Wind-Geothermal-Diesel Hybrid Microgrid Development: A Technical Assessment for Nome, AK

Jeremy B Vander Meer (jbvandermeer@alaska.edu)
Department of Physics, University of Oldenburg
Oldenburg, Germany

Marc Mueller-Stoffels (mmuellerstoffels@alaska.edu)
Alaska Center for Energy and Power, University of Alaska Fairbanks
Fairbanks, AK, USA

Abstract

This paper investigates the effect of adding a geothermal electric power source to the remote wind-diesel microgrid of Nome, AK. The proposed geothermal source would displace most of the base load and not be able to load follow. A time step simulation was created to model the grid behavior for different levels of geothermal power and additions to the diesel generator fleet. With increased geothermal power input, the diverted[1] wind energy increased quadratically while the diesel generators' displaced output increased linearly, average load factor decreased and switching increased. Adding diesel generators of varying size to the fleet decreased the diverted wind energy, increased the displaced energy and average load factor of diesel generators, but also increased the diesel generator switching.

Keywords: Microgrid; geothermal power; wind power; diesel scheduling.

Introduction

The City of Nome, Alaska, population 3,759, has an average electrical load of about 4 MW and is powered by an islanded wind-diesel grid. Nome has recently increased its nameplate wind power capacity to 2.7 MW. Currently, the potential for electrical low temperature geothermal power (Organic Rankin Cycle) is being explored near Nome. Models suggest that there is potential for 2 MW_e power from this resource. This poses several key questions for Nome: How would adding the geothermal power affect the operation of the grid? What would the added value of the geothermal power be? What grid modifications could help with the integration of geothermal energy by improving grid performance?

Research Objectives

This paper seeks to answer the following questions:

1. How would adding geothermal power and diesel generators affect the operation of the diesel fleet?
2. How much would diesel generator output be reduced?
3. How much wind power would have to be diverted[1]?

Methods

A time step simulation was created to model the Nome grid using two years of grid data in 10 minute intervals. The following sections describe the load, how wind production data was generated from partial data, how the diesel fleet was scheduled and the specifics of the geothermal resource.

Load Characteristics

The measured grid consumption over two years was used in the simulation as the load. The load had a seasonal variation, with an overall average of 4 MW, which rose to around 4.5 MW in January, and dropped to around 3.5 MW in July. The base load was 2.5 MW and peak load was 6 MW.

Estimating Wind Power Available

The City of Nome has two wind farms. Farm A has 18 older 50 kW turbines and Farm B has two 900 kW turbines. There was only 6 months of production data for both wind parks. There was 2 years of grid data during which Farm A was in operation, but measurements were only made at the feeder level. The main load on Farm A's feeder was a mothballed mine and found to be relatively constant. Thus a calculated constant load was subtracted to obtain an approximation for Farm A's output. The approximation was then compared with the 6 months of actual measured wind park outputs to obtain a correlation between the two. In addition, measured wind speeds from nearby met towers and theoretical power curves were used to validate the model of wind power output. The resulting estimated power outputs for Farm A and B had the same average output as the actual outputs, with correlation coefficients of 93% and 71% respectively. The estimates were then applied to the 2 years of grid data to obtain an approximation for what the wind farm outputs would have been during those 2 years.

Diesel Fleet Scheduling

The current grid has 1.9, 3.7, and two 5.2 MW diesel generators. There is a 0.4 MW generator that could be brought online in the future. Different combinations of these generators, along with a hypothetical 1 MW diesel generator, were simulated.

The following operating bounds were placed on the diesel generators in the simulation:

1. Minimum operating time (MOT): Each diesel generator has a minimum amount of time it must run before it can be switched off.

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[1] Diverted is to be understood as supplying managed loads, or curtailment of wind turbine output. Electric boilers are used in Nome and generating heat is of significant economic value, but is not addressed as part of this study.

2. Warm up/cool off: Each diesel generator must run a certain amount of time before coming online and after going offline.
3. Minimum optimal loading (MOL): Each diesel generator has a size dependent minimum power output below which it should not be operated.
4. Spinning reserve capacity (SRC): A set amount of online diesel generator capacity must remain available to handle a sudden increase in load.
5. Cover wind production: In addition to the required SRC, there must be online available diesel generator capacity equal to the wind production that is supplying unmanaged loads. This would allow the grid to handle a sudden drop in wind production.

These operating bounds were set to model the current grid operation and are fairly conservative. While more advanced control schemes involving a dynamic relationship between the SRC and covering wind production (Chen, 2008), demand response and energy storage (Lu et al., 2011) are possible, for this simulation it was important to obtain results that are directly applicable to the current grid setup.

When scheduling the diesel generators, the combination with the lowest combined MOL that met the above requirements was chosen. This allowed for a maximum import of wind power into the grid and for the diesel generators to operate with a higher load factor (Katiraei & Abbey, 2007). More complex scheduling algorithms are possible that minimize operating costs but require more operating and cost information about the grid and generating units than was available at Nome (Logenthiran & Srinivasan, 2009)(Cecati, Citro, Piccolo, & Siano, 2011).

Geothermal Resource Integration

Preliminary drilling and models suggest that there is a 2 MW_e potential geothermal resource near Nome (Miller, McIntyre & Holdmann, 2014). If developed, this power source is not expected to be able to load follow and will have a seasonal variation due to a reduced temperature differential during the summer months. The seasonal variation was modelled as being the nameplate capacity from October to April, 92% capacity in May and September, 83% capacity in June and August and 75% capacity in July. Geothermal power production cannot be curtailed quickly, unlike wind power, and the grid must accept whatever is produced. Although there is a potential of 2 MW_e, outputs ranging from 0 to 5.5 MW_e were simulated to understand underlying principles that may govern this type of hybrid system.

Results

The results of the simulation of adding geothermal power to Nome's grid are presented in this section. First, the effect on the operation of the diesel generators is discussed and then the displaced diesel generator energy and diverted wind energy.

Diesel Generator Operation

Four different groupings of diesel generators were simulated, as listed in Table 1.

Table 1: Groupings of diesel generators; Case 1 is the base (current) case.

Case #	**Available Diesel Generator Capacities [MW]**	**Marker-style on plots**
1	5.2, 5.2, 3.7, 1.9	circle
2	5.2, 5.2, 3.7, 1.9, 0.4	square
3	5.2, 5.2, 3.7, 1.9, 1	diamond
4	5.2, 5.2, 3.7, 1.9, 1, 0.4	cross

Figure 1 shows the average diesel generator load factor for the different levels of geothermal input to the grid. The different lines represent the different combinations of available diesel generators, as outlined in Table 1.

Four main observations can be made:

1. By adding smaller diesel generators to the fleet, the average diesel load factor at a given geothermal power increases, as the online capacity can be better matched to the load. In this case, adding a 1 MW generator generally results in a higher load factor than a 0.4 MW, since it allows a more even step size between generator combination capacities. In general, a higher load factor results in increased efficiency and optimal operation for diesel generators.
2. At very high geothermal power output, the diesel generator load factor bottoms out at the MOL of the smallest generator, which also means that all wind power is diverted.
3. There are distinct maxima in the slope of the line for Case 1 (blue) around 0, 1.5 and 3 MW geothermal output. These represent scenarios at which there is one predominant diesel generator combination online, since the average diesel generator output falls in the middle of its operating range. The local minimum in the curve between these peaks represent scenarios switching between predominant online generator combinations. With added diesel generators, the local minimum is removed, as there is less of a difference between the capacities of possible diesel generator combinations. Again, adding a 1 MW generator improves performance more than the 0.4 MW, since it allows for a more even step size between generator combination capacities.
4. Diesel generator switching increases with geothermal power output and with a larger diesel generator fleet (see Figure 2). The smaller diesel generators tend to switch more often than the larger ones. Increased switching consumes diesel and can increase the stress on the diesel generators. Changes to the generator scheduling can reduce the switching, but would also reduce the positive effects listed in the previous points.

In summary, adding smaller capacity diesel generators to the fleet increased the average diesel generator load factor and allowed a more constant change in the load factor for changes in geothermal power output. Also, adding diesel generators which allow for a more constant step size between generator combination capacities increased both these results. In general, the amount of diesel generator switching increased with an increase in the number of available diesel generators and geothermal power output.

While operating at a higher load factor generally results in a higher efficiency and optimal operation for diesel generators, switching consumes diesel and can increase the stress on the diesel generators.

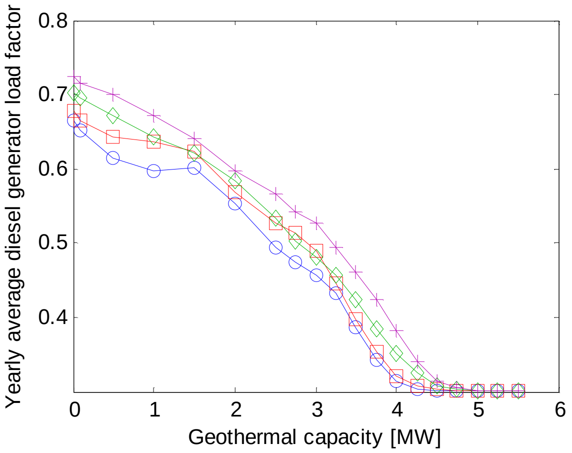

Figure 1: Average diesel generator load factor for different diesel generator scenarios (see Table 1).

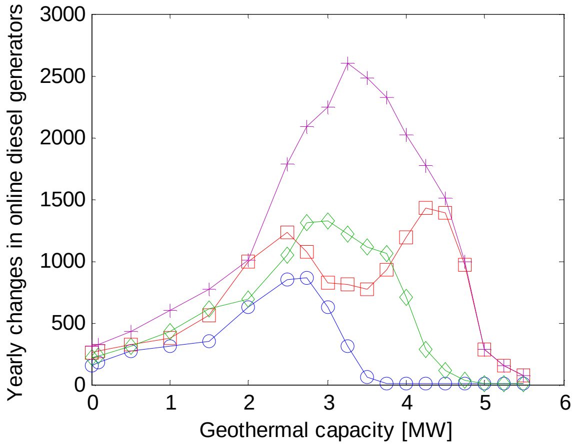

Figure 2: Number of changes of online diesel generator combinations per year for different diesel generator scenarios (see Table 1).

Wind Energy Diversion and Displaced Diesel Output

This section investigates the relationship between increased diverted wind energy and saved diesel generator output for increased geothermal power output. Discussion is limited to results of geothermal capacity less than the base load. Exceeding base load leads to diversion of significant amounts of geothermal energy.

An energy balance shows the relationship between diesel generator output (E_{DEG}), wind energy (E_{WTG}), diverted wind energy (E_{div}), the load (E_{load}) and average geothermal power production ($\tilde{P}_{GTG}$) per year (8760 h):

$$E_{DEG} + E_{WTG} + 8760\,h \cdot \tilde{P}_{GTG} = E_{load} + E_{div} \qquad (1)$$

Changing the value of $\tilde{P}_{GTG}$ changes the energy balance. The change in the energy balance is shown by Equation 2. E_{load} and E_{WTG} are not affected by a change in $\tilde{P}_{GTG}$ and thus cancel out.

$$\Delta E_{DEG} + 8760\,h \cdot \Delta\tilde{P}_{GTG} = \Delta E_{div} \qquad (2)$$

If the base case scenario had no geothermal production, then $\tilde{P}_{GTG_0} = 0$ MW and $\Delta\tilde{P}_{GTG} = \tilde{P}_{GTG}$. Displaced diesel generator output resulting from adding geothermal production equals a negative change in diesel generator output; $E_{disp} = -\Delta E_{DEG}$. Equation 3 results from substituting these definitions into Equation 2:

$$E_{disp} + \Delta E_{div} = 8760 * \tilde{P}_{GTG} \qquad (3)$$

Based on Equation 3, the total displaced diesel generator energy and the increase in wind energy diversion should add up to a linear line with a slope of 8760 h as a function of average geothermal power for different fleet cases.

Several key simulation results follow:

1. Geothermal outputs above the maximum displaceable base load (base load – MOL of the smallest diesel generator) either need to be diverted at times or be able to load follow. Load following capabilities would significantly change the outcome of this study, with 100% diesel displacement being possible at times.
2. A second order polynomial fits the relationship between increasing wind energy diversion and increasing average geothermal output well (see Figure 3). Adding smaller diesel generators to the fleet lowers the slope of the curve, resulting in less diverted wind energy. Again, adding a 1 MW diesel generator (case 3) performs better than adding the 0.4 MW diesel generator (case 2).
3. The displaced diesel generator output has an equal and opposite quadratic component to the diverted wind, but is predominantly linear (see Figure 4). The quadratic and linear coefficients for wind diversion and displaced diesel generator output can be seen in Table 2. The quadratic coefficients cancel out and the linear coefficients add up to roughly 8760 h.
4. The displaced diesel generator output is predominantly linear, with approximate slopes shown in Figure 4. Thus, with the diesel generator fleet in case 1, the annually displaced diesel generator output will increase with a slope of 8060 h per MW of average geothermal power input to the grid.

In summary, the annual displaced diesel generator output and diverted wind energy, as functions of added geothermal power, add up to a linear line with a slope of 8760 h. Less wind energy is diverted with a larger number of diesel generators of varying size, which means more diesel generator energy is displaced. The diverted wind energy has a significant quadratic component, while the displaced diesel generator energy is predominantly linear.

Table 2: Diverted wind and displaced diesel vs average geothermal power output curve coefficients.

Case #	**Diverted wind coefficients**		**Displaced diesel coefficients**	
	X^2	**X**	**X^2**	**X**
1	2.2e2	1.9 e2	-2.2e2	8.6e3
2	1.5e2	2.2e2	-1.5e2	8.5e3
3	1.9e2	-5.1	-1.9e2	8.7e3
4	2.3e2	-1.2e2	-2.3e2	8.9e3

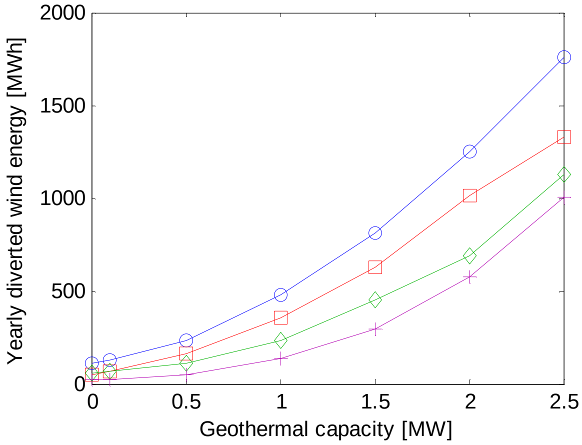

Figure 3: Annual wind electrical energy diversion for different diesel generator scenarios (see Table 1).

Discussion

The effects of adding geothermal power to the operation of the wind-diesel grid at Nome have been summarized for the current grid setup and for possible upgrades to the diesel generator fleet. These results can be used to help determine the value of adding geothermal power and diesel generators to the grid.

The slopes of the displaced diesel generator energy and diverted wind energy as functions of added geothermal power add up to a linear line with a slope of 8760 h. The diverted wind energy was found to have a quadratic increase. Due to a predominant linear term, the displaced diesel generator energy could be approximated as a linear increase.

The diesel generators' average load factor was found to decrease and switching to increase for added geothermal power to the grid. Adding to the diesel generator fleet to create smaller, more constant, differences between the combined capacities of diesel generator combinations resulted in less diverted wind energy, more displaced diesel generator energy, a higher diesel generator load factor and more diesel generator switching.

Thus, when determining the value of adding geothermal power to the grid, the decrease in diesel generator performance due to increased switching and decreased load factor needs to be considered. Similarly, when determining the value of adding diesel generators to the fleet, the advantages will have to be weighed against the increase in switching.

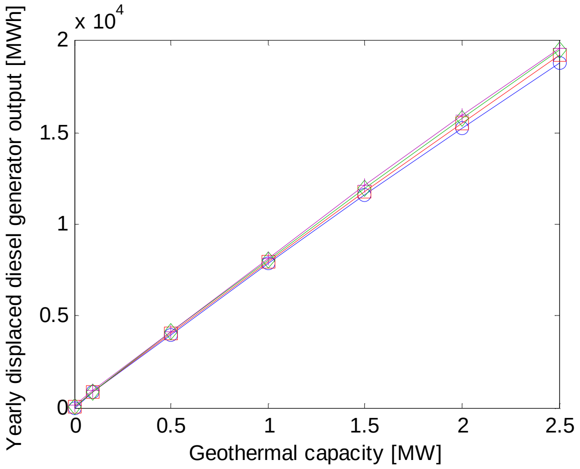

Figure 4: Displaced diesel generator output for different diesel generator scenarios (see Table 1). The slope of Case1 is 8060 h, Case2 is 8200 h, Case3 is 8320 h and Case4 is 8360 h.

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