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Integration of Renewable Energy Systems to Reduce Greenhouse Gas Emission

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Abstract – With recent technological advancements in energy systems, power production using wind and solar-based renewable energy systems has become more viable. This paper presents the integration of solar energy systems as a power source displacing green house gas intensive electricity production in Saskatchewan. For this study, facilities from the industry, which are dispersed throughout Saskatchewan, are taken as case systems. Solar data from diverse parts of the province are collected and analysed to calculate installed capacity and amount of carbon emissions reduction at those particular locations. Hosting capacity analysis is performed in selected individual sites to ensure that the current grid can accommodate bulk solar generation. Finally, the results from economic analysis reflect the viability of integrating renewable energies at a specific location.

***Keywords*:** greenhouse gas, grid integration, renewable energy, hosting capacity

1. Introduction

Renewable energy sources (RES) are clean forms of energy which produce less green house gas (GHG) emission compared to non-renewable sources such as coal. Technological advancements in energy storage systems [1] has improved the feasibility of power production and integration of RES with grid. Currently, coal plants are the major source of power production in Saskatchewan and comprise about 32% of the total electrical energy generation. SaskPower, Saskatchewan's primary utility company, is taking initiative of reducing the greenhouse gas emissions by 40% by the year 2030 [2]. The utility plans to achieve this goal by significantly increasing renewable generation and supporting independent power producers who can host renewables and modernizing the grid. During the past decade, several research papers and standards have appeared explaining the grid interconnection of renewable energy sources [3]-[4]. Countries such as Australia, Denmark, Germany, UK, and some states in the USA, such as California, have adopted large amounts of solar photovoltaic generation and wind generation. However, there is a very limited amount of solar photovoltaic and wind generation currently being used in Canada except for solar PVs in Ontario. A recent work from the research group analysing the hosting capacity of photovoltaic (PV) for a remote community in the northern part of Saskatchewan has been described in [5]. Limited planning studies and research literature are dealing with replacing current coal based electricity production in the Canadian context.

Along with SaskPower, the Government of Saskatchewan, is also encouraging renewable energy integration through various incentive programs: net metering [6], power generation partner program (PGPP) [7] and climate action incentive fund [8]. Most of the leading industries in Saskatchewan are focusing on implementing solar and wind energy systems as a power source displacing their current GHG intensive electricity production dispersed throughout the province in an attempt to lower their power bills, and to produce clean energy reducing their overall carbon footprint. The feasibility study of integration of renewable energy systems (solar generation) with net metering and PGPP incentive opportunities for a particular industry has been presented in this paper.

2. Solar Generation and Installed Capacity

2.1. Solar Data and PVSyst 7.0

The load demand for each categories of facilities are calculated by taking average of kWh power consumption data provided by the industry. The exact coordinates of the facilities are traced from Google Earth and the coordinates are used to associate the location with the relevant solar irradiance data. NASA's surface meteorology [9] and solar energy exploration (SEE) data set are used to extract solar data for each particular location and the data are inserted on PVSyst 7.0 to run analysis for all sites. PVSyst utilizes the SSE data set and require information such as the site coordinates, available area, type of installation, and the tilt of the solar panels. In order to ensure the accuracy of the results obtained from PVSyst, the results are compared against an existing 24 kW solar plant installed at University of Saskatchewan, Canada.

Table 1: Comparison of actual generation from 24 kW solar plant with simulation results from PVSyst 7.0

	Actual Generation in First Year (2013)	Results from Simulation	Percentage Difference (%)
Annual Energy Generation (kWh/ year)	30,579	29,859	2.35
Capacity Factor (%)	14.5	14.2	2.06

In 2013, the annual output from the plant was 30,579 kWh, and the PVSyst simulations gave an output of 29,859 kWh, based on the 2013 SSE data set. The simulation results matched well with the actual output from the plant and the PVSyst software is used for further analysis for each of the sites.

2.2. Size and Geometry of PV Panels

The analysis for all the sites is performed using Generic 300 W 27 V PV module with dimension of 1.64 m x 0.992 m. A spacing of 0.475 m is assumed between two arrays. Inclination angle of 27 degrees and 15 degrees are chosen for ground mounted & flat rooftops solar panels and inclined surfaces respectively [10]. All solar panels are assumed to face south with azimuth angle of zero degrees and the axis of the panels are kept fixed throughout the year.

2.3. Calculation of Installed Capacity and Annual Energy Generation

Minimum available area for each facility is estimated from Google Earth Satellite view. Based on the available area and geometry of the PV panels used, the installed capacity for the given location is determined using Equations (1)-(3).

$$PV\ Limiting\ Area = (1.64 * 0.992) + (1.64 * 0.475) = 2.41\ m^2 \tag{1}$$

$$No.of\ modules\ used = \frac{Min.Available\ Area}{PV\ Limiting\ Area} \tag{2}$$

$$Installed\ Capacity = No.of\ modules * Capacity\ of\ each\ module \tag{3}$$

An extrapolation method is used to calculate solar energy generation for similar facilities within same region. From the GPS location, the facilities nearby are grouped together. A simulation of one facility is performed in PVSyst to obtain monthly and annual energy generated from the given facility. Since, the clustered facilities are situated near each other, the solar radiation data for each facilities are similar. Taking reference of energy generated from the first facility, the output from other facilities are calculated.

If the available area is large enough to allow installation of enough solar panels to reach over 100 kW to 1 MW capacity, the facility is considered under the PGPP program while under 100 kW capacity, the facility is considered under net metering program. There are two sites where the available land area allows for installation of bulk solar plants more than 1 MW of capacity. Those facilities are considered under behind-the-meter program.

3. Hosting Capacity Analysis

Hosting capacity is the maximum capacity of distributed generation that can be integrated in a distributed network without violating specific network parameters. Hosting capacity analysis is performed to determine whether the current SaskPower grid can host 1 MW of solar generation for PGPP. As per SaskPower's grid interconnection requirement [11], SaskPower grid can host a distributed energy resource (DER) if the interconnected DER keeps the voltages of each bus of the grid within their acceptable limit without overloading any of the transmission lines of the grid. For the analysis, overall SaskPower grid is modelled in PSS Sincal. Based on SaskPower's requirements, the solar generation from each facilities are connected to 25 kV distribution system of their respective location. The system is then simulated in PSS Sincal by performing load flow and short circuit analysis. The results are then checked with the above criteria to find out the capability of SaskPower grid to host these renewable generations.

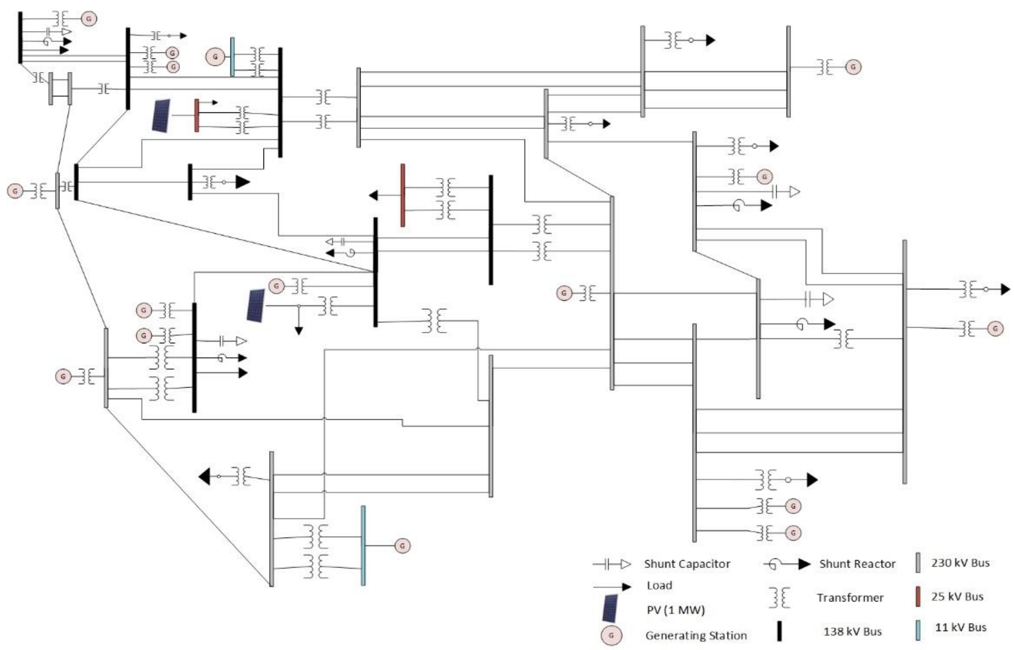

Fig. 1: SaskPower grid

4. Greenhouse Gas Emission Offset

It is seen that, from recent SaskPower's data, the amount of carbon emitted from SaskPower Grid is about 652 kg CO_2 per MWh energy generation. Similarly, the median value of GHG emission from PV technologies is about 50 kg CO_2 per MWh energy generation [12]. Hence, the amount of carbon emission that can be reduced using solar is calculated using Equation (4):

$$CO_2\ Emission\ Offset = \frac{Energy\ Generated\ by\ Solar\ (MWh) * (652 - 50)}{1000}\ tons\ CO_2 \qquad (4)$$

5. Net Metering Program

SaskPower's net metering program will allow customer to connect their roof top photovoltaic power station to Saskatchewan's utility grid. The program allows capacity up to 100 kW, and the customer is able to utilize the generated power while selling the excess to SaskPower at a rate of CAD 0.07/kWh. The average installation and O&M cost for net metering program is shown in Table 2.

Table 2: Installation and O&M cost for net metering program

Interconnection Study Fee	CAD 315
Bi-directional Meter	CAD 475
Circuit Breaker	CAD 1,000
Disconnect	CAD 3,695.46
Relay	CAD 1,120.06
Transformer	CAD 7,687.23
HV Protective Device	CAD 3,000
Total Installation Cost	CAD 17,292.75
O&M (CB, Transformer, Disconnects)	1.25 % of Total Installation Cost

5. Power Generation Partner Program (PGPP)

With power generation partner program, all produced power is sold to SaskPower. This program is utilized at sites where capacity of over 100 kW to 1 MW is possible. There is no standard price at which the generated power is sold, instead the customer bids how much they would like to sell the generated power for with highest bidding amount being CAD 0.0983/kWh. For this study, the selling rate is considered similar to net metering program, which is CAD 0.07/kWh. Table 3 shows the average installation and O&M cost for PGPP.

Table 3: Installation and O&M cost for PGPP

Application Fee	CAD 315
Interconnection Study Fee	CAD 1,050
Interconnection Cost	CAD 17,000 /MW
Transmission Line Cost	CAD 43,000 /km
O&M Cost (CB, Transformer, Disconnects)	1.25 % of Interconnection Cost

6. Behind-the-Meter

Behind-the-meter system allows the industry to install a large photovoltaic solar power station to meet a portion or all of the demands for its facilities. Whereas the amount of energy generated under the net metering and PGPP is limited by SaskPower, the energy generated through behind-the-meter system is up to the discretion of the customer. SaskPower requires the installation of reverse power flow protection, which ensures that power is not fed into the utility grid while the panels are generating powers. The industry has two sites with large amount of available land suitable for behind-the-meter program.

6.1. Site I

This site constitute hundreds of facilities with an aggregate annual energy demand of 50 GWh. The amount of available land area at this location is 465,388 m2, which allows installation of 18.228 MW photovoltaic solar power station, resulting in maximum annual energy generation of 25.73 GWh. Table 4 summarizes the analysis of Site I based on percentage of annual load demand.

Table 4: Calculation for Site I based on percentage of annual load demand

Percentage of Annual Load (%)	Installed Capacity (MW)	Annual Energy Generation (MWh)	GHG Emissions Offset (tons CO_2/year)	Cost (CAD)
5	1.771	2,500	1,505	1,992,470
25	8.855	12,500	7,525	9,962,350
40	14.169	20,000	12,040	15,939,759
50	17.711	25,000	15,050	19,924,698
51.46	18.228	25,730	15,489	20,506,500

6.1. Site II

The annual energy consumption for this site is 317.7 MWh. The facility has available land area of about 36,323 m2, which allows installation of 1.414 MW photovoltaic solar power station, resulting in maximum annual energy generation of 1,963 MWh. In order to fulfil 100% load demand, the required installed capacity is 229 kW. Table 5 summarizes the analysis of Site II based on percentage of annual load demand.

Table 5: Calculation for Site II based on percentage of annual load demand

Percentage of Annual Load (%)	Installed Capacity (MW)	Annual Energy Generation (MWh)	GHG Emissions Offset (tons CO_2/year)	Cost (CAD)
5	11	15.89	9.56	12,868
25	57	79.43	47.81	64,340
50	114	158.85	76.50	128,681
100	229	317.70	191.26	257,361

Since these sites are being considered for bulk power generation, hosting capacity analysis is performed for installed capacity of 1 MW to determine whether the SaskPower grid can host these solar generations for PGPP. Each 1 MW solar is connected to their nearest 25 kV primary distribution lines in PSS Sincal module described above. After load flow and short circuit simulation, it is found that the bus voltages and transmission line capacity are within the limit validating the hosting capacity of SaskPower grid for these 1 MW solar generations.

7. Economic Analysis

The overall project is divided into four sub-projects: (i) facilities under net metering, (ii) facilities under PGPP, (iii) facilities under behind-the-meter, and (iv) facilities under none of these programs. The feasibility of facilities under each sub-projects are determined by calculating the economic indicators like net present value (NPV), payback period, return on investment (ROI) and Benefit/Cost ratio. For the analysis, project life of 25 years is considered with an assumption of 2% inflation on O&M cost each year. If the total cost of the project is less than CAD 250,000, a government subsidy of 25% is applied [8]. Discount rates of 0% and 8% are considered for sub-projects (i), (ii) and (iv) while for sub-project (iii), analysis is performed with different discount rates of 0%, 3%, 5% and 8%. PV degradation rate of 0.5% per year is assumed in all cases. For the SaskPower bill rebate, SaskPower's tariff structure of small commercial rate (loads less than 75 kVA) is applied for (i), (ii), and (iv) while SaskPower's tariff structure of standard rate (non-residential and non-farm loads greater than 75 kVA) is applied for (iii). Table 6 shows the installation and O&M costs of solar systems considered for economic analysis.

Table 6: Installation and O&M costs for solar panels

	Small Facilities under sub-projects (i), (ii) and (iv)	Large Facilities under sub-project (iii)
Installation Cost	CAD 1.772 /W [10]	CAD 1.125 /W [10]
Annual O& M Cost	CAD 17.5 /kW	CAD 12.5 /kW

The annual O&M costs for both small and large facilities are assumed considering the trend of decreasing cost in year 2023 [13].

8. Results

Among 372 small facilities dispersed throughout the province, 30 are found to be suitable for net metering, 59 are found suitable for PGPP and the rests are not suitable for either net metering or PGPP. The combined analysis of the facilities is summarized in Table 7-8.

Table 7: Average results of overall facilities

Average Installed Capacity	70.08 kW
Average Annual Energy Consumption	132.76 MWh
Average Annual Energy Generation	92.26 MWh
Average Capacity Factor	15.07 %
Average Annual GHG Emissions Offset	55.54 tons CO_2/year
Average Cost	CAD 124,173.4
Average Annual Bill Rebate	CAD 9,506.05
Average Annual Saving on Carbon Charge	CAD 760

Table 8: Combined results of overall facilities

Total Annual Energy Consumption	54.697 GWh
Total Annual Energy Generation	34.322 GWh
Total Annual GHG Emissions Offset	20,662.12 tons CO_2/year
Total Cost	CAD 46,192,496
Total Annual Bill Rebate	CAD 3,536,250
Total Annual Saving on Carbon Charge	CAD 196,496

By installing photovoltaic solar power stations on 372 individual facilities, the industry will be able to offset 20,662.12 tons CO2 per year at a total cost of CAD 46,192,496. The replacement of current GHG intensive generation with solar will save them CAD 3,536,250 on annual bills and CAD 196,496 on annual carbon charge. Similarly, by implementing behind-the-meter system which meet 50% of the load demand at Site I and full load demand at Site II, around 15,145 tons CO2 per year can be reduced at a cost of CAD 20,053,380.

Economic analysis is performed to determine the feasibility of each sub-projects. Using the economic parameters described in Section 7, the economic analyses for all 372 small facilities are performed on separated discount rates of 0% and 8%. The economic analyses for 2 sites under behind-the-meter program are performed on discount rates of 0%, 3%, 5% and 8%. Based on payback period, B/C ratio, ROI and NPV, feasibility of each of these sub-projects (net metering or PGPP or none) are determined. The summary from economic analysis for 372 facilities is shown in Table 9 and results from economic analysis for 2 sites under behind-the-meter is shown in Table 10.

Table 9: Feasibility of projects based on economic analysis of 372 small facilities

Facilities	Discount Rate (0%)		Discount Rate (8%)	
	Feasible Projects	Infeasible Projects	Feasible Projects	Infeasible Projects
Neither Net Metering of PGPP	283	0	283	0
Net Metering	30	0	5	25
PGPP	56	3	0	59
Total Facilities	369	3	288	84

Table 10: Feasibility of projects based on economic analysis of sites under behind-the-meter program

Economic Indicators	Site I		Site II	
	Discount Rate (0%)	Discount Rate (3%)	Discount Rate (0%)	Discount Rate (3%)
B/C Ratio	1.66	1.18	1.73	1.23
Payback Period (years)	14.20	19.21	13.60	18.09
ROI (%)	62.87	16.79	69.52	21.46

Most of the projects are almost infeasible for discount rate of 8%. It is because higher discount rate means incorporating higher risks in the project. Also, the tariffs at which the SaskPower buys power for both net metering and PGPP are low and the cost of interconnection with SaskPower is higher, resulting projects to be infeasible for higher discount rates. It is assumed that the distance between the facility and SaskPower 25 kV Distribution grid to be 200 m. This may not be the case for every facility. Some facilities may be at a distance less than 200 m which causes a vast difference in grid interconnection cost. In addition, we have assumed CAD 0.07/kWh as selling rate for PGPP but instead the selling rate can be up to CAD 0.0983/kWh. Higher selling rate results in better chance of project feasibility. The choice of the discount rate to be used before any financial assessment and investing a project is left in the hands of the investor.

9. Conclusions

The studies reported in the paper demonstrated that the industries in Saskatchewan can take advantage of the behind-the-meter systems, PGPP and net metering programs to install solar generation on their facilities and offset substantial amount of GHG emissions in Saskatchewan. By replacing their current GHG intensive generation with solar, the industries can save substantial amount on their annual energy bills and reduce their annual carbon tax charges. It is recommended that behind-the-meter PV systems be considered along with PGPP and net metering programs. Behind-the-meter allows more freedom to the customer when deciding the size of the installed capacity of PV. The capacity available under the PGPP and Net Metering programs is dictated by SaskPower. As seen from the comparison between dispersed small generations with behind-the-meter system, the implementation of behind-the-meter system seems more effective compared to disperse smaller solar generations as similar amount of carbon emission can be reduced annually by installing bulk solar plants at almost half of the cost.

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