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Configuration of a renewable micro-power system for a remote village in Mongolia

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Abstract – Electricity generation by renewable energy sources such as solar panels and win turbines is being widely accepted as an eco-friendly complement to the conventional electric generation by fossil fuel which has provided convenient and economical means but also caused environmental pollution. However, electric generation by the renewable energy sources, due to its inherent dependence on weather condition and thus production intermittency and fluctuation, has its own problem of low reliability. Therefore, a renewable energy system tends to be composed of stand-alone Micro-grid or interconnection of grid power source. This paper aims to (1) configure a self-sustaining micro-power system of renewable energy sources and storage devices for a community of Bayangnuur in Mongolia using theoretical approaches and a simulation tool, HOMER, (2) analyze available configurations in capacity and cost under different weather conditions of the region, and (3) suggest the optimal configuration for the system.

Keywords: Renewable Energy, Reliability, Micro-grid, HOMER, Optimal Configuration

1. Introduction

Due to the safety concerns on nuclear energy and the ill-effect of air pollution from fossil fuel-based generating plants, renewable energy sources are being widely and speedily accepted around the world.

Renewable energy sources have the major advantage in that they can reduce carbon emissions without the use of underground resources, but have disadvantage also in that their energy output vary under different weather and geographical conditions. In order to compensate for these shortcomings, Micro-grid configurations of various energy sources equipped with energy backup systems are considered viable option for utilizing renewable sources and of supplying energy more reliably[1].

The Bayangnuur region, located about 190[km] west of the capital, Ulaanbaatar, is a large grassland area and had been famous for orchards. Since 1990s, however, the area had lost water resources and has suffered from rapid desertification. To prevent the desertification, an NGO of Korea has planting trees in the region[2]. On the other hand, a small scale water supply project for the region launched in 2009 deploying one 2[kW] submersible water pump with 2.4[kW] photovoltaic panels and four 200[Ah] batteries, which due mainly to the lack of detailed studies on generation capacity and capability under different weather conditions had met many difficulties in meeting operational requirements.

This paper aims to fill the gap of detailed studies lacked in the 2009 project and to provide a micro-power system with various generation resources to meet the load demand for the region. The micro-power system is designed to become an independently (or stand-alone) operational system which is not connected to a power grid. For the study of this stand-alone micro-power system, we calculate the generation capacity and optimal generation combination for different sources under different weather conditions and performed economic analyses. The principal tool for the study is the HOMER simulation tool developed from NREL.

2. Micro-Power System Configuration and Simulation

2.1 HOMER

Many demonstration-level and experimental micro-power systems of renewable energy sources have much focused on the installation of renewable energy sources without enough and thorough investigation of the feasibility and the optimal combination of the resources and thus have met numerous problems including failure to meet the load demand, economically unacceptable system configuration, too expensive a cost of generation, and over-capacity

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design. These problems could be easily solved using optimal system configuration software with economic viability and cost analysis prioritized. One of such optimal configuration software for renewables is HOMER.

HOMER (Hybrid Optimization Model for Electric Renewable). Developed at institute of NREL (National Renewable Energy Laboratory) in U.S, is a design software that can be used to analyze micro-power system's configuration with various resources for economics of the optimal combination of them to meet the load demand. Fig. 1 shows the basic algorithm of HOMER. It shows the calculation result of the number of cases of hundreds or thousands of combinations to find the optimal combination of different renewable under weather conditions, load demands, capacity ranges, fuel costs, and carbon emission constraints[3].

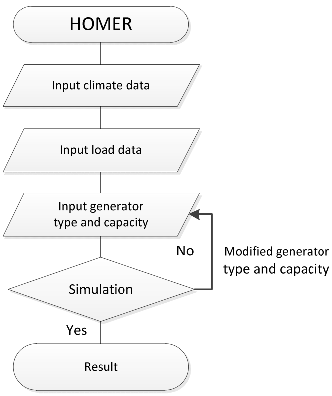

Fig. 1. Algorithm of HOMER

2.2 System design Consideration

In configuring a system for renewables, the climate and weather conditions must be firstly considered for the location of the installation. The Bayangnuur area in Mongolia is a dry region with annual precipitation at 150[mm] and is characterized by long day time but wide variation in yearly temperatures range up to 70[℃]. This harsh condition eliminates the adopt of a fuel cell because the efficiency drops fast when the temperature is below the freezing point of the reaction gases (hydrogen and oxygen). Also, the cold winter weather bring in a 5[kW] heater to the battery bank facility in order to prevent the batteries being slow in chemical reaction and low in efficiency[4]. As depicted in Fig. 2, the batteries are to be used to store the energy generation by both PV panels and wind turbines and to back-up supply electricity to the load. In addition, the heater for the battery storage facility is powered by a heater and a dump load which works only by the excessive energy generated from the renewable sources. Also shown in Fig. 2 is a converter to converter DC sources generated from the renewables and the batteries for the AC loads.

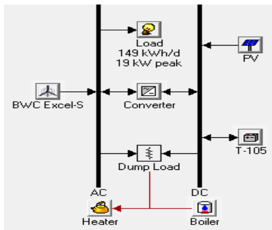

Fig. 2. System diagram to be simulated

2.3 Weather data

To calculate the generation amount from the renewables, solar radiation and wind speed data are needed to supply to the HOMER as inputs. They are available from the NASA sponsored climate data information website OPENEI (Open Energy Information)[5]. Table 1 shows the monthly solar radiation and wind speed of the region obtained from OPENEI by entering Bayangnuur's latitude(47°59') and longitude(104°59'). Average annual solar radiation is found to be 4.09[kWh/m^2/d], maximum 6.04[kWh/m^2/d] in June, and minimum 1.44[kWh/m^2/d] in December. Average annual wind speed is 5.86[m/s], with maximum 6.61[m/s] in December, and minimum 4.99[m/s] in July.

Table 1. The caption must be followed by the table

Month	Solar	Wind	Month	Solar	Wind
Jan	1.77	6.55	Jul	5.91	4.99
Feb	2.84	6.00	Aug	5.26	5.13
Mar	4.25	5.71	Sep	4.40	5.42
Apr	5.53	6.34	Oct	3.07	5.78
May	6.32	5.86	Nov	1.92	6.42
Jun	6.40	5.49	Dec	1.44	6.61

*Solar : Radiation[kWh/m^2/d], Wind : Speed[m/s]

2.4 Load Demand Analysis

The village residents are comprised of 46persons of 21 households, which include 42locales and 4NGO staff members who occupy a space as a living quarter and office, the 2manager of the space are the locals. There are 4Pump. The daily load demand is 141.92[kWh/day].

Table 2 details the type and number of loads in the village. It also shows the power rating of each type of the load and the daily total power consumption amount determined by the usage hour of it. Among the type of load, the pump load is rated the highest with 2.2[kW] and also total energy at 52.8[kWh] daily which amounts to about 37[%] of the total village energy consumption.

Table 1. The caption must be followed by the table

	Unit power rating[kW]	Usage time[h]	Total consum-ption[kWh]
TV(22)	0.16	7	14.08
Fridge(22)	0.06	24	19.8
Lamps(66)	0.06	18	17.82
Pumps(4)	2.2	7	52.8
Other(46)	0.01	13	1.84
Total	2.49		141.92

The daily load profile is obtained after measuring the power consumption in the village. Fig. 3 shows the HOMER-generated graph of the hourly load based on the load study input. The high peaks in the daytime are contributed mostly by the pump loads.

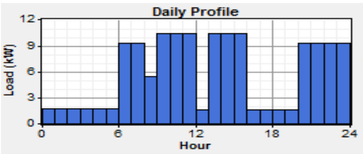

Fig. 3. Daily Loads Profile

For monthly or seasonal load profile, the heating load is fixed in its power consumption of 5[kWh] per month in the months from November to March, the input data provided to the simulation software.

2.5 Component

<u>Photovoltaic Panel (PV)</u>

One of the main renewable adopted for the system configuration is a PV system is of the fixed angle(at 47.98°), without a tracker. The normal operational temperature is assumed to be 47[℃] and the output variation is considered as -0.5[%] per degree [℃] increase. PV's lifetime is set as 20years with de-rating factor of 80[%]. Other features of the PV are shown in Fig. 4. The cost of the PV, including the installation cost but ignoring operational and management cost, is chosen as $3,000, the end the replacement cost as 10[%] of the PV Cost.

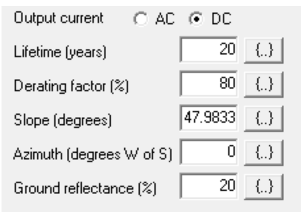

Fig. 4. Properties of PV panel

<u>Wind Turbine (W.T)</u>

For the wind turbine, one of the HOMER-provided primary turbine models, EXCEL-S with rated power of 10[kW] from Bergey, is selected. The power output characteristic curve of the model is provided in Fig. 5. It can be seen that the start-up wind speed is 4[m/s] and the rated wind speed 12[m/s]. Hub height is assumed to be 30[m] with 15years of lifetime. The price for the wind turbine including the initial installation is chosen as $48,000. Operation and maintenance (O&M) and replacement costs are set as 5[%] and 10[%] of the wind turbine cost, respectively.

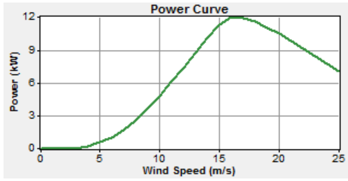

Fig. 5. Power curve of Wind Turbine (EXCEL-S)

<u>Battery Bank</u>

For strong excessive generation or meeting excessive demand, a bank of batteries is included in the micro-power system configuration, which in both cases stabilizes converter outputs. The selected batteries are T105 model from Trojan which is characterized with nominal voltage of 6[V], nominal capacity of 225[Ah], and the lifetime throughput of 845[kWh]. The DC bus voltage is selected as 48[V] following the convention of the more than 3[kW] converter output. The costs for the battery bank are: $230 for component, O&M of 5[%] of the component cost, and replacement at 10[%] of the component cost.

<u>Converter</u>

A converter is to converter the DC stored in the battery bank ("inversion") and to convert AC power generated from a renewable to DC power ("rectification"). The efficiencies of the converter for inversion and rectification are set a 90[%] and 85[%], respectively. The cost for the converter are: $2,400 for a component of capacity 3[kW], O&M of 5[%] of the component cost, and replacement at 10[%] of the component cost.

3. Simulation Result

The calculation of HOMER produces the best (or least cost) combinations in 2different configurations as illustrated in Fig. 6. The first combination comprises of a 45[kW] PV, a 10[kW] W.T, a battery bank of 344 batteries, and 18[kW] converter. This first combination's initial cost is $276,520 and the total net present cost(NPC) is $402,627. The cost of energy per kWh is $0.569. The second combination with 60[kW] PV, a battery bank of 424 batteries, and 21[kW] converter does not include W.T. Its NPC is $404,148 with the energy cost of $0.572 per kWh. Therefore the best (most economical) configuration selected is the first combination. In both combinations the second to the last column indicates the percentage of generation by the renewables.

	PV (kW)	XLS	T-105	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)
	45	1	344	18	CC	$ 276,520	9,865	$ 402,627	0.569	0.85	1,769
	60		424	21	CC	$ 294,320	8,591	$ 404,148	0.572	0.87	1,780

Fig. 6. Simulation Result

3.1 Economic analysis

It is noted that the cost of energy of the configured system, $0.569/kWh, is about 10 times more expensive than grid price of $0.05/kWh. Also, as shown in Table 3 and Fig. 7, the initial capital cost (ICC) of the entire components of the configuration is about 69[%] of the total costs with $276,520, of which the PV system accounts for about 50[%]. In terms of NPC, the PV and the batteries account for approximately 68[%] of the total net cost. Boiler is not given a consideration in terms of capital cost

Table 3. Net present costs of the system

Com-ponent	ICC [$]	Replace-ment[$]	O&M [$]	Fuel [$]	Salvage [$]
PV	135,000	4,209	0	0	-2,359
WT	48,000	2,003	30,680	0	-373
Battery	79,120	6,885	52,770	0	-922
Converter	14,400	601	9,204	0	-122
Boiler	-	-	-	23,520	0
Total	276,520	13,698	92,654	23,520	-3,765

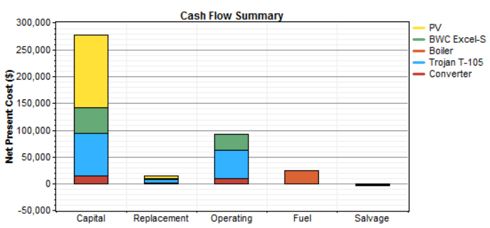

Fig. 7. Cash Flow Summary

3.2 Electricity Production from the renewables

The expected yearly electric energy production is expected to be 86,605[kWh], and as illustrated in Fig. 8, PV produces 85[%] of the energy with 73,673[kWh] while the rest, 15[%] with 12,932[kWh], by the wind turbine. This production ratio between the PV and the wind turbine is consistent each month over the year.

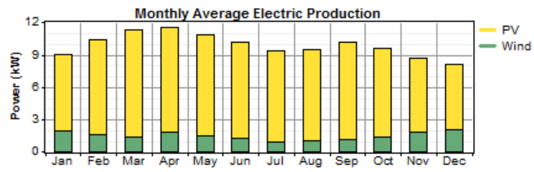

Fig. 8. Monthly Average Electric Production

Energy produced by PV

Table 4 summarizes the PV generated energy. Among them are the total production of 73,673[kWh/year] and the levelized cost of energy 0.145[$/kWh]

Table 4. PV Energy Production Output

Quantity	Value	Units
Mean output	8.41	kW
Mean output	202	kWh/d
Total Production	73,673	kWh/yr
Capacity Factor	18.7	%
PV penetration	143	%
Hours of operation	4,380	Hr/yr
Levelized cost	0.145	$/kWh

Energy produced by Wind Turbine

Table 5 summarizes the wind turbine generated energy. Among them are the total production of 12,932[kWh/year] and the levelized cost of energy 0.486[$/kWh]

Table 5. Wind turbine output

Quantity	Value	Units
Mean output	1.48	kW
Total Production	12,932	kWh/yr
Capacity Factor	14.8	%
Wind penetration	25.1	%
Hours of operation	7,881	Hr/yr
Levelized cost	0.486	$/kWh

3.3 Emission Analyses

The system configured for the Mongolia region has to include a diesel-fueled boiler system to protect the battery system under harsh winter weather condition. To minimize the use of diesel fuel, the configuration tries to supply the heater with surplus energy. However, there is no way to make the system emission free. Table 6 summarizes the emission produced from the configured system and the difference between it and the equivalent amount of emission from a diesel generator which would meet the same load of the region. The emission types and amounts from the configured systems are as follow: CO_2 emissions of 4,681[kg/yr] and SO_2 emissions of 9.57[kg/yr]. However, a diesel generator system for the equivalent load demand would produce CO_2 emissions of 80,933[kg/yr] and SO_2 emissions of 163[kg/yr], which are about 17 times higher than their counterparts in the configured micro-power system of renewables.

Table 6. Emission Generation of the Configuration

Pollutant [kg/yr]	Emission of the System	Emission from a diesel generator
CO_2	4,681	77,176
CO	0	190
C_5H_{12}	0	21.1
SO_2	9.57	155
NO_2	0	1,700

If we adopt an emission tax system on CO_2 emissions in the U.S, 7[$/ton] in the state of Colorado in particular, the diesel generator system would be charged $566.53 annually while the renewable micro-power system would be only $32.77, which would have annual cost reduction of $534.

4. Sensitivity Analyses

<u>Component Cost</u>

A sensitivity analysis is done on the component costs for PV, W.T, and battery systems. The normalized price is used in this analysis. The normalized price of 1.0 is the case that there is no price change in the component while 0.75 indicates that the component price is lower by 25[%] of the original price. In each combination of the normalized prices of the 3components, the initial component cost and the energy cost are calculated as illustrated in Table 7.

The lowest energy cost is obtained from Case6 in which the prices of both PV and battery system are lowered by 25[%] and from Case8 in which all three component prices are 25[%] lowered. It can be noted that the both cases have the highest generation capacity. It is also noted that, in Case2 and 4, when the prices of batter systems and the PV are not changed, the presence or absence of W.T determines the initial installation cost and the energy cost. In general, W.T are a major variable in the economic analysis of the overall system configuration

Table 7. Effect of component costs the system economics

CASE	PV	WT	Battery	PV [kW]	WT [kW]	Battery [EA]	Converter [kW]	ICC [$]	COE [$/kWh]
1	1.00	1.00	1.00	45	10	344	18	276,520	0.569
2	1.00	1.00	0.75	57	0	456	18	264,060	0.532
3	1.00	0.75	1.00	42	10	344	18	264,520	0.551
4	1.00	0.75	0.75	63	10	368	18	239,880	0.521
5	0.75	1.00	1.00	63	0	416	18	251,830	0.502
6	0.75	1.00	0.75	63	0	416	18	227,910	0.466
7	0.75	0.75	1.00	51	10	312	18	236,910	0.499
8	0.75	0.75	0.75	63	0	416	18	227,910	0.466

<u>Electric Energy Production</u>

The nest sensitivity analysis is performed on the energy cost under the total electric energy production. As illustrated in Fig. 9, it is clear that the energy cost is lowered as the electric generation increases. This inverse relationship is the main characteristic of renewable which do not need fuel for energy production. Even with the diesel boiler system included in the proposed configuration, the fuel cost does not increase proportional to the energy production. Therefore, with higher initial capital cost, the increased generation capacity lowers the energy cost of the micro-power system of renewables.

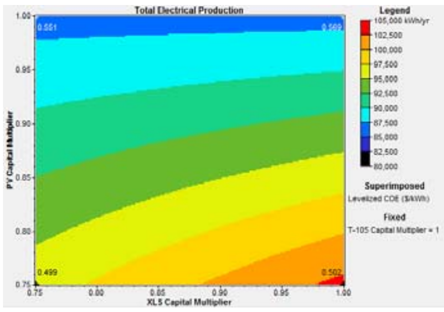

Fig. 9. C.O.E by Total Electrical Production

<u>Total operating cost</u>

A sensitivity analysis focuses on the CO_2 emission under different total operating costs for the configured system. It shows that when operating cost decrease the emission increases. This relationship can be explained as follows. The configured system contains a diesel boiler and if there is not enough surplus energy to supply the heater, the diesel boiler would work more consuming more diesel fuel and thus more emission. Fig. 10 chart the relationship.

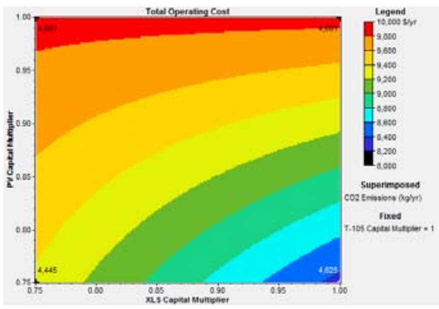

Fig. 10. $CO_2$by Total Operating Cost

Conversely, increase in the initial capital cost would increase energy production, which in turn would lower the operating and energy costs, which finally results in the reduce CO_2 emission. In other words, an over-capacity configuration would minimize the operation of the diesel boiler and reduce the emission and lower the energy cost. This over-capacity and higher initial cost is one of the characteristics of the renewable energy sources.

Conclusively, the final micro-power system for the Bayangnuur region is configured as a stand-alone system with a 63[kW] PV and a 10[kW] W.T. This slightly over-designed configuration has to invest $35,500 more for the initial installation cost, but will have $1,149 reduction in operating cost, $20,910 reduction in the NPC, and the yearly reduction of the emission in the amount of 510[kg]

5. Conclusion

This paper configured a micro-system of renewables for the Bayangnuur region in Mongolia to meet the load while minimizing the operating cost and the emission production. The configured system was simulated using HOMER and sensitivity analyses were performed. The optimal configuration acquired was comprised of a 63[kW] PV system, a 10[kW] W.T, a bank of 264batteries, and a converter of 18[kW]. Under the optimal configuration, 85[%] of power was expected to be generated by the PV system and the rest by the W.T. the operating cost of the configuration was 10 times higher than gird power cost of fossil fuel; however, CO_2 emission amount from the configuration was 17 times lower than that of an equivalent diesel generator system. The sensitivity analysis of the configuration confirmed the main characteristics of renewable energy systems by demonstrating that an increase in the initial capital cost increase energy production, which in turn lowered the operating and energy cost, resulted in the reduced CO_2 emission. The configuration and simulation proved the concept and realization of a stand- alone renewable micro-power system which was economical, reliable, and emission-free.

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