Wind-Diesel-Storage Modeling Project

Emerging Energy Technology Fund Application

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

3/9/2012

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

This project has not been submitted to any previous AEA or Denali Commission Application process. This project does not involve any formal collaboration with the University of Alaska. Total project cost: $120,000—Request $100,000 from EEFT, $20,000 in kind labor cost share from EEE.

Modeling of Wind-Diesel-Battery Hybrid Systems

Remote power systems used in Alaska villages have historically been powered 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 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 savings 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. 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 (KEA) and proposed battery demonstration projects, to maximize the information from these investments.

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 electronic injected diesel generators are capable of producing about 14.5 kilowatt-hours of electricity per gallon of diesel fuel consumed—at $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 at will—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.

Loads in small communities follow seasonal and daily cycles, and vary somewhat on a second by second basis. These variations have been of little significance to this point because the systems are well adapted to follow these loads, and costs (associated with filling fuel tanks) are incurred only at widely spaced intervals. Most diesel systems have several generators of varying sizes, and utilities have become adept at “economic dispatch”, meaning that the most efficient generator is used to match the load level experienced at that point in time.

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”, 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 load-following issue of the wind-diesel system 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 (increased penetration and peak shaving) and also to provide additional fuel savings after the wind event (load shifting). However, the precise amounts of energy that can be generated through increased penetration, 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 properties of the battery. The amount of energy stored depends on the battery technology, the rate of charge, the state of charge (if the battery is full, no additional energy can be stored), and other issues, including temperature and the condition of the battery. Batteries also lose 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. Installing renewable energy systems requires 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, allowing additional fuel savings. But it is not clear what is the ideal wind power installation, what size 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 need to be "spilled".

Previous modeling efforts to project the economic value of wind turbines in rural communities in Alaska have not been validated by outcomes. In the 2009 state energy plan exercise, Unalakleet was listed as a class 6 wind resource, and HOMER projected that a 1000 kW wind system would cost $6.4 M and would generated 1.86 million kilowatt hours per year. The wind farm installed in Unalakleet actually cost $9M for 600 kW (a cost increase of 234% on a per installed kW basis) and generated .96 million kilowatt hours in 2010 (86% of projected power on an per installed kW basis), for a total cost of power 275% of the projected cost.

Given the significant public investment in wind systems in rural Alaska (to date: approximately $131 million dollars, excluding Kodiak, and railbelt systems), and the poor predictions offered by modeling efforts to date, it is prudent to attempt to model high penetration wind systems with storage before significant public funds are invested in multiple installations.

The model needs to include a variety of states, including (but not limited to):

- No wind, battery at low state of charge, diesel on
- Moderate wind, battery charging, diesel on with reduced fuel consumption
- Sudden drop in wind, battery injects power, diesel on (peak shaving mode, stabilized by battery)
- Higher wind, battery charging and discharging, diesel off (peak shaving mode)
- High wind, battery full, diesel off, energy diverted to dump load for usable heat
- High wind, battery full, diesel off, dump load to atmosphere (spilled energy)

- Wind event ends, battery discharges, diesel remains off (load shifting)

Electricity and heat sales count as income; capital costs, O&M, and fuel costs will offset the income.

The model needs to include all installed capital costs, electrical and heat load profiles.

The model will include

- Diesel engine efficiency profiles to calculate fuel consumption
- Village electrical load profiles
- Wind turbine output data, either measured or calculated based on wind speed from met tower data
- Heat demand profiles
- Battery properties, including maximum charge/discharge rates, estimates of state of charge, losses (dependent on charge and discharge rates), parasitic losses (especially for flow batteries), and storage losses.
- Thermal loads and storage (dump loads, hot water tanks, or ceramic stoves)

The model will:

- Accrue all costs (capital and fuel) and income (electricity and heat sales) on a one second basis
- Baseline results on conventional technologies (straight diesel electric generation and heating fuel for heat)
- Develop a baseline "wind event" to measure model system performance by adding various components—wind turbines, storage devices, heating loads—and changing control strategies (exactly when to charge and discharge the battery, for example) and seeing how this affects system economics.
- Develop models for various diesel gen sets, wind turbines, and battery technologies so that these can be mixed and matched
- Use current and proposed Alaska diesel wind hybrid systems as test systems for model validation, including the KEA Premium Power battery, and the proposed ABB Battery project in Kwigillingok.
- Provide a tool for evaluation of the economics of high penetration wind systems, with or without storage, in other communities in Alaska.

1. General Project information

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 and flow batteries) 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 storage modules, model fuel savings, and estimate total life cycle costs (capital, O&M, and fuel costs) for these systems. Use of excess electricity for heat loads will be modeled.

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 approximately $500,000 in public funding and 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 (MatLab and Simulink) and electrochemistry (for batteries) to properly address this need.

2. Technology Validation and Research Methodology (sec. 4.7)

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

b. Methodology: 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. Data from current battery storage demonstration projects will be used, as well as installed costs of existing wind diesel installations. Model development is already underway—a Simulink model of the Premium Power Battery in Kotzebue has already been completed (including electrochemical effects and parasitic loads), as well as generic diesel efficiency and heat production curves (the loss of heat from the diesel engine may have significant economic impacts in some communities). Importing wind and load data into the model has not yet occurred. This request is to expand this model to other communities and energy storage technologies.

3. Summary of Project Schedule and Summary of Project Budget

a. Project will require approximately 6 months of effort, requested budget is for software ($2500 for Matlab/Simulink software, $1500 for dedicated modeling computer, $5000 travel budget, balance for labor). Cost share--$20,000 in-kind labor.

4. Project Team Qualifications

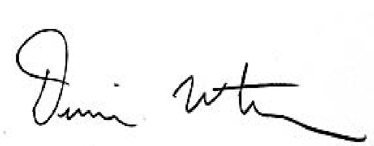
PI—Dr. Dennis Witmer, Senior Analyst, Energy Efficiency Evaluations. Extensive experience in evaluations of electrochemical systems (Fuel Cells and Batteries), and in economic evaluations of energy projects in Alaska. Supervised the successful modeling of a fuel cell turbine hybrid project by PhD student Winston Burbank currently employed by BP Alaska to model the gas distribution system in Prudhoe Bay. [1, 2] Additional staff will be hired as needed.

5. Discussion of Commercialization of Funded Technology

While adding energy storage to wind-diesel hybrid systems provides well understood technical benefits (increasing system stability, increasing renewable penetration), it remains unclear if these storage systems provided an economic benefit, or what size components maximize the economic benefit. This modeling activity is essential to understanding if and when energy storage systems provide an economic benefit. This should be understood during the demonstration phase of the technology, so that good decisions can be made about the large scale deployment of these systems.

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**.