Wind-Diesel-Storage Modeling Project

Emerging Energy Technology Fund Application Round 2

Dennis Witmer eeedew@gmail.com 907-590-2836

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An earlier version of this project was submitted to the first round of EETF applications as an independent project and was not accepted for funding. Initial modeling was done as part of the Kotzebue Electric Association Flow Battery project. This project is intended to extend the modeling efforts to additional Wind-Diesel hybrid projects in Alaska. Total project cost: $120,000—Request $100,000 from EEFT, $20,000 in kind labor cost share from EEE.

Project Summary: Modeling of Wind-Diesel-Battery Hybrid Systems

This proposal is to extend the use of the EEE Wind Diesel Hybrid model currently being developed for flow battery and lithium ion battery systems to other high penetration wind diesel systems in Alaska. It should be noted that this model in its current form is not intended for public distribution or use, and remains the intellectual property of EEE.

Modeling is a process in which a real, complicated physical system is simplified through the use of assumptions to a mathematical system, usually constructed in a computer software structure. Computer models of 20 years ago were largely constructed in programming code (a tedious process), but recent improvements in computational speed and capacity have allowed the use of graphical programming languages. Simple models can be constructed quickly, run, and compared to expected results, and modified as necessary.

In addition to software and a modeler who knows how to use it, good modeling needs two additional inputs: good input data, and clear communications with the customer. In the case of Wind Diesel Hybrid modeling, clean data on village load, diesel engine output, and wind farm output must be provided, as a single piece of missing data will prevent the model from running. Since most data sets have missing or obviously erroneous data, cleaning the data set before running the model is critical, and the rules by which bad data is identified and corrected must be made clear. Simulated data can be created for model inputs, but the methods of creating this simulated data must be understood. Clear communications with the customer are important for a host of reasons: the customer must understand the limits of the model, as it provides results only as valid as the assumptions used to make it; and obtaining accurate information about the exact hardware installed, the location of sensors (such as the height of an anemometer) directly affects the quality and utility of the results. For this reason, this project includes a significant travel component, both for travel to utility sites, and for face to face meetings with the utility owners and operators.

One observation, made by many, is that Wind-Diesel systems installed in rural Alaska have largely failed to deliver the expected savings based on earlier modeling. The reasons for this are many, but given that decisions to invest in projects is often based on modeling results, it must also be noted that the investments made have largely failed to provide the expected returns. Given that the level of investment in wind systems in rural Alaska is well over $100,000,000, it seems prudent to invest in better modeling, to understand why existing systems are performing the way they are, to help identify ways in which they could operate better, and to allow funding agencies a better understanding of the true nature of the investments they are making.

Modeling of Wind-Diesel-Battery Hybrid Systems

Remote power systems used in Alaska villages have historically been power by diesel generators, with heat for residential and commercial spaces using heating oil. With the rise in crude oil prices in recent years, the costs of operating these systems has risen steeply. Wind-diesel hybrid systems, and Wind-diesel-battery hybrid systems have been proposed to reduce the cost of energy to users of these systems. However, these systems have increased capital costs, and have unknown lifetimes, and it is not clear at this point if the fuel savings achieved by the use of renewable energy results in an overall reduction in the cost of energy.

In addition, system designers do not have tools that allow them to properly size components or understand control strategies to optimize the economics of the system. This is particularly true as new battery technologies, such as Lithium ion and flow batteries, are added to the systems. Existing models, such as the commonly used HOMER, apparently have embedded assumptions (such as the idea that diesels off happens when winds average 150% of load) that provide suspect results.

This modeling effort is an attempt to answer these questions, especially the tricky question of the value of energy storage and heat. The model will do this by breaking all costs down into capital costs and fuel costs (or value), and calculating the overall system costs to meet a given load, for both electrical and heat loads. This model will use information from existing and proposed battery demonstration projects.

Diesel Power Generation and Heating Fuel base case:

Providing electricity from a diesel generator involves three costs: the capital cost of the generator, the fuel costs to generate the power, and the O&M costs. Of these costs, fuel costs are the most significant. Current large electronic injected diesel generators are capable of producing about 14.5 kilowatt-hours of electricity per gallon of diesel fuel consumed—if this fuel costs $4 per gallon, this corresponds to a fuel only cost of 27.6 cents per kilowatt hour. One advantage of diesel generators is that they are quite adept at load following, meaning that they can efficiently follow changes in typical loads (with some exceptions—abrupt changes in loads caused by intermittent operation of large electric motors such as sawmills can be a problem). As part of this ability, there is no "spilled" energy, meaning that the system never has losses associated with excess electrical generation. A tank of fuel can be thought of as a reservoir of stored energy that can be used—but it cannot be replenished, except by buying more fuel.

Heating residential and commercial spaces with heating fuel is similar—a tank of fuel is purchased, and then consumed to meet a given heat load. The system lifetime cost of the fuel far exceeds the capital cost of installing the heating device. A gallon of heating fuel contains about 39 kilowatt-hours of heat energy—if a boiler is 85% efficient, at $4 per gallon, the cost of this energy is about 12 cents per kilowatt hour, or about $33.85 per million BTU.

Wind-Diesel Hybrid Systems

Wind is an abundant resource in many locations in Alaska, and does not require fuel. However, the installed capital cost of wind systems is often quite high, and represents the most significant cost of this generation system. It cannot load follow—it can only be produced when there is sufficient wind to drive the turbines. If the size of the wind turbine is larger than the maximum load, there is the possibility that some energy must be "spilled" to maintain system electrical stability, ie, converted to heat, either to meet a heat load, or simply dissipated to the atmosphere. In addition, the second to second variation in the wind can lead to operation of the diesel generator in a less efficient part of the operating curve, meaning that the cost of power being provided by the diesel generator increases for that increment of power. There is also the possibility that rapid changes in the wind could lead to a destabilization of the system, leading to a black-out, where the power plant is forced to drop the load to protect the system. Proper modeling of this system must be done on a time scale associated with the rise and fall of the wind power, which occurs on the level of seconds.

Wind—Diesel—Battery Hybrid Systems

The addition of battery storage to a wind-diesel hybrid system attempts to solve the inability of the wind-diesel system to load follow by allowing electrical energy to be stored, and then injected back into the system at a later time. The use of the battery to stabilize the system on a second by second basis allows for the use of higher penetration wind systems, and therefore a lower diesel consumption during a wind event (peak shaving) and also to provide additional fuel savings after the wind event (load shifting). However, the precise amounts of energy that can be absorbed or injected during a wind event (for peak shaving) or stored for fuel displacement later (load shifting) will depend on system details, especially the losses that occur in the battery. The amount of energy stored depends on the rate of charge, the current state of charge (if the battery is full, no additional energy can be stored), and the temperature of the battery. Batteries also loose energy over time, either though "self discharge" (typically 1% a day for Lithium Ion batteries) or through parasitic losses such as pumps for flow batteries.

The need for modeling

Installing renewable energy systems makes economic sense only if the resulting cost of producing that energy is less than that of the conventional diesel/heating fuel case. Renewable energy systems require the investment of up-front capital in exchange for long term fuel savings. Adding an expensive battery to the system adds to the capital expense, but allows the use of larger, cheaper (on a per kW basis) wind turbines, hopefully allowing additional fuel savings. But it is not clear what is the ideal wind power installation, what sized battery is appropriate, or if the addition of the battery is cost effective. The possible use of excess electricity for the generation of heat is also possible. However, during strong wind events, the battery may become filled, and the thermal loads may become saturated (especially during summer months), and energy may still need to be "spilled".

Current state of the existing model:

This modeling effort was initiated as part of the Kotzebue Electric Battery project. One deliverable in that project was the delivery of an economic estimate of the value of the proposed battery. That effort resulted in a one-second time based model using load and wind farm output data from the KEA installation. The model included electrochemical and parasitic data associated with the Premium Power Zinc Bromine flow battery. Preliminary results were submitted to DOE, but additional refinement of the model occurred after delivery of this report. A report suitable for publication is currently under review by program participants.

Additional modeling has been done. The model currently incorporates:

- State of the art time based commercially available software.
- Diesel efficiency curves for multiple diesel engines, including common engines in Alaska.
- Wind turbine power curves for wind turbines for common turbines in Alaska.
- Battery and inverter curves.
- Residential electrical thermal stove performance data.
- Utility scale electric boiler operation.
- "State function" developed for diesels off operation, allowing diesel engines to be operated when needed (no wind, during battery charging, and after battery discharges)
- Economic data, including capital, O&M, and fuel consumption data collected for baseline diesel operation and hybrid configuration

The model has been operated using one second data provided from several 24 hour datasets. This allowed:

- Comparison between diesel fuel consumption calculated by model, reported by system data acquisition, and measurement of fuel added to day tank during 24 hour period with wind event, resulting in acceptable experimental verification.
- Wind speed to turbine output results compared to output from HOMER based on same input and wind turbine curve (based on one hour wind speed data, agreement within 0.5%).

In addition, the following model projections have been completed:

- Operation of a system including the Li battery, (model shows considerable additional fuel savings due to diesels off operation) based on one second data from period with a wind event.
- Annual operation of residential electric thermal storage stoves based on one hour projected wind output, with economic calculations of savings for homeowners and benefits to utility. Preliminary results show that diesel fuel savings at the power plant are the most significant economic factor, but both village residents and the utility can realize economic benefits from the use of distributed electric stoves.

1. Project Summary

a. Project Description: Modeling of Diesel, Wind-Diesel, and Wind-Diesel-Storage energy systems to assess fuel savings and economic impacts.

b. Project Eligibility: Wind diesel hybrids including energy storage have been used in Alaska since the Wales project in the late 1990s. New battery technologies (LI developed for automotive uses, flow batteries, high temperature sodium batteries, and flywheels) are currently being brought to market that may change the economics of wind energy in Alaska. Demonstration projects are being funded in Alaska to verify the technical suitability of these new batteries, but economic modeling has not yet demonstrated that these new systems can reduce energy costs in remote communities.

c. Project Innovation: This modeling activity will allow the proper sizing of high penetration wind-diesel systems in Alaska, including wind turbines and energy storage modules, and heating loads, model fuel savings, and estimate total life cycle costs (capital, O&M, and fuel costs) for these systems.

d. Priority: This proposal is from an Alaskan Small Business. This proposal does not include cooperation with the University of Alaska, as previous attempts to use researchers at UAF to develop a model similar to the one described in this proposal did not result in an acceptable product, despite more than $500,000 in public funding and more than five years of effort. While it appears that the university is developing some skills in testing, data collection and analysis, it still lacks sufficient skills in modeling and electrochemistry to properly address this need. Recent discussions (July 2013) with UAF researchers indicate that they continue to believe that development of a model as described above will cost at least $1,000,000.

2. Technology Validation and Data Collection

a. Objectives: Economic and energy modeling of high penetration wind-diesel-storage systems for remote Alaska communities.

b. Data Collection: Wind and community load profiles will be used as inputs to a model that will calculate the economic value of both high penetration wind and storage systems.

3. Project Schedule and Project Budget

a. Software license renewal fees $1,000 and $10,000 travel budget, balance for labor.

b. Cost share--$20,000 in-kind labor.

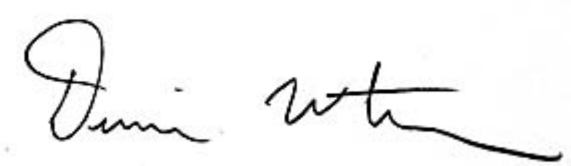
4. Project Team Qualifications

PI—Dr. Dennis Witmer, Senior Analyst, Energy Efficiency Evaluations. Extensive experience in evaluations of electrochemical systems (Fuel Cells and Batteries), and in economic evaluations of energy projects in Alaska [1, 2] Additional staff may be hired as needed.

5. Discussion of Commercialization of Funded Technology See item 1 above

6. Signed Applicant Certification

"By signature on this application, I certify that we are complying and will comply with the amount of matching funds being offered."



Dennis Witmer, EEE Owner

1. Burbank, W., *Building a Toolset for Fuel Cell Turbine Hybrid Modeling*, in *Mechanical Engineering*. 2006, University of Alaska Fairbanks: Fairbanks. p. 156.
2. Burbank, W.S., D.E. Witmer, and F. Holcomb, *Model of a Novel Pressurized SOFC-GT Hybrid Engine.* Journal of Power Sources, 2009. **POWER-D-09-00248R1**.