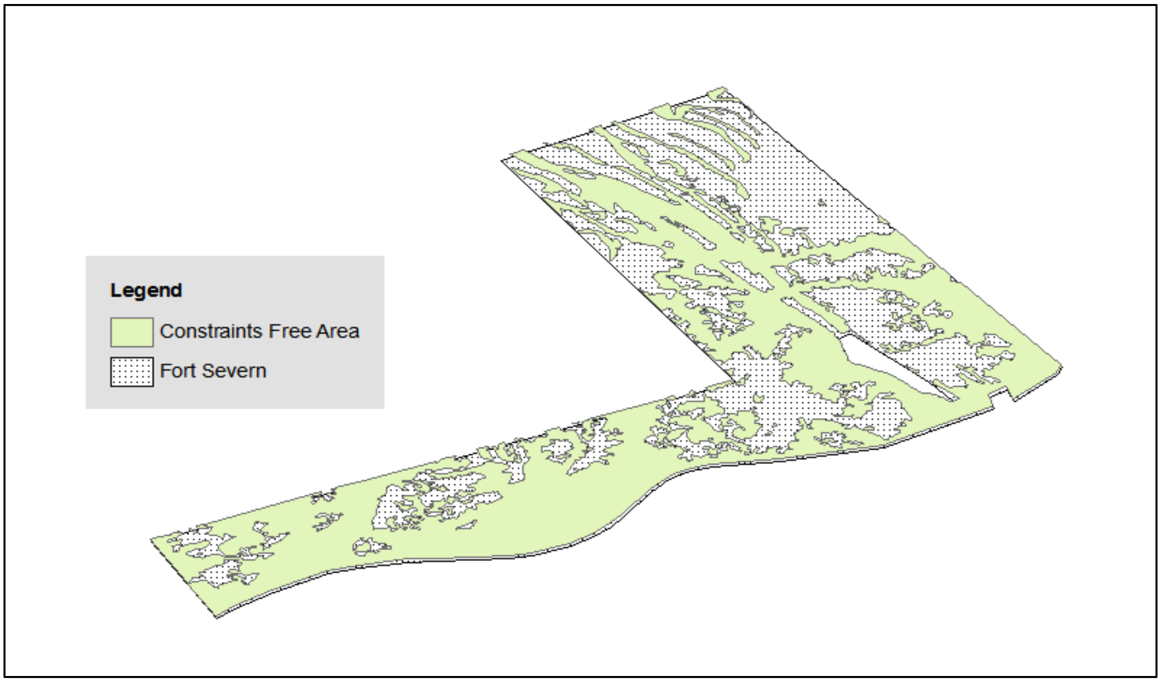


Figure 4-5 Constraints free areas in Fort Severn Area

In order to find the sites within 500 meter and at least 200 meter away from the roads, multiple ring buffer tool was used to generate an area with minimum 200 meter and maximum 500 meters distance from roads. The result of multiple ring buffers is shown in Figure 4-6. This area was clipped from 'Constraints Free Area' to generate another shape file free from constraints and within proposed road distance. This shape file was named as 'Candidate Areas' as shown in Figure 4-7

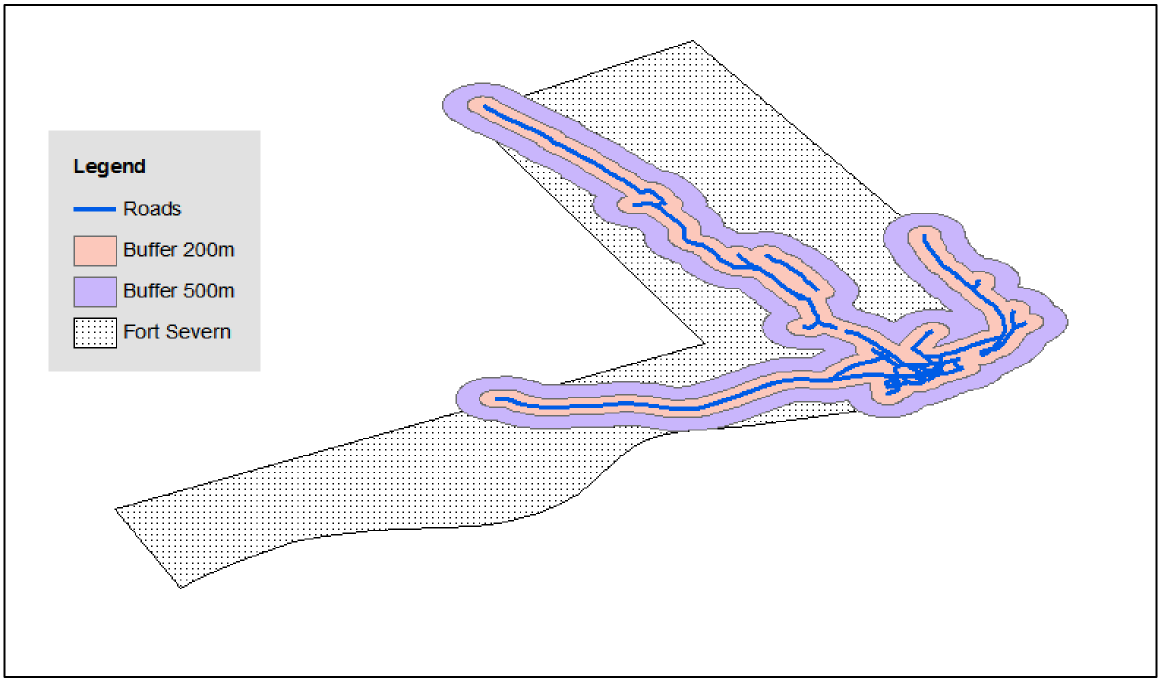


Figure 4-6 Buffer zones around roads

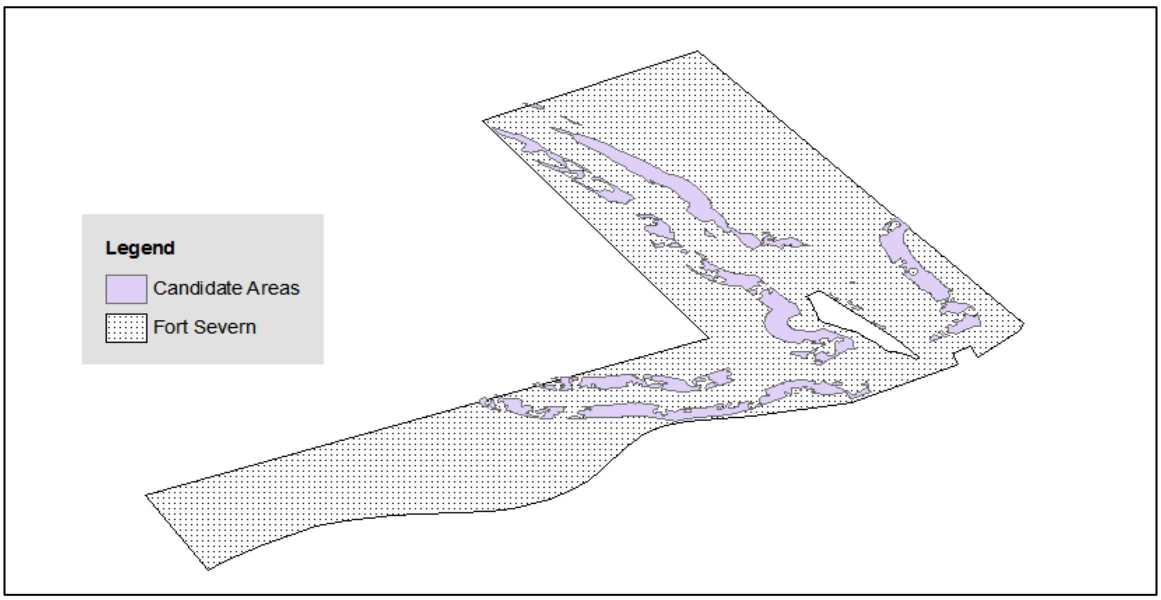


Figure 4-7 Candidate areas within buffer zone

Using ArcGIS, the area was divided into multiple rectangles using ArcGIS shape Editor, where sites could be formed. After cutting these rectangles, Multipart to Single part tool was used to generated areas, named as 'Candidate Sites' as shown in Figure 4-8.

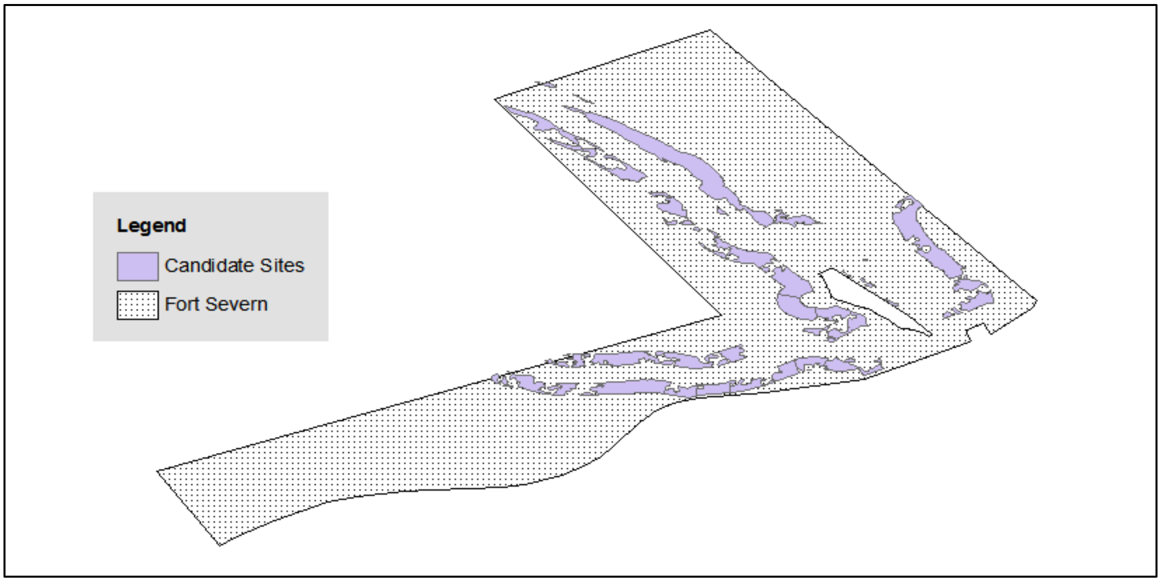


Figure 4-8 Candidate sites

The waterbodies shape file (Ontario Ministry of Natural Resources 2010) was downloaded to select best suitable waterbody for site. The waterbodies file was processed by Spatial Join tool to find waterbodies within 1 Km of Fort Severn. After processing, 181 waterbodies were found as shown in Figure 4-9. Out of these waterbodies, Fort Severn River was selected having largest flow. The shape file of Fort Severn River was extracted from waterbodies shape file using Select tool.

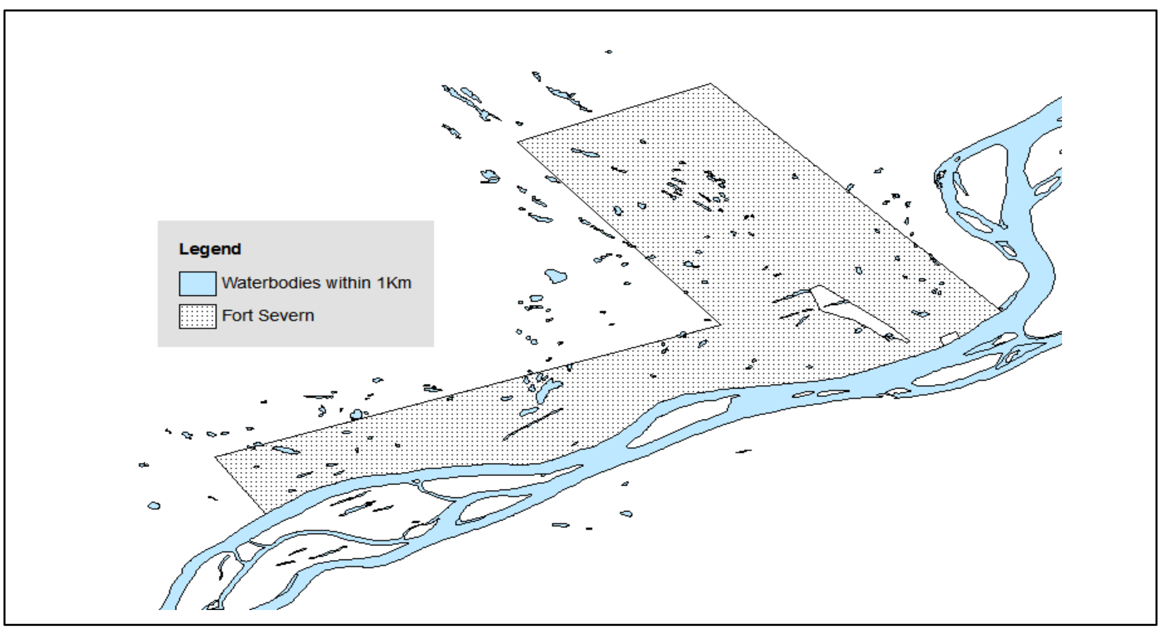


Figure 4-9 Waterbodies within 1 Km of Fort Severn

The shape file of Fort Severn Diesel generator was created using ArcGIS using its location from Google maps. The Diesel Generator is shown in Figure 4-10 as point feature.

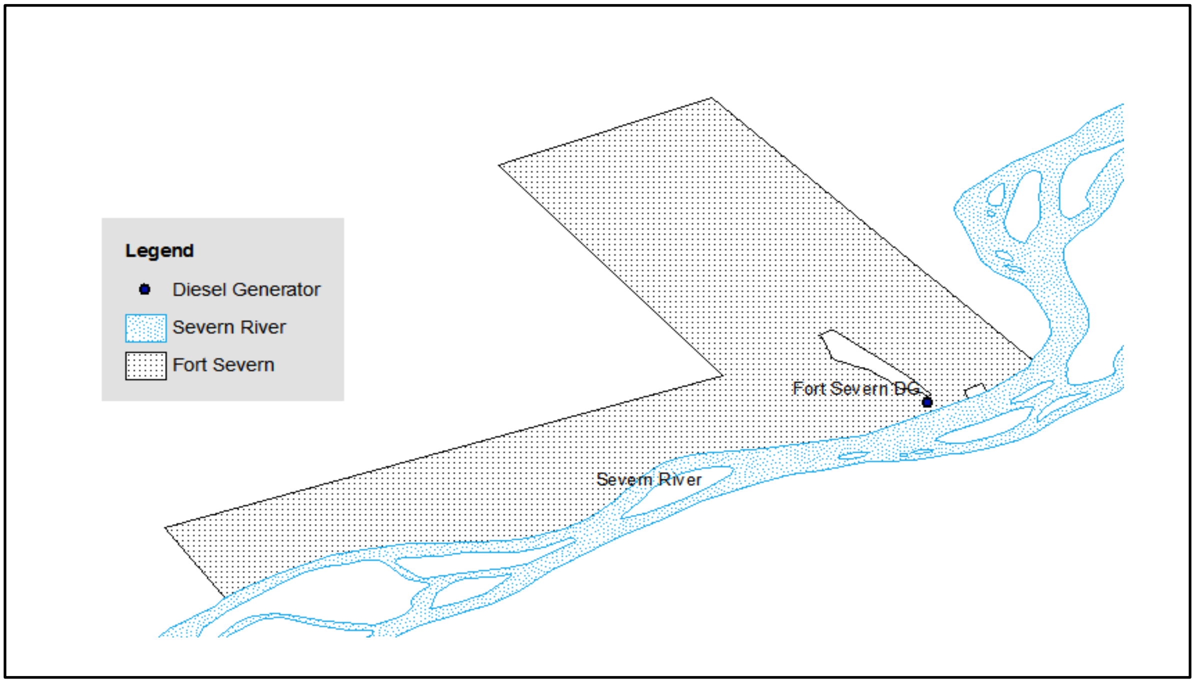


Figure 4-10 Location of Severn River and Fort Severn diesel generator

Sites with minimum Area of 70,000 m^2 was extracted as shown in Figure 4-11, labeled as ‘sites with minimum area’.

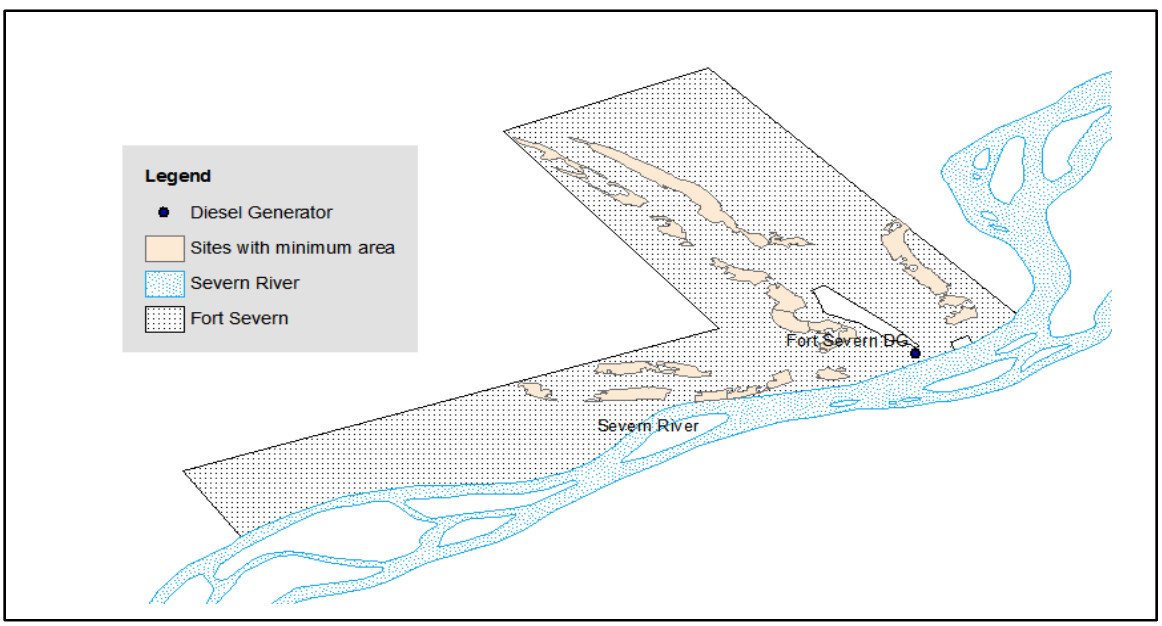


Figure 4-11 Sites with minimum required area

Distances from Severn River and Fort Severn DG were calculated using 'Near' tool. Sites with maximum distance of 200m from Severn River were selected for processing, as shown in Figure 4-12.

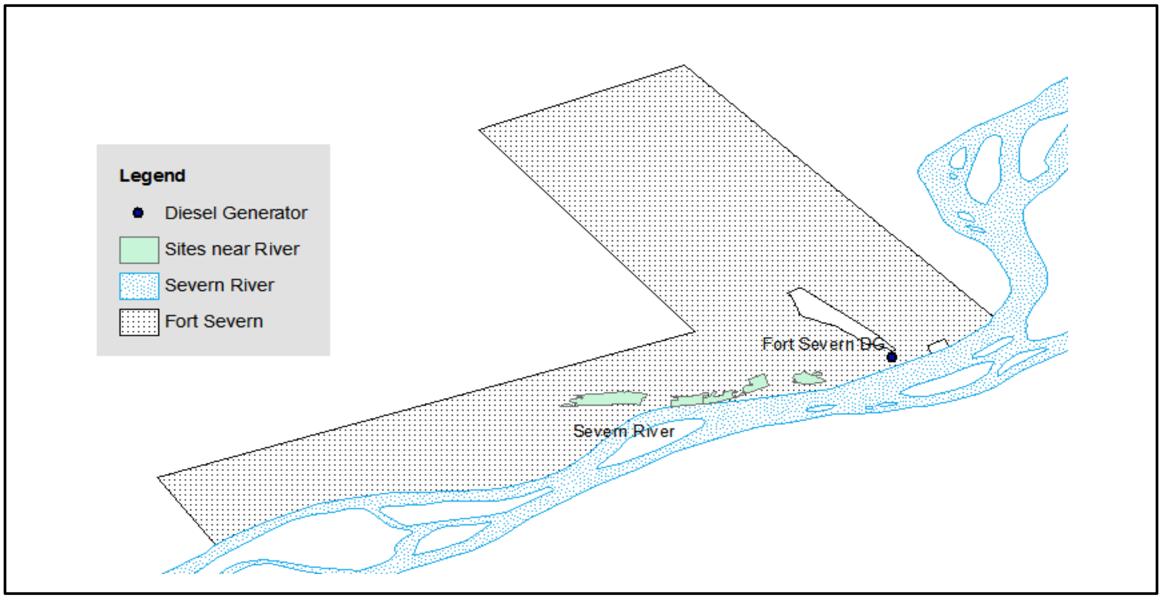


Figure 4-12 Sites near Severn River

Finally, a distance of 1200 meter was applied to select the final site as shown in Figure 4-13.

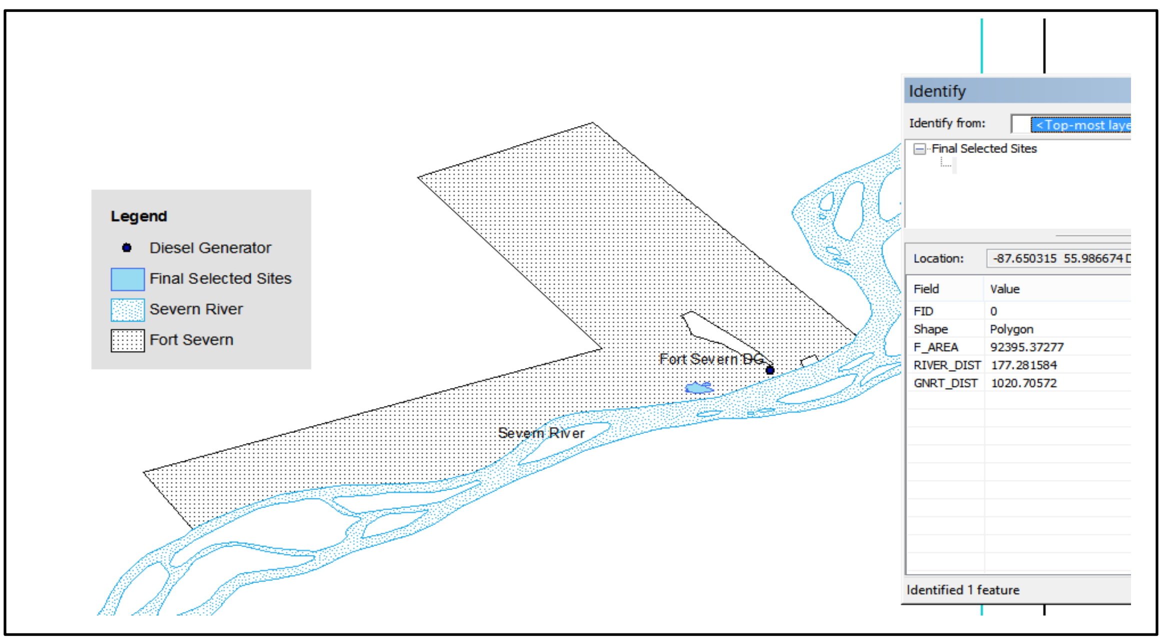


Figure 4-13 Final selected sites

4.3.2 Locating Waterbody in Proximity to UPHSM Site

In order to establish the UPHSM site, a map of Fort Severn area was downloaded from the website: https://library.ryerson.ca/gmdc/madar/geo-data/search of Ryerson University Library and Archives (RULA) to study the available water bodies in this area. The

water bodies map prepared by Ontario Ministry of Natural Resources (2010) was considered for this study. It was observed that Limestone Rapids station at Severn River is the nearest discharge recording station for Fort Severn community area. The location located map of Severn River is shown in Figure 4-14.

Figure 4-14 Location map of Severn River segment in vicinity of Fort Severn area
Source: https://www.travelblog.org/Photos/5290962 (Cited on Nov 09, 2017)

The average monthly discharge of Severn River at station Limestone Rapids (Station No. 04CC001) was taken from "National water data archive" database. The mean flow values as obtained from database are provided in Table 4-6.

Table 4-6 Average monthly flows for Limestone Rapids station

Month	**Average Flow (m^3/sec)**
January	274.27
February	215.68
March	181.45
April	218.52
May	1164.28
June	1201.27
July	952.04
August	807.26
September	771.47
October	776.56
November	598.04
December	401.52

The above flow data shows that the minimum available discharge of the Severn River is 181.45 m^3/ sec in the month of March which is much higher than the minimum water flow requirement for the UPHSM system (28.9 m^3 /sec as calculated in section 4.3). Therefore, it is confirmed that the Severn River is a suitable waterbody for the proposed UPHSM system in the Fort Severn community area. The schematic diagram of the Established UPHSM unit is shown in Figure 4-15.

Figure 4-15 Schematic diagram of UPHSM System integrated with Renewables and DG Plant

4.4 Results and Discussions

The proposed UPHSM system is designed for a life period of 50 years. The system purchases energy from renewable generators and stores in the membrane chamber. The system works on mix power supply concept managed by UPHSM and DG. The proposed model is applied on a case study area of Fort Severn, Ontario. The optimization results provided the power supply to consumers in off, mid and peak hours by UPHSM and DG as shown in Table 4-7.

Table 4-7 Optimal output values of variable terms

Year	Winter									Summer								
	Energy supply by DG (DS)				Energy supply by UPHSM (US)					Energy supply by DG (DS)				Energy supply by UPHSM (US)				
	OFF	MID	ON	TOTAL	OFF	MID	ON	TOTAL	US+DS	OFF	MID	ON	TOTAL	OFF	MID	ON	TOTAL	US+DS
	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)	(kWh)
2017	3265	0	0	3265	980	6013	7428	14421	17686	0	0	1334	1334	2802	4803	4403	12008	13342
2018	3436	0	0	3436	980	6256	7728	14964	18400	0	0	1388	1388	2915	4997	4581	12493	13881
2019	3613	0	0	3613	980	6507	8038	15525	19138	0	0	1444	1444	3032	5197	4764	12994	14437
2020	3802	0	0	3802	980	6774	8368	16122	19923	0	0	1503	1503	3156	5411	4960	13527	15030
2021	3996	0	0	3996	980	7049	8708	16737	20733	0	0	1564	1564	3284	5631	5161	14076	15640
2022	4196	0	0	4196	980	7332	9058	17370	21566	88	0	1538	1627	3328	5857	5457	14642	16269
2023	4407	0	0	4407	980	7632	9427	18039	22446	228	0	1465	1693	3328	6096	5816	15240	16933
2024	4624	0	0	4624	980	7939	9807	18727	23351	371	0	1390	1762	3328	6342	6184	15854	17616
2025	4853	0	0	4853	980	8263	10207	19450	24303	522	0	1311	1833	3328	6600	6572	16501	18334
2026	5087	0	0	5087	980	8595	10617	20192	25279	677	0	1230	1907	3328	6865	6970	17163	19070
2027	5333	0	0	5333	980	8943	11047	20970	26303	839	0	1145	1984	3328	7143	7387	17858	19842
2028	5590	0	0	5590	980	9307	11497	21784	27374	1009	0	1056	2065	3328	7434	7823	18585	20650
2029	5852	0	0	5852	980	9679	11957	22616	28469	1182	0	966	2148	3328	7731	8269	19329	21476
2030	6127	0	0	6127	980	10068	12437	23484	29611	1363	0	871	2234	3328	8042	8735	20104	22338
2031	6412	0	0	6412	980	10472	12937	24389	30801	1552	0	772	2324	3328	8365	9219	20912	23236
2032	6709	0	0	6709	980	10893	13456	25330	32039	1748	0	669	2417	3328	8701	9724	21753	24170
2033	7018	0	0	7018	980	11330	13996	26307	33324	1951	0	563	2514	3328	9050	10247	22626	25140
2034	7338	0	0	7338	980	11784	14556	27320	34657	2162	0	452	2615	3328	9412	10790	23531	26145
2035	7675	0	0	7675	980	12261	15146	28387	36062	2385	0	335	2720	3328	9794	11362	24484	27205
2036	8023	0	0	8023	980	12755	15756	29491	37514	2615	0	215	2830	3328	10188	11954	25470	28300
2037	8389	0	0	8389	980	13273	16396	30648	39037	2856	0	89	2945	3328	10602	12575	26504	29449
2038	8766	0	0	8766	980	13807	17055	31842	40608	3105	0	0	3105	3328	11028	13173	27529	30634
2039	9160	0	0	9160	980	14365	17745	33091	42251	3365	0	0	3365	3328	11474	13706	28508	31873
2040	9566	0	0	9566	980	14940	18455	34375	43941	3633	0	0	3633	3328	11933	14254	29515	33148
2041	9989	0	0	9989	980	15539	19195	35714	45702	3912	0	0	3912	3328	12412	14825	30565	34477
2042	10428	0	0	10428	980	16162	19965	37107	47535	4203	0	0	4203	3328	12910	15420	31657	35860
2043	10885	0	0	10885	980	16809	20764	38554	49439	4504	0	0	4504	3328	13427	16037	32792	37296
2044	11365	0	693	12059	980	17489	20911	39380	51439	4821	0	0	4821	3328	13970	16686	33984	38805
2045	11862	0	2267	14130	980	18193	20207	39380	53510	5149	0	0	5149	3328	14532	17358	35218	40367
2046	12376	0	3895	16272	980	18922	19478	39380	55652	5488	0	0	5488	3328	15114	18053	36495	41983
2047	12913	0	5596	18509	980	19682	18718	39380	57889	5843	0	0	5843	3328	15722	18779	37828	43671
2048	13473	0	7369	20842	980	20476	17924	39380	60222	6212	0	0	6212	3328	16355	19535	39218	45431
2049	14056	0	9214	23270	980	21301	17099	39380	62650	6597	0	0	6597	3328	17014	20323	40665	47262
2050	14662	0	11132	25793	980	22159	16241	39380	65173	6997	0	441	7438	3328	17700	20700	41728	49166
2051	15290	0	13122	28412	980	23049	15351	39380	67792	7412	0	2001	9413	3328	18411	19989	41728	51141
2052	15941	0	15184	31125	980	23972	14428	39380	70505	7841	0	3619	11460	3328	19148	19252	41728	53188
2053	16621	0	17337	33958	980	24935	13465	39380	73338	8290	0	5307	13597	3328	19917	18483	41728	55325
2054	17329	0	19580	36909	980	25938	12462	39380	76289	8758	0	7066	15824	3328	20719	17681	41728	57552
2055	18066	0	21914	39980	980	26982	11418	39380	79360	9244	0	8896	18140	3328	21552	16848	41728	59868
2056	18832	0	24338	43169	980	28067	10333	39380	82549	9750	0	10797	20546	3328	22419	15981	41728	62274
2057	19626	0	26852	46478	980	29192	9208	39380	85858	10274	0	12768	23042	3328	23317	15083	41728	64770
2058	20454	0	29475	49930	980	30365	8035	39380	89310	10821	0	14825	25646	3328	24255	14145	41728	67374
2059	21317	0	32207	53524	980	31587	6813	39380	92904	11390	0	16967	28357	3328	25231	13169	41728	70085
2060	22214	0	35047	57261	980	32858	5542	39380	96641	11982	0	19195	31177	3328	26246	12154	41728	72905
2061	23145	0	37996	61141	980	34177	4223	39380	100521	12597	0	21507	34104	3328	27299	11101	41728	75832
2062	24110	0	41053	65164	980	35545	2855	39380	104544	13234	0	23904	37138	3328	28392	10008	41728	78866
2063	25116	0	44237	69353	980	36969	1431	39380	108733	13898	0	26401	40299	3328	29530	8870	41728	82027
2064	26161	50	47497	73709	980	38400	0	39380	113089	14588	0	28997	43585	3328	30713	7687	41728	85313
2065	27252	1596	49407	78255	980	38400	0	39380	117635	15308	0	31707	47015	3328	31947	6453	41728	88743
2066	28384	3198	51386	82968	980	38400	0	**39380**	122348	16055	0	34515	50570	3328	33227	5173	**41728**	92298

Note: The design capacity of the UPHSM system that would be considered as the maximum power supply by UPHSM in a day during whole life period is **41728 kWh**

4.4.1 Energy Supply by UPHSM

The Figure 4-16 presents the energy supplied by UPHSM over the life period during summer and winter seasons starting from year 1 to year 50 as per optimization result. Initially, at year 1 during winter and summer the daily energy supplied by UPHSM is 14421 and 12008 kWh respectively, which is 34.50% and 28.8% respectively of the designed capacity of the UPHSM as unit and balance power demand of the community is met by DG. The situation gradually increases up to year 28 giving maximum for winter as 94.3% of UPHSM design capacity and remains steady for the remaining 22 years of the design period. In summer season, it gradually increases from year 1 to year 34 to reach its maximum designed capacity. It remains steady for the remaining 16 years period.

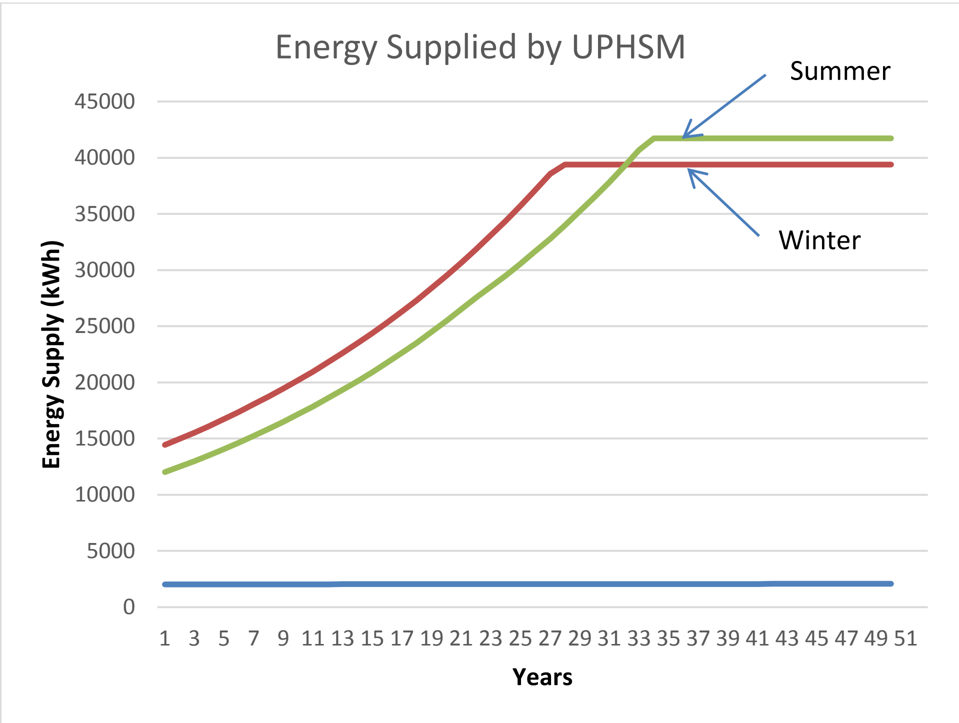


Figure 4-16 Energy supplied by UPHSM over the life period

4.4.2 Renewables Potential

Figure 4-17 shows the utilization of available renewable potential over the life period in summer and winter starting from year 1 to year 50 as per optimization result. Initially at year1, in winter and summer the system utitizes renewable energy almost 34% to 28.8% respectively as compared to total available renewable potential. It reaches to 94% in the year 28th in winter and to its maximum available potential in 34th year during summer. For the remaining 22 years, the system utilizes 94% of available renewable potential in winter and remaining 16 years of during summer seson it utilizes the total available renewable energy potential during remaining years.

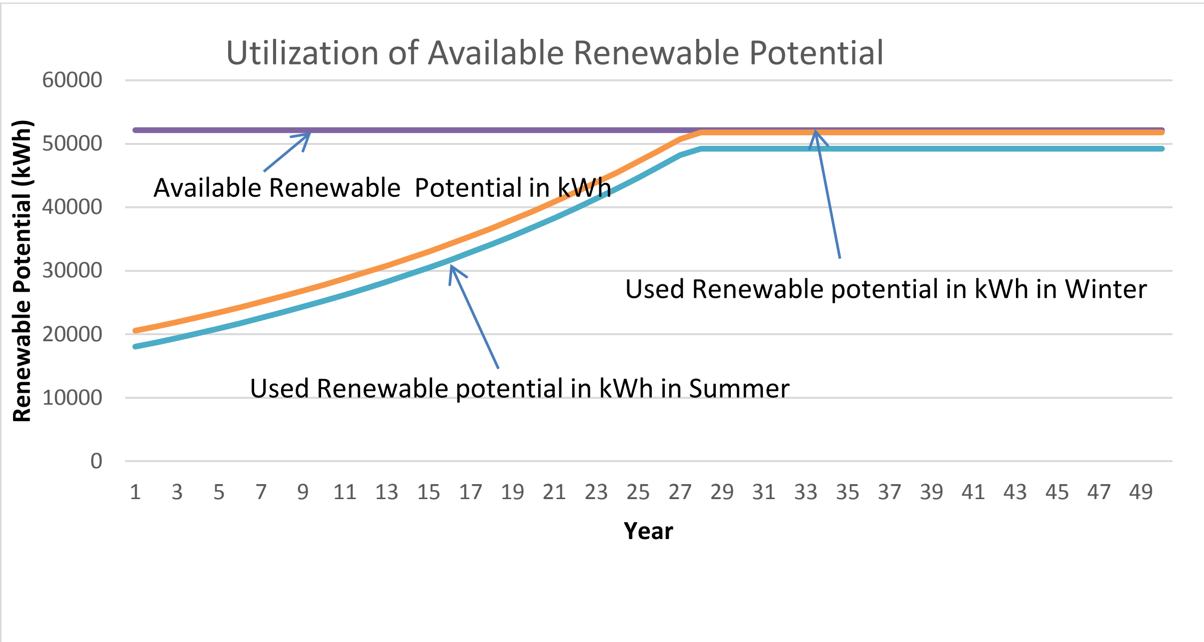


Figure 4-17 Utilization of available renewable potential over the design period

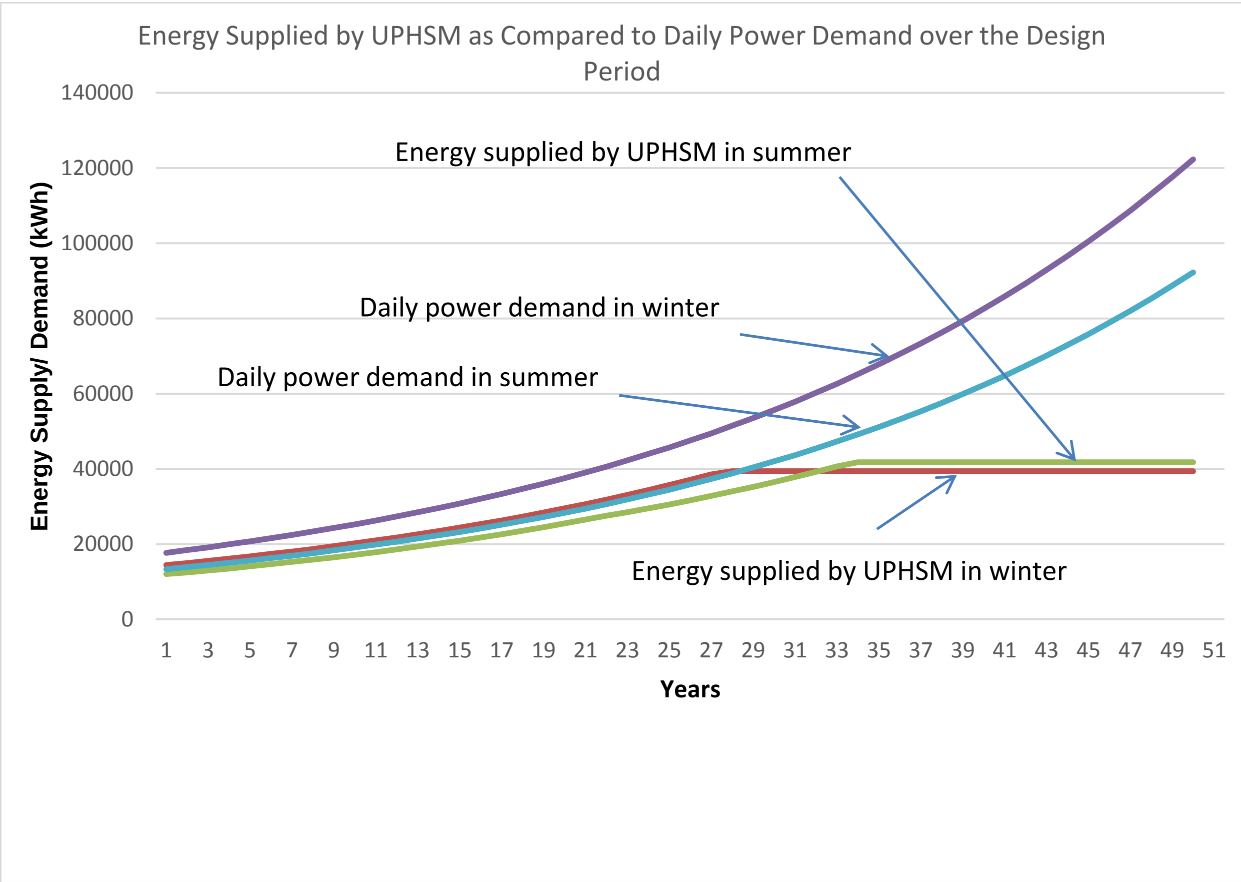
4.4.3 Energy Supplied by UPHSM Versus Daily Power Demand

Figure 4-18 and Table 4-8 presents the energy supplied by UPHSM with respects to daily power demand over the life period.

Table 4-8 Energy supplied by UPHSM versus daily power demand over the life period

Year	Energy Supplied by UPHSM (Winter) kWh	Daily Energy Demand (Winter) kWh	UPHSM Energy %	Energy Supplied by UPHSM in Summer kWh	Daily power Demand in kWh Summer Years	UPHSM Supply as Compared to demand (%)
2017	14421	17686	82	12008	13341.9	90
2018	14964	18400	81	12493	13880.61	90
2019	15525	19138	81	12994	14437.27	90
2020	16122	19923	81	13527	15029.84	90
2021	16737	20733	81	14076	15640.37	90
2022	17370	21566	81	14642	16268.86	90
2023	18039	22446	80	15240	16933.26	90
2024	18727	23351	80	15854	17615.62	90
2025	19450	24303	80	16501	18333.89	90
2026	20192	25279	80	17163	19070.12	90
2027	20970	26303	80	17858	19842.26	90
2028	21784	27374	80	18585	20650.32	90
2029	22616	28469	79	19329	21476.33	90
2030	23484	29611	79	20104	22338.26	90
2031	24389	30801	79	20912	23236.1	90
2032	25330	32039	79	21753	24169.85	90
2033	26307	33324	79	22626	25139.52	90
2034	27320	34657	79	23531	26145.1	90
2035	28387	36062	79	24484	27204.55	90
2036	29491	37514	79	25470	28299.92	90
2037	30648	39037	79	26504	29449.15	90
2038	31842	40608	78	27529	30634.3	90
2039	33091	42251	78	28508	31873.32	89
2040	34375	43941	78	29515	33148.25	89
2041	35714	45702	78	30565	34477.06	89
2042	37107	47535	78	31657	35859.73	88
2043	38554	49439	78	32792	37296.27	88
2044	39380	51439	77	33984	38804.64	88
2045	39380	53510	74	35218	40366.89	87
2046	39380	55652	71	36495	41983	87
2047	39380	57889	68	37828	43670.94	87
2048	39380	60222	65	39218	45430.7	86
2049	39380	62650	63	40665	47262.3	86
2050	39380	65173	60	41728	49165.72	85
2051	39380	67792	58	41728	51140.97	82
2052	39380	70505	56	41728	53188.04	78
2053	39380	73338	54	41728	55324.9	75
2054	39380	76289	52	41728	57551.54	73
2055	39380	79360	50	41728	59867.97	70
2056	39380	82549	48	41728	62274.18	67
2057	39380	85858	46	41728	64770.18	64
2058	39380	89310	44	41728	67373.91	62
2059	39380	92904	42	41728	70085.39	60
2060	39380	96641	41	41728	72904.61	57
2061	39380	100521	39	41728	75831.57	55
2062	39380	104544	38	41728	78866.27	53
2063	39380	108733	36	41728	82026.66	51
2064	39380	113089	35	41728	85312.76	49
2065	39380	117635	33	41728	88742.51	47
2066	**39380**	122348	32	**41728**	92297.95	45

Figure 4-18 Energy supplied by UPHSM versus daily power demand over the life period



4.4.4 Diesel Energy Savings after Integrating UPHSM System

Table 4-9 presents the savings in diesel energy in summer and winter over the life period for 50 years.

Table 4-9 Seasonwise diesel energy savings

Year	Winter			Summer		
	Daily power Demand in Winter (kWh)	Energy Supplied by DG in Winter (kWh)	Diesel Power savings (%)	Daily power Demand in Summer (kWh)	Energy Supplied by DG in Summer (kWh)	Diesel Power savings (%)
2017	17686	3265	82	13342	1334	90
2018	18400	3436	81	13881	1388	90
2019	19138	3613	81	14437	1444	90
2020	19923	3802	81	15030	1503	90
2021	20733	3996	81	15640	1564	90
2022	21566	4196	81	16269	1627	90
2023	22446	4407	80	16933	1693	90
2024	23351	4624	80	17616	1762	90
2025	24303	4853	80	18334	1833	90
2026	25279	5087	80	19070	1907	90
2027	26303	5333	80	19842	1984	90
2028	27374	5590	80	20650	2065	90
2029	28469	5852	79	21476	2148	90
2030	29611	6127	79	22338	2234	90
2031	30801	6412	79	23236	2324	90
2032	32039	6709	79	24170	2417	90
2033	33324	7018	79	25140	2514	90
2034	34657	7338	79	26145	2615	90
2035	36062	7675	79	27205	2720	90
2036	37514	8023	79	28300	2830	90
2037	39037	8389	79	29449	2945	90
2038	40608	8766	78	30634	3105	90
2039	42251	9160	78	31873	3365	89
2040	43941	9566	78	33148	3633	89
2041	45702	9989	78	34477	3912	89
2042	47535	10428	78	35859	4203	88
2043	49439	10885	78	37296	4504	88
2044	51439	12059	77	38805	4821	88
2045	53510	14130	74	40367	5149	87
2046	55652	16272	71	41983	5488	87
2047	57889	18509	68	43670	5843	87
2048	60222	20842	65	45431	6212	86
2049	62650	23270	63	47263	6597	86
2050	65173	25793	60	49166	7438	85
2051	67792	28412	58	51141	9413	82
2052	70505	31125	56	53188	11460	78
2053	73338	33958	54	55325	13597	75
2054	76289	36909	52	57552	15824	73
2055	79360	39980	50	59868	18140	70
2056	82549	43169	48	62274	20546	67
2057	85858	46478	46	64770	23042	64
2058	89310	49930	44	67373	25646	62
2059	92904	53524	42	70085	28357	60
2060	96641	57261	41	72904	31177	57
2061	100521	61141	39	75831	34104	55
2062	104544	65164	38	78866	37138	53
2063	108733	69353	36	82026	40299	51
2064	113089	73709	35	85312	43585	49
2065	117635	78255	33	88742	47015	47
2066	122348	82968	32	92298	50570	45

The overall savings in diesel energy and respective consumption of fuel during the life period of UPHSM is calculated as 64.2%. Accordinly the reduction in CO_2 emmission has been calculated as given below:

Total saving on DG = Total DG supply x saving factor kWh

= (4,781,479 x 365) x 64.2/100 = 1,120,443,974 kWh

Fuel Saving = 1,120,443,974 kWh/10 = 112,044,397L

(Assuming that 1L of diesel producs 10 kWh:

https://deepresource.wordpress.com/2012/04/23/energy-related-conversion-factors/)

Reduction in CO2 emission = (112,044,397 x 2.639)/1000 t = 296,696 t

(Assuming that 1L of diesel produces 2.639 kgs of CO_2 : https://carbonpositivelife.com/co2-per-litre-diesel/)

The above calculation estimate the total reduction of 295,696t on CO_2 emissions over the life period of UPHSM.

5 Engineering Economic Analysis of UPHSM

The financial analysis of the system was performed based on the optimization results. Table 5-1 presents the results of financial indicators including yearly cash flows, NPV, IRR, and payback period of UPHSM unit.

Table 5-1 Yearly cash flows, NPV, IRR, and payback period of UPHSM system

Year		Winter	Summer	Total	Yearly O&M Cost	Net Cash Flow	NPV	Payback Period
		(C$)	(C$)	(C$)	(C$)	(C$)	(C$)	(C$)
	0			Capital Invest. Cost		- 14,938,624	- 14,938,624	-14,938,624
2017	1	213,169	180,436	393,605	47,804	345,802	324,061	-14,592,822
2018	2	227,053	192,696	419,749	48,282	371,467	336,992	-14,221,355
2019	3	241,805	205,735	447,540	48,764	398,775	350,209	-13,822,580
2020	4	257,757	219,855	477,612	49,252	428,360	364,173	-13,394,220
2021	5	274,682	234,849	509,531	49,745	459,786	378,403	-12,934,433
2022	6	292,628	250,759	543,388	50,242	493,146	392,892	-12,441,288
2023	7	311,958	267,917	579,875	50,744	529,130	408,094	-11,912,158
2024	8	332,428	286,099	618,527	51,252	567,275	423,536	-11,344,883
2025	9	354,423	305,655	660,078	51,764	608,314	439,667	-10,736,569
2026	10	377,689	326,354	704,043	52,282	651,761	456,021	-10,084,808
2027	11	402,633	348,567	751,200	52,805	698,395	473,040	- 9,386,413
2028	12	429,348	372,375	801,723	53,333	748,390	490,709	- 8,638,023
2029	13	457,562	397,533	855,094	53,866	801,228	508,571	- 7,836,795
2030	14	487,721	424,444	912,165	54,405	857,760	527,061	- 6,979,035
2031	15	519,928	453,204	973,132	54,949	918,183	546,165	- 6,060,852
2032	16	554,291	483,909	1,038,200	55,498	982,702	565,869	- 5,078,151
2033	17	590,924	516,661	1,107,584	56,053	1,051,531	586,160	- 4,026,620
2034	18	629,943	551,566	1,181,509	56,614	1,124,895	607,024	- 2,901,725
2035	19	671,899	589,126	1,261,025	57,180	1,203,845	628,875	- 1,697,880
2036	**20**	716,516	629,087	1,345,603	57,752	1,287,851	651,267	**- 410,029**
2037	**21**	764,379	671,981	1,436,360	58,329	1,378,031	674,609	**968,002**
2038	22	815,203	716,461	1,531,664	58,913	1,472,751	697,946	
2039	23	869,609	761,597	1,631,206	59,502	1,571,704	721,046	
2040	24	927,302	809,400	1,736,702	60,097	1,676,605	744,600	
2041	25	988,945	860,400	1,849,345	60,698	1,788,647	768,982	
2042	26	1,054,747	914,763	1,969,511	61,305	1,908,206	794,176	
2043	27	1,124,925	972,667	2,097,592	61,918	2,035,674	820,161	
2044	28	1,179,481	1,034,724	2,214,205	62,537	2,151,668	839,201	
2045	29	1,210,737	1,100,718	2,311,455	63,162	2,248,293	848,874	
2046	30	1,242,822	1,170,848	2,413,670	63,794	2,349,876	858,885	
2047	31	1,275,756	1,245,791	2,521,547	64,432	2,457,115	869,391	
2048	32	1,309,564	1,325,801	2,635,365	65,076	2,570,289	880,382	
2049	33	1,344,267	1,411,147	2,755,414	65,727	2,689,687	891,848	
2050	34	1,379,890	1,486,400	2,866,290	66,384	2,799,906	898,736	
2051	35	1,416,457	1,525,790	2,942,247	67,048	2,875,199	893,421	
2052	36	1,453,994	1,566,223	3,020,217	67,719	2,952,498	888,132	
2053	37	1,492,524	1,607,728	3,100,252	68,396	3,031,856	882,869	
2054	38	1,532,076	1,650,333	3,182,409	69,080	3,113,329	877,632	
2055	39	1,572,676	1,694,067	3,266,743	69,771	3,196,972	872,421	
2056	40	1,614,352	1,738,959	3,353,312	70,468	3,282,843	867,235	
2057	41	1,657,133	1,785,042	3,442,174	71,173	3,371,001	862,076	
2058	42	1,701,047	1,832,345	3,533,392	71,885	3,461,507	856,942	
2059	43	1,746,124	1,880,902	3,627,027	72,604	3,554,423	851,834	
2060	44	1,792,397	1,930,746	3,723,143	73,330	3,649,813	846,752	
2061	45	1,839,895	1,981,911	3,821,806	74,063	3,747,743	841,696	
2062	46	1,888,652	2,034,432	3,923,084	74,804	3,848,281	836,665	
2063	47	1,938,702	2,088,344	4,027,046	75,552	3,951,494	831,660	
2064	48	1,990,077	2,143,685	4,133,763	76,307	4,057,456	826,681	
2065	49	2,042,814	2,200,493	4,243,307	77,070	4,166,237	821,728	
2066	50	2,096,949	2,258,806	4,355,755	77,841	4,277,914	816,800	
		Residual Value of UPHSM Plant (15% of Capital Cost)				2,240,794	427,844	

Total NPV	**19,931,388**
IRR	**6.52%**
Payback period	**20.3 Years**

Table 5-1 shows that the payback period of UPHSM unit is 20.3 years, NPV is C$ 19,931,388 and IRR is 6.52%.

5.1 Financial Analysis for Proposed Wind Farm

The Table 5-2 below presents the financial analysis for the proposed wind farm.

Table 5-2 Yearly cash flows, NPV, IRR and Payback period for proposed wind farm

Year		Total Power Sold in Winter and Summer	Power Selling Rate	Total Revenue Earned	Yearly O&M Cost	Net Cash Flow	NPV	Payback Period
		(kWh)	(C$/kWh)	(C$)	(C$)	(C$)	(C$)	(C$)
	0				Capital Investment Cost	- 7,000,000	- 7,000,000	- 7,000,000
2017	1	5,158,429	0.20	1,011,052	- 22,400	1,033,452	968,478	- 5,966,548
2018	2	5,366,711	0.20	1,079,750	- 22,624	1,102,374	1,000,064	- 4,864,174
2019	3	5,581,934	0.21	1,152,813	- 22,850	1,175,663	1,032,480	- 3,688,511
2020	4	5,811,044	0.21	1,231,933	- 23,079	1,255,012	1,066,955	- 2,433,499
2021	**5**	6,047,096	0.22	1,315,948	- 23,310	1,339,257	1,102,204	**- 1,094,242**
2022	**6**	6,310,436	0.22	1,409,647	- 23,543	1,433,189	1,141,829	**338,947**
2023	7	6,599,407	0.23	1,513,264	- 23,778	1,537,042	1,185,450	
2024	8	6,896,188	0.24	1,623,222	- 24,016	1,647,237	1,229,853	
2025	9	7,208,588	0.24	1,741,718	- 24,256	1,765,974	1,276,383	
2026	10	7,528,799	0.25	1,867,293	- 24,499	1,891,791	1,323,639	
2027	11	7,864,630	0.25	2,002,276	- 24,744	2,027,019	1,372,948	
2028	12	8,216,081	0.26	2,147,184	- 24,991	2,172,175	1,424,264	
2029	13	8,575,341	0.27	2,300,461	- 25,241	2,325,702	1,476,215	
2030	14	8,950,222	0.28	2,464,656	- 25,493	2,490,149	1,530,103	
2031	15	9,340,723	0.28	2,640,353	- 25,748	2,666,101	1,585,884	
2032	16	9,746,844	0.29	2,828,163	- 26,006	2,854,168	1,643,517	
2033	17	10,168,585	0.30	3,028,725	- 26,266	3,054,991	1,702,959	
2034	18	10,605,946	0.31	3,242,707	- 26,528	3,269,235	1,764,169	
2035	19	11,066,737	0.31	3,473,256	- 26,794	3,500,050	1,828,386	
2036	20	11,543,148	0.32	3,718,780	- 27,062	3,745,841	1,894,273	
2037	21	12,042,989	0.33	3,982,625	- 27,332	4,009,958	1,963,056	
2038	22	12,548,843	0.34	4,259,884	- 27,606	4,287,490	2,031,869	
2039	23	13,056,387	0.35	4,549,630	- 27,882	4,577,511	2,100,012	
2040	24	13,578,642	0.36	4,857,003	- 28,160	4,885,163	2,169,557	
2041	25	14,122,965	0.37	5,185,574	- 28,442	5,214,016	2,241,630	
2042	26	14,689,354	0.38	5,536,466	- 28,726	5,565,192	2,316,176	
2043	27	15,277,811	0.39	5,910,851	- 29,014	5,939,865	2,393,137	
2044	28	15,738,804	0.40	6,250,569	- 29,304	6,279,873	2,449,297	
2045	29	16,022,663	0.41	6,531,929	- 29,597	6,561,526	2,477,395	
2046	30	16,316,311	0.42	6,827,909	- 29,893	6,857,801	2,506,542	
2047	31	16,623,009	0.43	7,140,594	- 30,192	7,170,786	2,537,210	
2048	32	16,942,759	0.44	7,470,811	- 30,494	7,501,305	2,569,367	
2049	33	17,275,559	0.45	7,819,423	- 30,799	7,850,222	2,602,981	
2050	34	17,520,000	0.46	8,140,211	- 31,107	8,171,317	2,622,895	
2051	35	17,520,000	0.48	8,355,926	- 31,418	8,387,344	2,606,231	
2052	36	17,520,000	0.49	8,577,358	- 31,732	8,609,090	2,589,676	
2053	37	17,520,000	0.50	8,804,658	- 32,049	8,836,708	2,573,228	
2054	38	17,520,000	0.52	9,037,982	- 32,370	9,070,351	2,556,887	
2055	39	17,520,000	0.53	9,277,488	- 32,693	9,310,182	2,540,653	
2056	40	17,520,000	0.54	9,523,342	- 33,020	9,556,362	2,524,523	
2057	41	17,520,000	0.56	9,775,710	- 33,351	9,809,061	2,508,499	
2058	42	17,520,000	0.57	10,034,767	- 33,684	10,068,451	2,492,578	
2059	43	17,520,000	0.59	10,300,688	- 34,021	10,334,709	2,476,761	
2060	44	17,520,000	0.60	10,573,656	- 34,361	10,608,017	2,461,046	
2061	45	17,520,000	0.62	10,853,858	- 34,705	10,888,563	2,445,433	
2062	46	17,520,000	0.64	11,141,485	- 35,052	11,176,537	2,429,921	
2063	47	17,520,000	0.65	11,436,735	- 35,402	11,472,137	2,414,509	
2064	48	17,520,000	0.67	11,739,808	- 35,756	11,775,564	2,399,197	
2065	49	17,520,000	0.69	12,050,913	- 36,114	12,087,027	2,383,984	
2066	50	17,520,000	0.71	12,370,262	- 36,475	12,406,737	2,368,870	
		Residual Value (15% of Capital Cost)				1,050,000	200,481	
						Total NPV	**93,503,655**	
						IRR	**19.16%**	
						Payback period	**5.76 years**	

Table 5-2 shows that payback period of proposed Wind Farm is 5.76 years, NPV is C$ 93,503,655 and IRR is 19.16%.

5.2 Financial Analysis for Proposed Solar Installations

Table 5-3 presents the financial analysis for the solar installations.

Table 5-3 Yearly cash flows, NPV, IRR and Payback period for proposed solar installation

Year		Total Power Sold in Winter and Summer	Power Selling Rate	Total Revenue Earned	Yearly O&M Cost	Net Cash Flow	NPV	Payback Period
		(kWh)	(C$/kWh)	(C$)	(C$)	(C$)	(C$)	(C$)
	0				**Capital Investment Cost**	- 864,320	- 864,320	- 864,320
2017	1	866,139	0.20	169,763	- 2,765.82	172,529	161,682	- 691,791
2018	2	892,158	0.20	179,497	- 2,793.48	182,290	165,372	- 509,501
2019	3	919,045	0.21	189,806	- 2,821.42	192,628	169,168	- 316,873
2020	**4**	947,666	0.21	200,904	- 2,849.63	203,754	173,222	**- 113,119**
2021	**5**	977,155	0.22	212,645	- 2,878.13	215,523	177,375	**102,404**
2022	6	987,165	0.22	220,516	- 2,906.91	223,423	178,002	
2023	7	987,165	0.23	226,360	- 2,935.98	229,296	176,845	
2024	8	987,165	0.24	232,358	- 2,965.34	235,324	175,696	
2025	9	987,165	0.24	238,516	- 2,994.99	241,511	174,556	
2026	10	987,165	0.25	244,837	- 3,024.94	247,862	173,423	
2027	11	987,165	0.25	251,325	- 3,055.19	254,380	172,298	
2028	12	987,165	0.26	257,985	- 3,085.74	261,071	171,180	
2029	13	987,165	0.27	264,822	- 3,116.60	267,938	170,071	
2030	14	987,165	0.28	271,839	- 3,147.77	274,987	168,969	
2031	15	987,165	0.28	279,043	- 3,179.24	282,222	167,875	
2032	16	987,165	0.29	286,438	- 3,211.04	289,649	166,789	
2033	17	987,165	0.30	294,028	- 3,243.15	297,271	165,709	
2034	18	987,165	0.31	301,820	- 3,275.58	305,096	164,638	
2035	19	987,165	0.31	309,818	- 3,308.33	313,127	163,574	
2036	20	987,165	0.32	318,028	- 3,341.42	321,370	162,517	
2037	21	987,165	0.33	326,456	- 3,374.83	329,831	161,467	
2038	22	987,165	0.34	335,107	- 3,408.58	338,516	160,425	
2039	23	987,165	0.35	343,988	- 3,442.66	347,430	159,390	
2040	24	987,165	0.36	353,103	- 3,477.09	356,580	158,361	
2041	25	987,165	0.37	362,461	- 3,511.86	365,972	157,340	
2042	26	987,165	0.38	372,066	- 3,546.98	375,613	156,326	
2043	27	987,165	0.39	381,925	- 3,582.45	385,508	155,319	
2044	28	987,165	0.40	392,046	- 3,618.28	395,665	154,319	
2045	29	987,165	0.41	402,436	- 3,654.46	406,090	153,325	
2046	30	987,165	0.42	413,100	- 3,691.00	416,791	152,338	
2047	31	987,165	0.43	424,047	- 3,727.91	427,775	151,358	
2048	32	987,165	0.44	435,285	- 3,765.19	439,050	150,385	
2049	33	987,165	0.45	446,820	- 3,802.84	450,623	149,418	
2050	34	987,165	0.46	458,660	- 3,840.87	462,501	148,457	
2051	35	987,165	0.48	470,815	- 3,879.28	474,694	147,504	
2052	36	987,165	0.49	483,292	- 3,918.07	487,210	146,556	
2053	37	987,165	0.50	496,099	- 3,957.25	500,056	145,615	
2054	38	987,165	0.52	509,245	- 3,996.83	513,242	144,680	
2055	39	987,165	0.53	522,740	- 4,036.80	526,777	143,752	
2056	40	987,165	0.54	536,593	- 4,077.16	540,670	142,830	
2057	41	987,165	0.56	550,813	- 4,117.94	554,931	141,914	
2058	42	987,165	0.57	565,409	- 4,159.11	569,568	141,004	
2059	43	987,165	0.59	580,393	- 4,200.71	584,593	140,101	
2060	44	987,165	0.60	595,773	- 4,242.71	600,016	139,203	
2061	45	987,165	0.62	611,561	- 4,285.14	615,846	138,311	
2062	46	987,165	0.64	627,767	- 4,327.99	632,095	137,426	
2063	47	987,165	0.65	644,403	- 4,371.27	648,774	136,546	
2064	48	987,165	0.67	661,480	- 4,414.98	665,895	135,672	
2065	49	987,165	0.69	679,009	- 4,459.13	683,468	134,804	
2066	50	987,165	0.71	697,003	- 4,503.72	701,507	133,942	
		Residual Value (15% of Capital Cost)				129,648	24,754	
						Total NPV	**6,977,481**	
						IRR	**20.65%**	
						Payback period	**4.52 Years**	

Table 5-3 shows that the payback period of solar installations is 4.52 years, NPV is C$ 6,977,481 and IRR is 20.65%.

6 Conclusion

6.1 Chapter Wise Summary

The chapter wise summary of this project is as follows:

Chapter 1 of this project is composed of the issues associated with DG, need to establish renewable generators, background of the project, problem statement, and project objectives.

Chapter 2 provides the literature review of energy storage technologies and particularly UPHSM technology with rationales for its selection. Chapter 3 is composed of a four step methodology which includes optimization to calculate amount of power supply by UPHSM unit and DG in off, mid and on peak time, establishing UPHSM model unit, application of this model on a case study and performing financial analysis of UPHSM. Chapter 4 provides the details of the selected case study area, establishing the prosed UPHSM system on case study area with results and discussions. Chapter 5 gives the financial analysis for life period of proposed UPHSM system, wind farm, and solar installations. Chapter 6 provides the overall conclusion of the project.

6.2 Project Conclusions

The conclusions of this project are summarized as follows:

- The proposed UPHSM system fully satisfied the utility of available renewable generation and respective reduction in diesel generation.
- The developed UPHSM system also confirmed that energy supply was capable to meet the energy demands in different periods that proved the system performance was satisfactory in terms of providing steady and reliable power supply. The engineering financial analysis confirmed that the developed UPHSM model is beneficial to all concerned stake holders.
- The engineering economic analysis of the proposed UPHSM system provided the total NPV as C$ 19,931,388 the payback period as 20.3 Years and IRR as 6.52%, which confirmed that the system is beneficial to all concerned stakeholders.
- The proposed UPHSM system offered an overall fuel saving of 64.2 percent and a reduction of 295,696 tons in CO_2 emission over the life period of the system.

- The comparison of two systems, DG only and hybrid of UPHSM with RE and DG concluded that the hybrid system has multiple benefits over DG only and can successfully work as a viable long term cleans energy power solution for off-grid remotes.

6.3 Project Contribution

The possible contribution of this project for off-grid community areas are as follows:

- Fuel cost reduction and less blackout risks;
- Greater penetration of renewable power in supply-mix;
- Direct benefit to Ontario's off-grid remote area communities;
- The developed model could be a sustainable and viable power supply solution to other similar remotes of Canada and the world;
- Creation of employment during construction and operational phases;
- Over indirect benefits it offers the improvement in quality of life of remote area communities and attract new settlers;
- Helpful in strengthening the existing businesses and establishing new businesses; and
- Helpful in promoting the overall growth of the off-grid remote area communities.

6.4 Future Work

- UPHSM is an emerging energy storage technology and therefore more studies are required to refine the system for economy, life and efficiency.
- Currently it is the policy of Canadian government to promote the renewable energy penetration in off-grid remotes. The energy storage associations can participate to strengthen the system sustainability. Further studies are therefore required to explore the best fit energy storage solutions to individual remote area conditions.
- Most of the Ontario off-grid remote communities are in the vicinity of natural water bodies, which offer an ideal situation for establishing UPHSM system. Therefore, further research is required to refine the establishment the UPHSM at such coastal off-grid remotes.

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