

# Development of Isolated Grid, Wind-Diesel Power Systems in Alaska

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# In this presentation...

- Wind-diesel concepts
- Alaska projects
- Modeling tools, legacy and new development

Background for Winterwind participants: wind-diesel is a specialty field of wind power applicable to many (often of indigenous peoples) isolated cold climate communities (USA, Canada, Russia, South America), mines, research stations (e.g., Antarctica) and also warm climate communities in Africa, Australia, Pacific Islands, Caribbean

# What is an Isolated Grid?

An aerial photograph of a small, isolated island or atoll in the middle of a vast ocean. The island is a thin, elongated strip of land with a small, irregularly shaped lagoon on one end. The surrounding water is a deep blue, and the sky is a pale, hazy blue. The island is the central focus of the image, illustrating the concept of an isolated grid.

- Electrical system not connected to a continent-wide, country-wide or regional grid
- Small: ~100 kW to several MW average load
- Islanded: literally or figuratively
- Power stability issues (voltage, frequency fluctuations)
- Diesel engines are main generation source (typically)

# What is Wind-Diesel?

Wind turbines combined with diesel engine generators

- Can also include other RE such as solar, biomass, small hydro

## Advantages

- Reduces dependency on fossil fuel and unpredictable energy cost
- Sustainability/renewable energy goals
- Wind power – environmentally friendly

## Disadvantages

- System complexity (diesel generators are very simple)
- Operator training
- Technical oversight required

# Wind-Diesel Concepts

- Wind penetration
  - Average
  - Instantaneous
- System control – power quality
  - Frequency
  - Voltage
- Energy storage
  - For excess wind and diesel energy
  - Thermal and electrical

# Wind Penetration

- Average

$$\frac{\text{Wind Energy (kWh/yr)}}{\text{Total Energy (kWh/yr)}}$$

- Instantaneous

$$\frac{\text{Wind Power (kW)}}{\text{Total Power (kW)}}$$

- Difference between the two:

- Average penetration is the project *goal*
- Instantaneous penetration dictates system design *complexity!*

# Wind Penetration (Alaska classification)

## Classification Type

- Very low
  - <8% average
  - <60% instantaneous
- Low
  - 8 to 20% average
  - 60 to 120% instantaneous
- Medium
  - 20 to 50% average
  - 120 to 300% instantaneous
- High
  - 50 to 150% average
  - >300% instantaneous

## Design Differentiation

- Very low
  - Diesels control frequency
  - Minor integration requirements
- Low to medium
  - Diesels always on
  - Secondary loads to control frequency and maintain diesel setpoint
- High
  - Control complexity
  - Diesels-off capability
  - Electrical energy storage options

# System Control Issues

## Wind power in an isolated grid

- Stochastic by nature (uncontrolled, highly variable)

## Generator behavior

- Diesel engine generators follow the load
- Wind turbine generators follow the wind

## Consequences

- Low penetration – few problems
- Medium to high penetration
  - Desirable to meet project fossil fuel use reduction goals
  - Complicated due to power system control requirements



# Power Quality in Wind-Diesel

Frequency – balance of supply and demand

- Diesel engine governor
- Wind turbine pitch control
- Secondary (thermal) Load Controller (sub-cycle, absorbs energy)
- Flywheel (sub-cycle, absorbs and injects energy)

Voltage – amplitude of wave form

- Electric generator voltage regulator
- Synchronous condenser (diesels-off operation)

Power factor – impedance devices require reactive power

Harmonic distortion – propagated disturbances in distribution

# Control Options

## Supply side

- Secondary (or dump) loads: balances load with generation
- Synchronous condenser: provides reactive power, controls voltage
- Energy storage: flywheel, batteries, pumped hydro
- Active renewable control: decrease wind power output with inverter control; curtailment

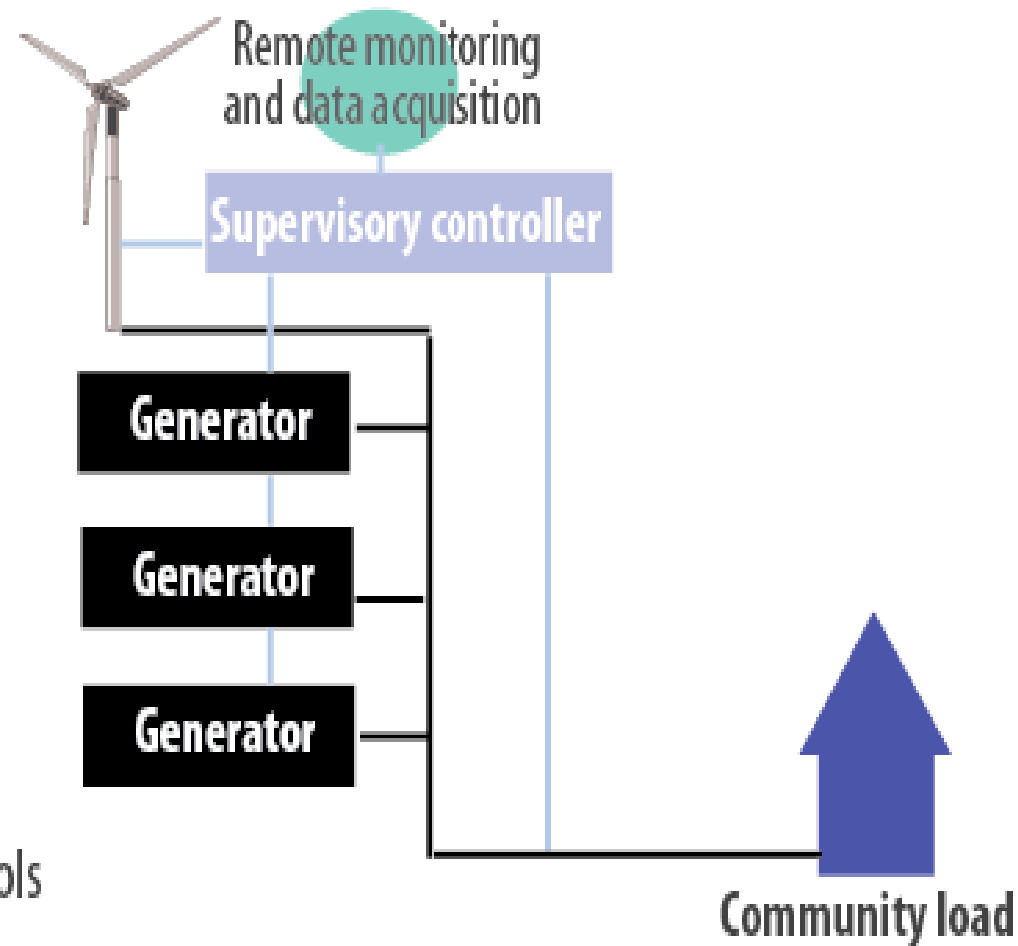
## Demand side

- Load dispatching: load shedding, load protection, dispatchable loads (heaters)
- Capacitor banks: correct power factor; smoothing
- Active load control: replace inefficient loads with better/different devices

# Very Low and Low Penetration W-D Configuration

## Wind-Diesel System, Low Penetration<sup>a</sup>

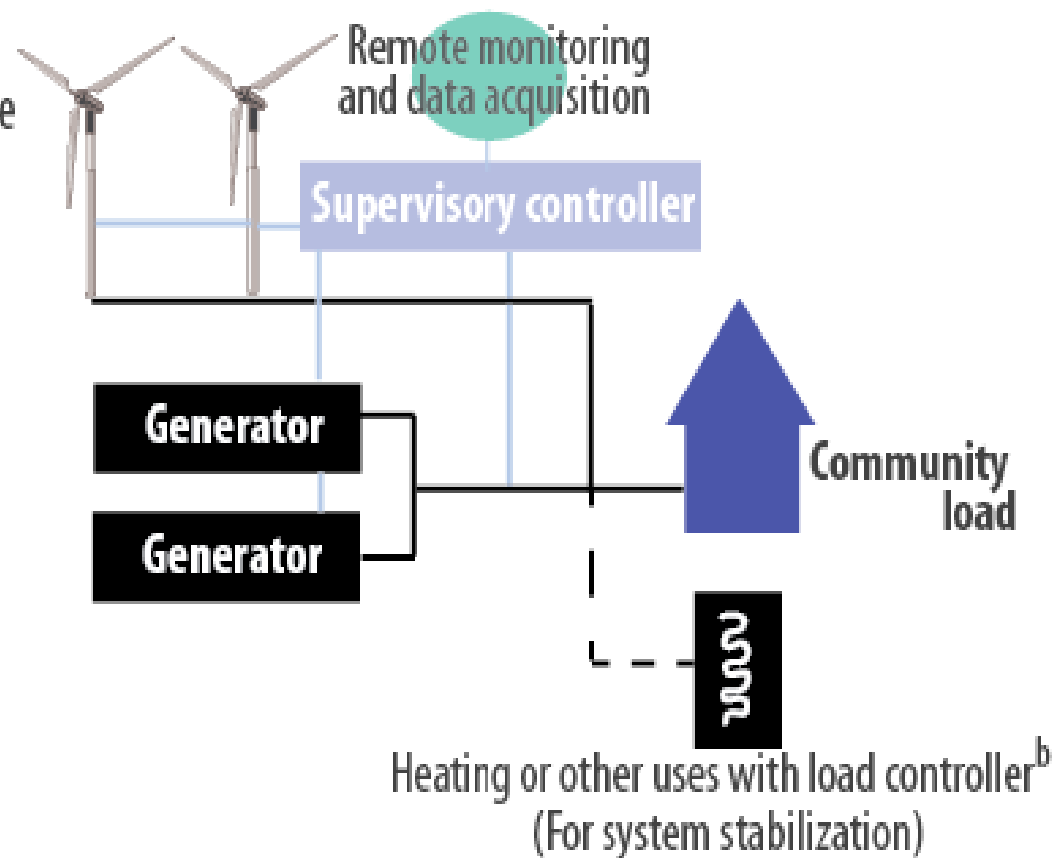
- Diesel generators must run at all times
- Wind power reduces load on generators
- All wind energy goes to primary community electrical load
- Annual average wind penetration under 20%
- Fuel savings up to 15%
- Lower installation costs, because system requires less complex controls



# Medium Penetration W-D Configuration

## Wind-Diesel System, Medium Penetration<sup>a</sup>

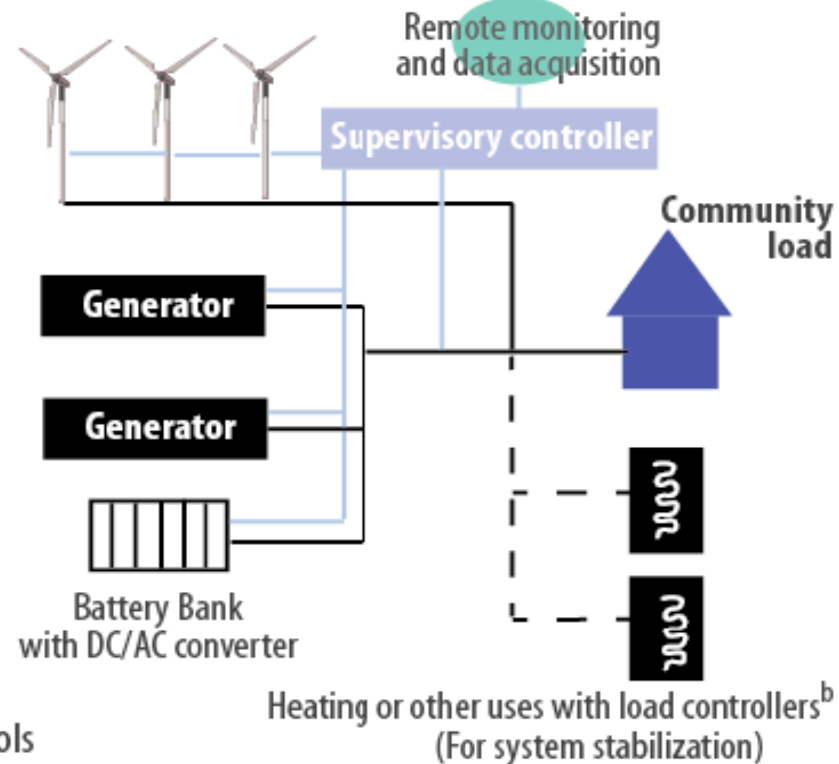
- Potential exists for diesel generators to run under lower, less efficient loads; this should be considered during design
- At high wind power production, part of wind energy diverted for space heating, or wind generation is curtailed
- Annual average wind penetration 20% to 50%
- Fuel savings 15% to 50%
- System controls must be more advanced, which increases installation costs



# High Penetration W-D Configuration

## Wind-Diesel System, High Penetration<sup>a</sup>

- If properly configured, diesel generators may be shut down when wind power exceeds electrical demand
- Auxiliary components regulate voltage and frequency when needed
- Power in excess of what is needed for primary electrical load can be used for space heating or stored in batteries
- Annual average wind penetration 50% to 150%
- Fuel savings 50% to 90%
- Higher installation costs, because system requires sophisticated controls
- Operators must be highly skilled



<sup>a</sup>Wind penetration is the percentage of electricity supplied by wind.

<sup>b</sup>Besides residential or commercial heating, possible other uses include charging electric cars.

Note: These are examples of systems; other configurations exist.

# Typical Alaska Rural Energy Project

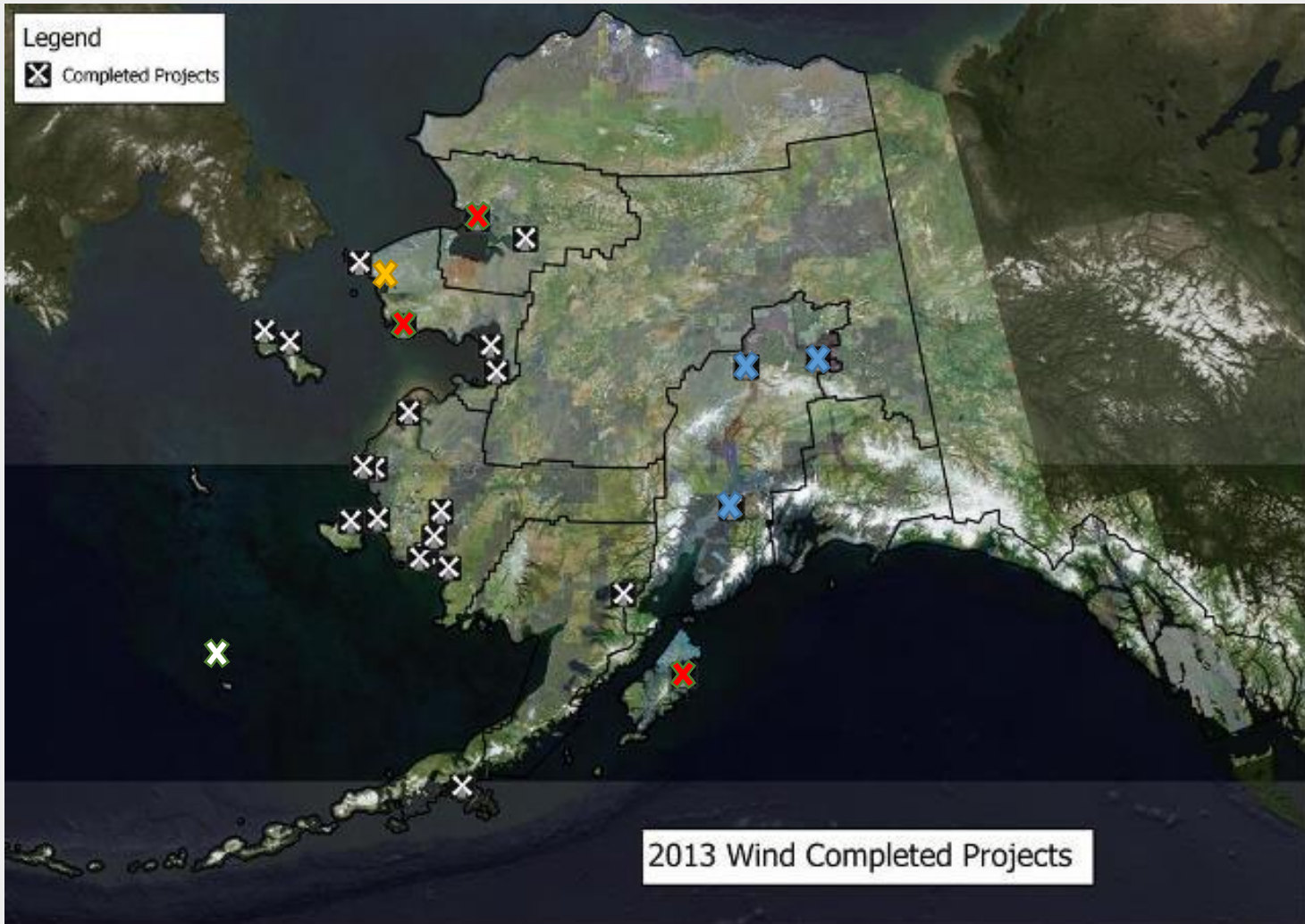
An aerial photograph of a rural Alaskan community. The scene shows a small town with several buildings, including a prominent red-roofed structure. A wide river flows through the town, and the surrounding landscape is a mix of green fields and blue water. The sky is a pale, hazy blue.

- Community Energy Uses – Supply
  - Primary electrical generation – diesel engines, 65 to 400 kW
  - Heat (thermal) generation – fuel oil boilers (district), Toyo stoves (household)
  - *Transportation – gasoline and diesel engines*
- Project Development Challenges
  - Isolation, no road access
  - High wind volatility
  - Volatile diurnal and seasonal energy demand
  - Unmanned powerplant operation
  - Permafrost, birds, roads, distribution lines
  - Airport operations/airspace restrictions

# Challenges of Isolation and Remoteness, more specifically...

- Lack of awareness of equipment status
- Difficult data communication (bandwidth and connection issues)
- Complex equipment and lack of qualified personnel to manage it
- Lack of continuous monitoring; difficult troubleshooting, repair, and maintenance planning
- High cost of travel; high equipment mobilization costs
- Weather delays and disruptions; high labor costs

# Alaska Wind Power Projects



- ✕ Utility grid-connected
  - Fire Island (Anchorage)
  - Eva Creek (Healy)
  - Delta (Delta Junction)
- ✕ Hub community wind-diesel
  - Kodiak
  - Kotzebue
  - Nome
- ✕ Village wind-diesel
  - Chevak, Emmonak, Gambell,
  - Hooper Bay, Kasigluk, Kokhanok,
  - Kongiganak, Kwigillingok, Mekoryuk,
  - Quinhagak, Saint Paul Island,
  - Sand Point, Savoonga, Selawik,
  - Shaktoolik, Tooksok Bay, Tuntululiak,
  - Unalakleet, Wales (non-operational)
- ✕ Military base
  - Tin City LRRS



# Village Wind-Diesel Wind Turbine Options

A large white wind turbine stands in a grassy field under a cloudy sky. The turbine is the central focus, with its three blades extending upwards. In the background, there are other smaller wind turbines and some industrial structures, possibly part of a wind farm or a village. The overall scene is somewhat overcast.

- Village-scale wind turbines – limited market and availability
- New
  - Aeronautica Wind, USA – 225 kW, 750 kW Norwin license (225 kW may no longer be available)
  - EWT, Netherlands – 900 kW (big for a village)
  - Northern Power, USA – 100 kW
  - Vernet, France – 275 kW
- Remanufactured
  - Vestas, Denmark (remanufactured in USA) – 90 to 500 kW
  - Windmatic, Denmark (remanufactured in USA) – 90 kW

# Alaska Wind-Diesel Performance History

Only low percentage of rural Alaska wind projects generate expected energy production; general reasons:

- No secondary loads/other configuration design problems
- Wind turbine problems; delayed repairs
- Limited on-site technical skill
- Limited troubleshooting information for off-site engineers, such as...
- Incomplete data
- Not all components tracked
- Lack of historical data; problems may have been pre-existing

# Wind-Diesel Project Design Tools

## Legacy (existing) modeling tools

- Homer software (USA)
  - Energy production
  - Energy balance
  - Economics
- RET Screen (Canada)
- Specialized Excel models

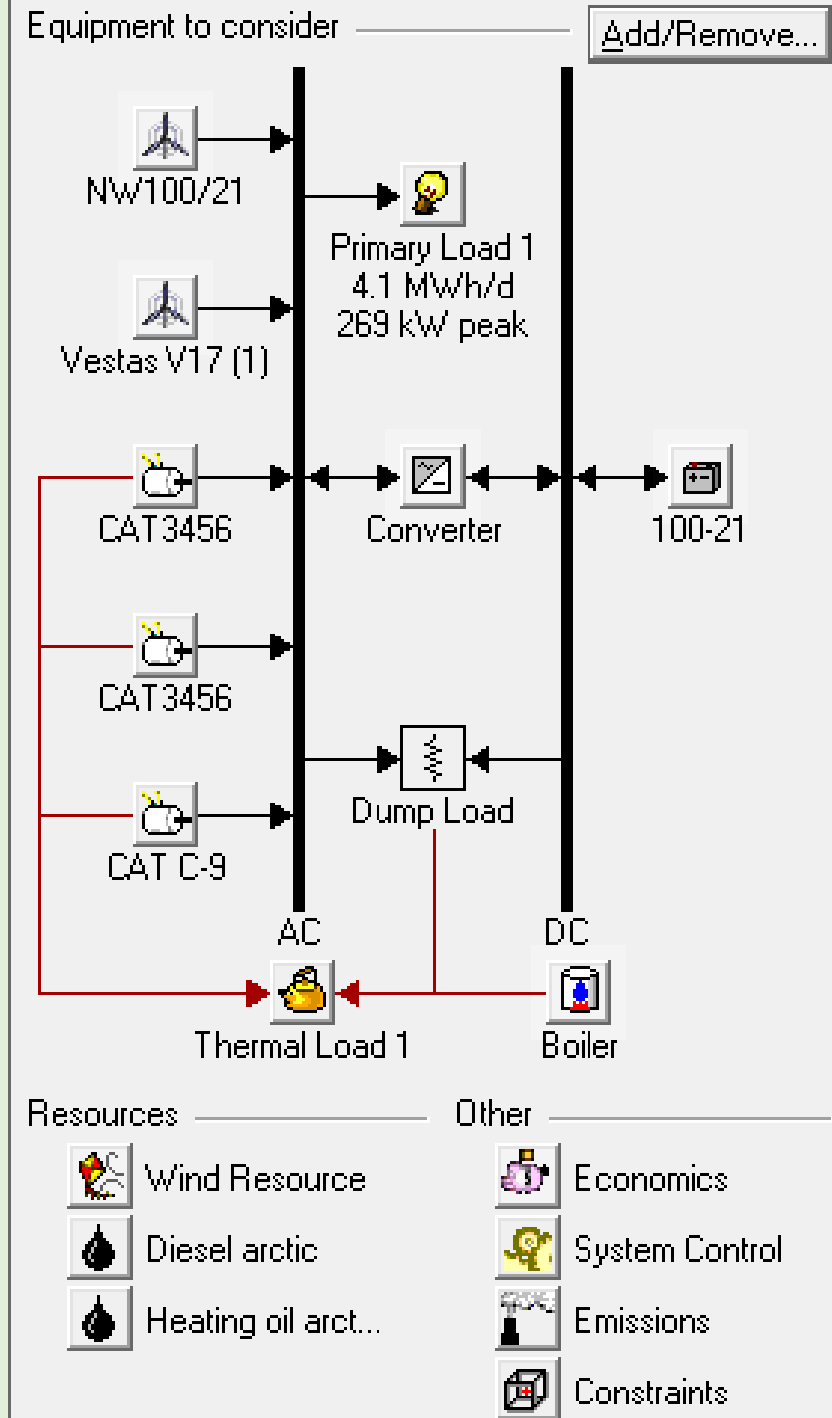
Note: these tools can also be used to model other renewable energy options

- Solar
- Hydro

# HOMER software

- Designed by U.S. Dept. of Energy's National Renewable Energy Laboratory (NREL) for village power program
- Now licensed to HOMER Energy in Boulder, Colorado, USA
- Distributed generation design – on and off grid
- Economic and technical feasibility of renewable energy options
- Optimization and sensitivity analyses
- Wide usage world-wide
- **Key point: one must collect, find, and/or synthesize data; typical analysis project includes all three**

# HOMER software - equipment configuration and bus visualization



# Import/synthesize electric and thermal load

**Primary Load Inputs**

File Edit Help

Choose a load type (AC or DC), enter 24 hourly values in the load table, and enter a scaled annual average. Each of the 24 values in the load table is the average electric demand for a single hour of the day. HOMER replicates this profile throughout the year unless you define different load profiles for different months or day types. For calculations, HOMER uses scaled data: baseline data scaled up or down to the scaled annual average value.

Hold the pointer over an element or click Help for more information.

Label:  Load type:  AC  DC Data source:  Enter daily profile(s)  Import time series data file

Baseline data

Month:  Day type:

| Hour          | Load (kW) |
|---------------|-----------|
| 00:00 - 01:00 | 1,921.000 |
| 01:00 - 02:00 | 1,837.000 |
| 02:00 - 03:00 | 1,793.000 |
| 03:00 - 04:00 | 1,752.000 |
| 04:00 - 05:00 | 1,769.000 |
| 05:00 - 06:00 | 1,798.000 |
| 06:00 - 07:00 | 1,871.000 |
| 07:00 - 08:00 | 2,117.000 |
| 08:00 - 09:00 | 2,398.000 |
| 09:00 - 10:00 | 2,464.000 |
| 10:00 - 11:00 | 2,505.000 |
| 11:00 - 12:00 | 2,473.000 |

|                 | Baseline | Scaled |
|-----------------|----------|--------|
| Average (kWh/d) | 52,592   | 52,592 |
| Average (kW)    | 2,191    | 2,191  |
| Peak (kW)       | 3,874    | 3,874  |
| Load factor     | 0.566    | 0.566  |

Time step (minutes):  Efficiency Inputs...

Random variability: Day-to-day  % Time-step-to-time-step  %

Scaled annual average (kWh/d)

**Thermal Load Inputs**

File Edit Help

Enter 24 hourly values and a scaled annual average value. Each of the 24 values in the load table is the average thermal demand for a single hour of the day. HOMER replicates this profile throughout the year unless you define different load profiles for different months or day types. HOMER uses scaled data for calculations.

Hold the pointer over an element or click Help for more information.

Label:  Data source:  Enter daily profile(s)  Import time series data file

Baseline data

Month:  Day type:

| Hour          | Load (kW) |
|---------------|-----------|
| 00:00 - 01:00 | 480.000   |
| 01:00 - 02:00 | 480.000   |
| 02:00 - 03:00 | 480.000   |
| 03:00 - 04:00 | 480.000   |
| 04:00 - 05:00 | 480.000   |
| 05:00 - 06:00 | 480.000   |
| 06:00 - 07:00 | 480.000   |
| 07:00 - 08:00 | 480.000   |
| 08:00 - 09:00 | 480.000   |
| 09:00 - 10:00 | 480.000   |
| 10:00 - 11:00 | 480.000   |
| 11:00 - 12:00 | 480.000   |

|                 | Baseline | Scaled |
|-----------------|----------|--------|
| Average (kWh/d) | 6,323    | 6,323  |
| Average (kW)    | 263      | 263    |
| Peak (kW)       | 592      | 592    |
| Load factor     | 0.445    | 0.445  |

Random variability: Day-to-day  % Time-step-to-time-step  %

Scaled annual average (kWh/d)

# Import wind resource and diesel fuel curves

**Wind Resource Inputs**

File Edit Help

HOMER uses wind resource inputs to calculate the wind turbine power each hour of the year. Enter the average wind speed for each month. For calculations, HOMER uses scaled data: baseline data scaled up or down to the scaled annual average value. The advanced parameters allow you to control how HOMER generates the 8760 hourly values from the 12 monthly values in the table.

Hold the pointer over an element or click Help for more information.

Data source:  Enter monthly averages  Import time series data file

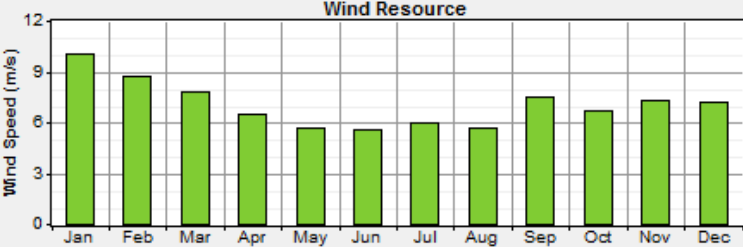
Baseline data (from St Mike wind file for Homer, 10 min.txt)

| Month     | Wind Speed (m/s) |
|-----------|------------------|
| January   | 10.118           |
| February  | 8.766            |
| March     | 7.820            |
| April     | 6.538            |
| May       | 5.718            |
| June      | 5.570            |
| July      | 6.028            |
| August    | 5.709            |
| September | 7.544            |
| October   | 6.669            |
| November  | 7.310            |
| December  | 7.184            |

Annual average: 7.071

Scaled annual average (m/s)  {5}

**Wind Resource**



Other parameters: Time step (minutes)  Altitude (m above sea level)  Anemometer height (m)

Advanced parameters: Weibull k  1-hr autocorrelation factor  Diurnal pattern strength  Hour of peak windspeed

**Fuel Curve Calculator**

Enter the generator's fuel consumption data and HOMER will calculate the two fuel curve input values. You must enter at least two points on the fuel curve. When you click OK, HOMER will copy the values to the Generator Inputs window.

Hold the pointer over an element name or click Help for more information.

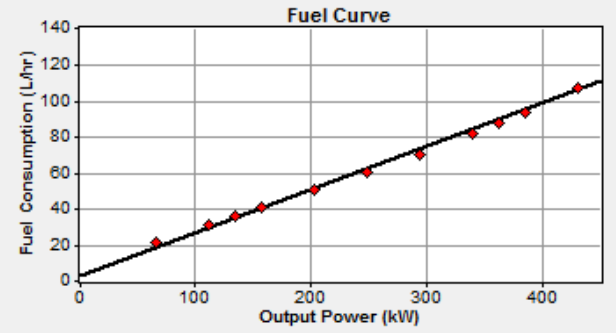
Generator size (kW)

Fuel consumption data

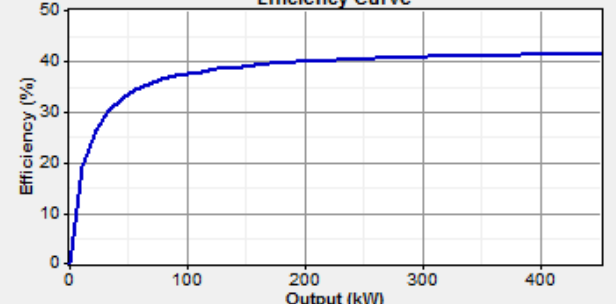
|    | Output Power (kW) | Fuel Consumption (L/hr) |
|----|-------------------|-------------------------|
| 1  | 476.000           | 123.013                 |
| 2  | 430.500           | 107.116                 |
| 3  | 385.000           | 93.111                  |
| 4  | 362.300           | 87.055                  |
| 5  | 339.500           | 81.378                  |
| 6  | 294.000           | 70.401                  |
| 7  | 248.500           | 60.560                  |
| 8  | 203.000           | 50.719                  |
| 9  | 157.500           | 41.257                  |
| 10 | 134.800           | 36.336                  |

Calculated fuel curve parameters: Intercept: 0.007307 L/hr/kW Slope: 0.2382 L/hr/kW

**Fuel Curve**



**Efficiency Curve**



# HOMER economic optimization output

File View Inputs Outputs Window Help

Equipment to consider Add/Remove...

Calculate Simulations: 0 of 7 Progress: Sensitivities: 0 of 2 Status:

Sensitivity Results Optimization Results

Sensitivity variables

Fixed Cap. Cost (\$)

Double click on a system below for simulation results. Categorized Overall Export... Details...

|  | NW100 | V17 | Gen 1 (kW) | Gen 2 (kW) | Gen 3 (kW) | 100-21 | Conv. (kW) | Initial Capital | Operating Cost (\$/yr) | Total NPC     | COE (\$/kWh) | Ren. Frac. | Diesel arctic (L) | Heating oil arctic (L) | Gen 1 (hrs) | Gen 2 (hrs) | Gen 3 (hrs) |
|--|-------|-----|------------|------------|------------|--------|------------|-----------------|------------------------|---------------|--------------|------------|-------------------|------------------------|-------------|-------------|-------------|
|  |       |     |            |            |            |        |            | \$ 5,155,000    | 1,425,161              | \$ 26,357,798 | 0.723        | 0.27       | 219,404           | 214,426                | 3,190       | 0           | 3,375       |
|  |       |     |            |            |            |        |            | \$ 3,685,000    | 1,529,735              | \$ 26,443,592 | 0.727        | 0.20       | 251,682           | 228,111                | 3,940       | 0           | 3,218       |
|  |       |     |            |            |            |        |            | \$ 4,435,000    | 1,489,394              | \$ 26,593,426 | 0.734        | 0.22       | 235,110           | 227,204                | 3,509       | 0           | 3,400       |
|  |       |     |            |            |            |        |            | \$ 3,245,000    | 1,584,672              | \$ 27,042,466 | 0.754        | 0.17       | 267,818           | 235,784                | 4,283       | 0           | 3,250       |
|  |       |     |            |            |            |        |            | \$ 3,715,000    | 1,567,972              | \$ 27,320,230 | 0.767        | 0.12       | 289,977           | 240,622                | 4,735       | 0           | 3,279       |
|  |       |     |            |            |            |        |            | \$ 2,805,000    | 1,647,809              | \$ 29,004,760 | 0.843        | 0.00       | 386,946           | 233,702                | 7,774       | 0           | 986         |

Resources Other

- Wind Resource
- Diesel arctic
- Heating oil arctic...
- Economics
- System Control
- Emissions
- Constraints

Document

Author: Doug Vaught

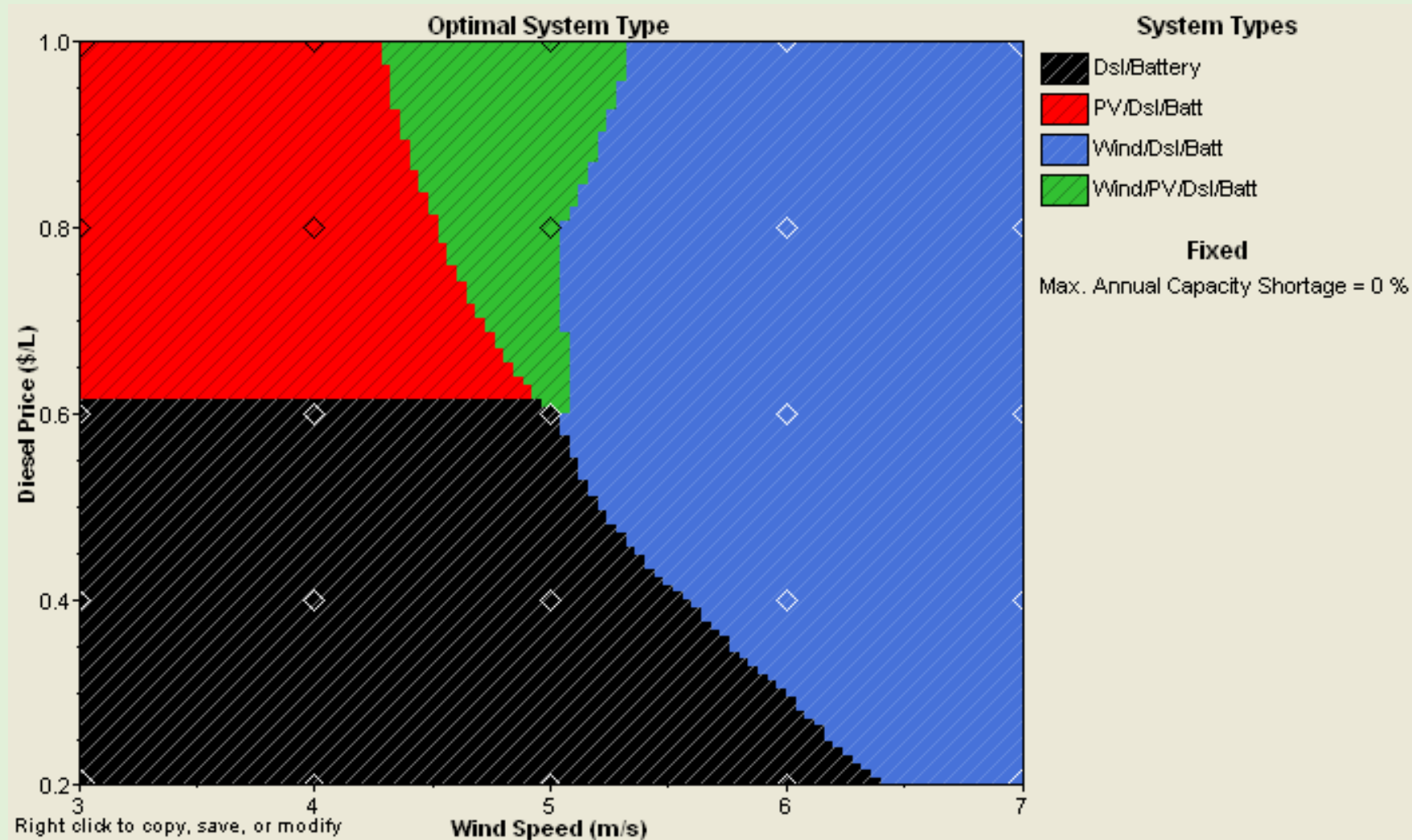
Notes: Gen1 - Cat. 475kW  
Gen2 - Cat. 475kW  
Gen3 - Cat. 175kW  
Generator O&M based on \$0.020/kWh and 169 kW avg load  
Buckland Site 5063 data  
Distribution line: 4.5 miles at \$250K/mile

NW100/21 search space may be insufficient.

Completed in 3 seconds.



# HOMER configuration optimization



# Pros and Cons of Legacy Modeling Tools

## Pros (+’s)

- Relatively easy to learn and inexpensive
- Quick “big picture” view of many renewable energy options and equipment configurations
- Optimization and sensitivity analyses

## Cons (-’s)

- Uses low sampling frequency data (typ. 10 min to 1 hour), resulting in...
  - Imprecise load (electrical and thermal); transients not captured
  - Short period wind speed variability not captured
- Non-common data collection equipment; time stamps not matched
- Data *does not* include transients; not suitable for control design

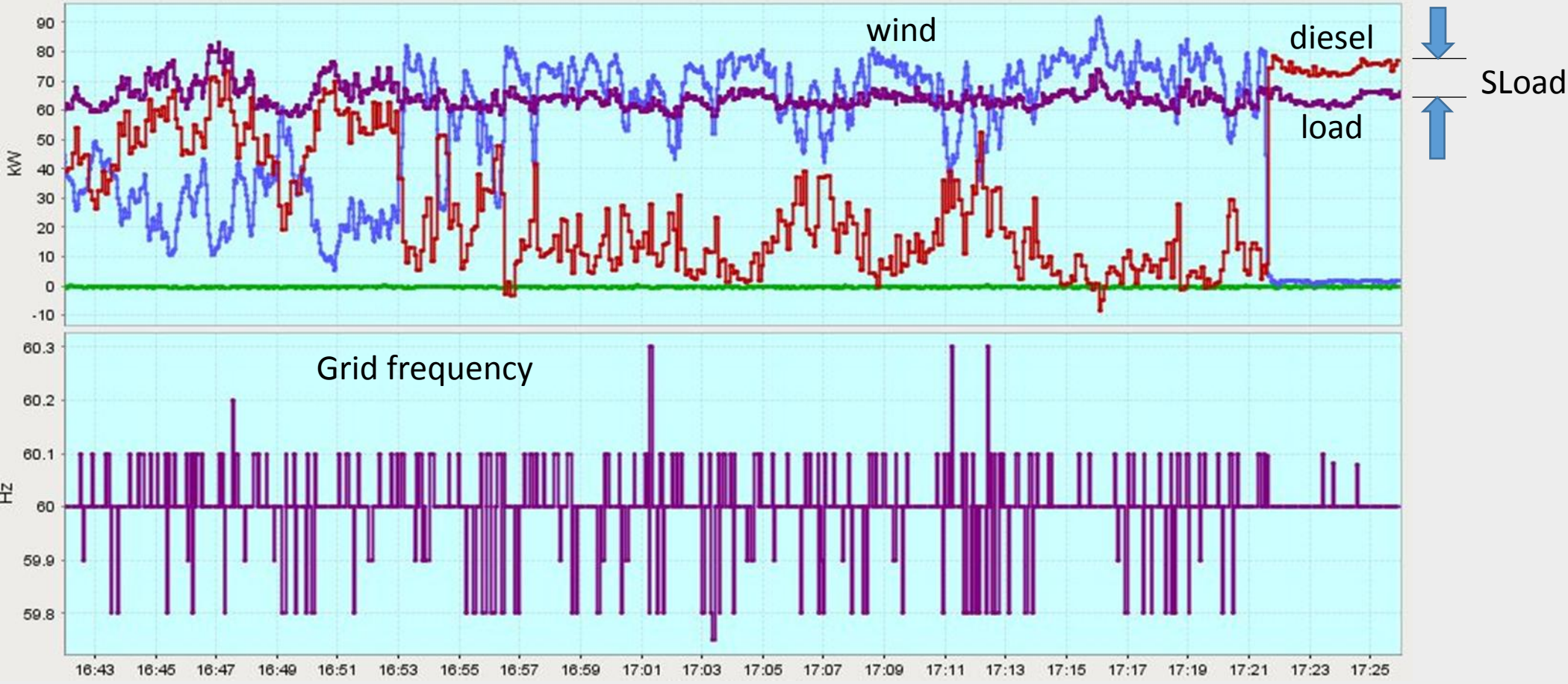
# Power Dashboard – Enhancing the Process

- ***Holistic approach*** to data collection of entire power system, *plus* the renewable energy (RE) resource: study, design, and operations
- Distinctive features:
  - High to extremely high sampling frequency (sub-cycle possible)
  - Real-time *and* historical data in one application
  - Historical transient data for design modeling
- Ignition by Inductive Automation™ (USA) software platform
  - Designed for HMI/SCADA (human-machine interface/supervisory control and data acquisition)
- ***Power Dashboard***: an application specialized for remote wind-diesel power plants

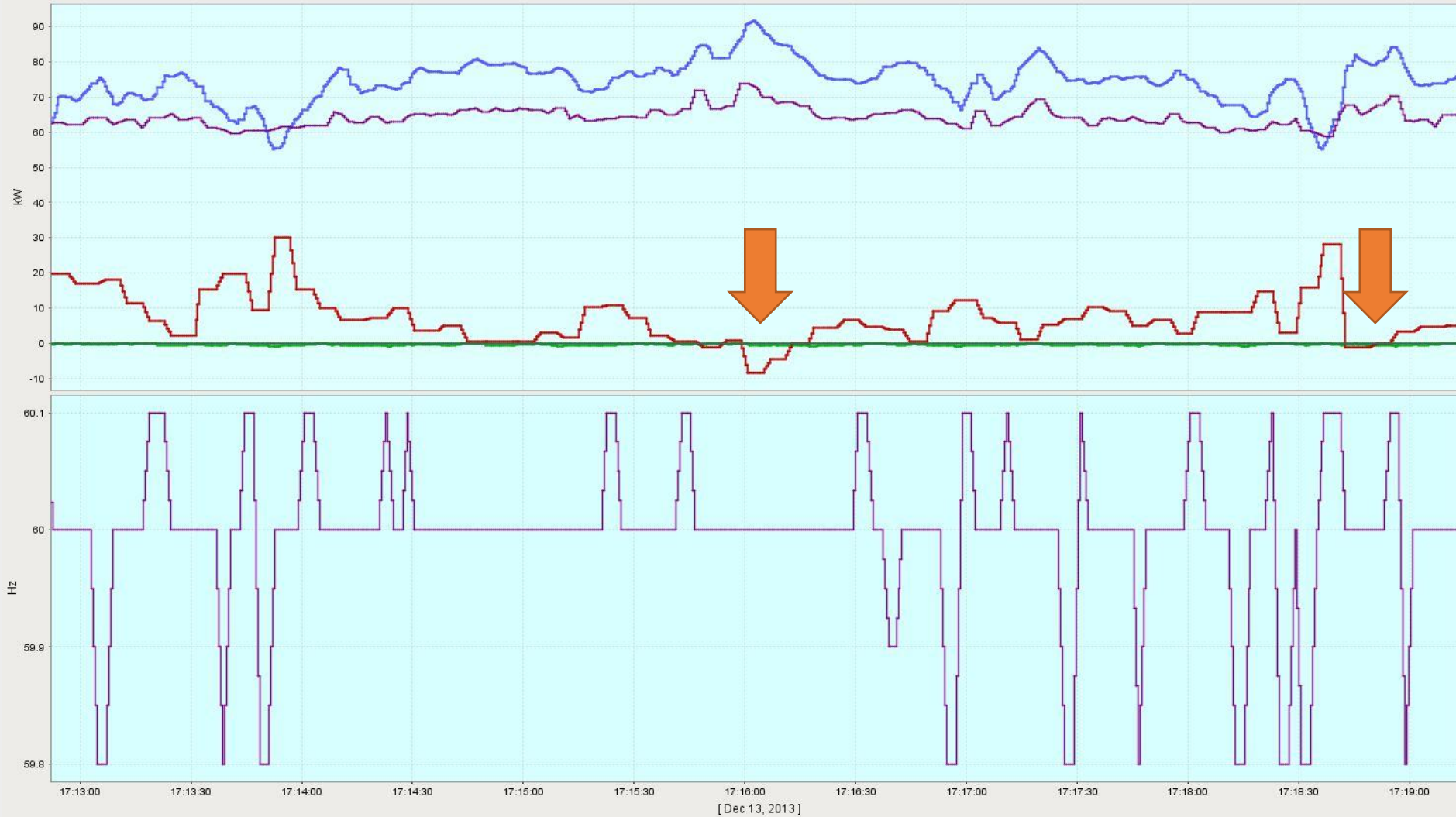
# Motivations for Power Dashboard to Model Isolated Grid Wind-Diesel

- Experimental 1 Hz monitoring of an existing Alaska wind-diesel powerplant (village of Kokhanok)
  - Revealed new insights into system and equipment behavior
  - Discovered optimization possibilities
- Computer simulations of wind-diesel power systems requires high quality data
  - Need high frequency data sampling for model validation
  - Transients for supervisory control programming
- Power Dashboard developed by Marsh Creek, LLC of Anchorage, Alaska ([www.marshcreekllc.com](http://www.marshcreekllc.com))

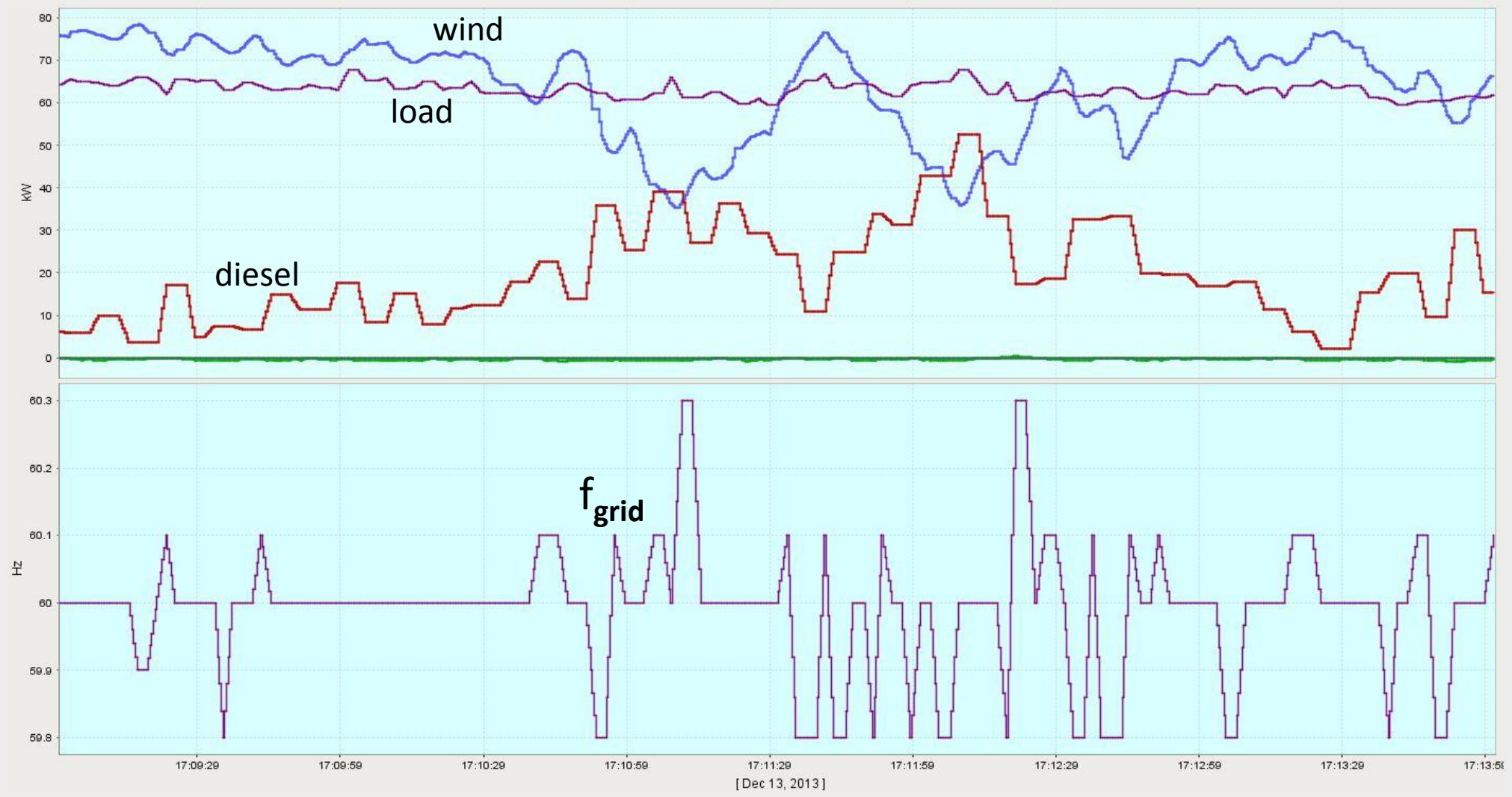
# Dynamic Nature of Isolated WD System



# Snapshot of Unwanted Diesel Operation

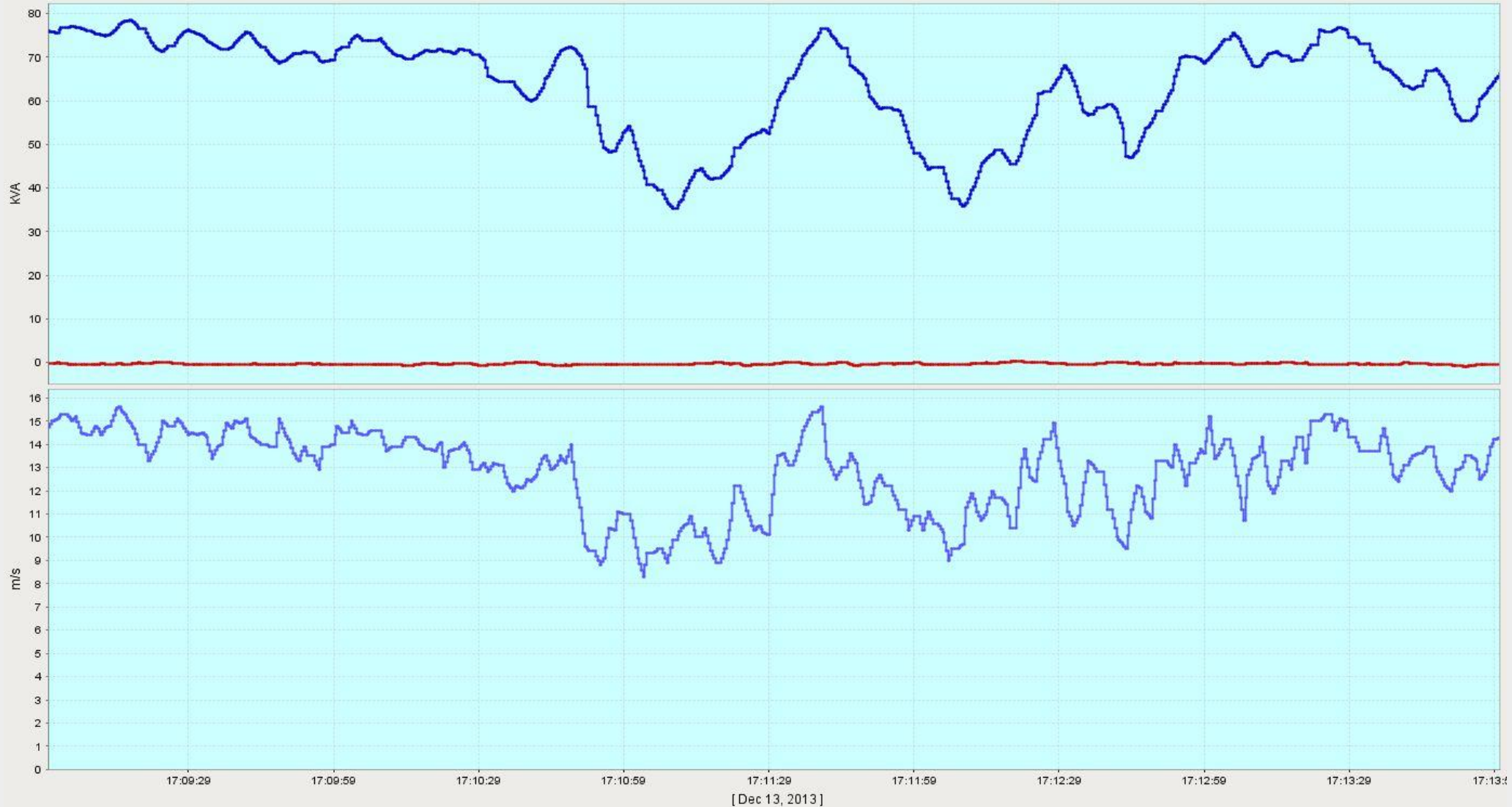


# Snapshot of diesel & turbine – 5 min interval



# Snapshot of Wind – 5 min interval

Wind  
Turbine  
Power,  
kW



Wind  
Speed,  
m/s



# Discovery with Power Dashboard...

- Even at low penetration wind power can adversely affect frequency, which requires control measures to mitigate
- Alternate wind penetration concept we've now adopted:
  - Low – control measures are not required
  - High – control measures are required
- Remember the goal...
  - Low penetration wind power in a small, isolated grid accomplishes little
  - High penetration meets project goals

# Holistic Approach of Power Dashboard – Lifetime Data Collection

## Study phase

- Wind data, diesel-electric generator, electric load, and thermal demand in one synchronized database

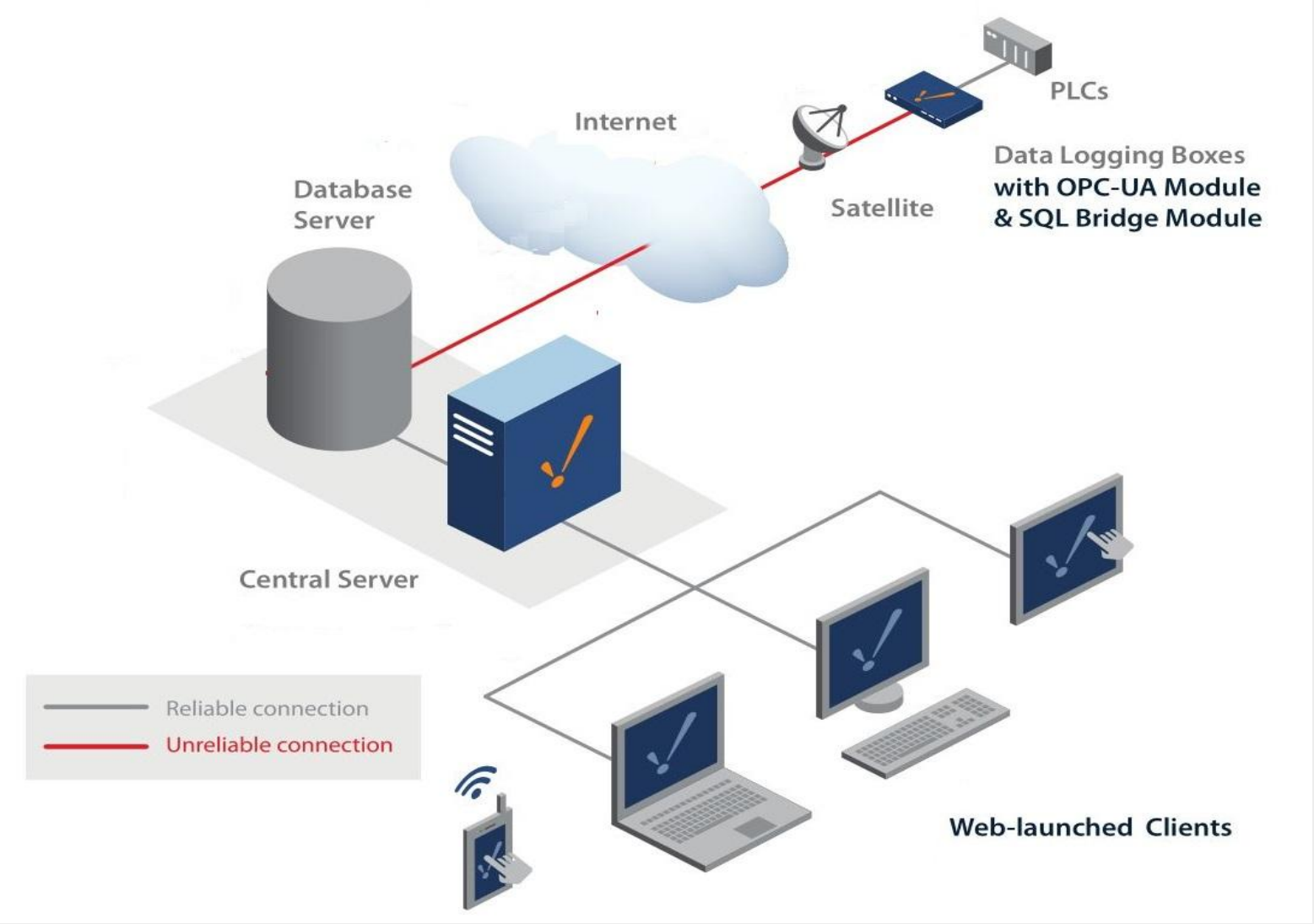
## Design phase

- Database used to identify existing powerplant problems; enables corrections *before* adding wind turbines
- High sampling rate captures transient behavior and improves design of control system
- Significantly enhances value of legacy modeling software such as HOMER

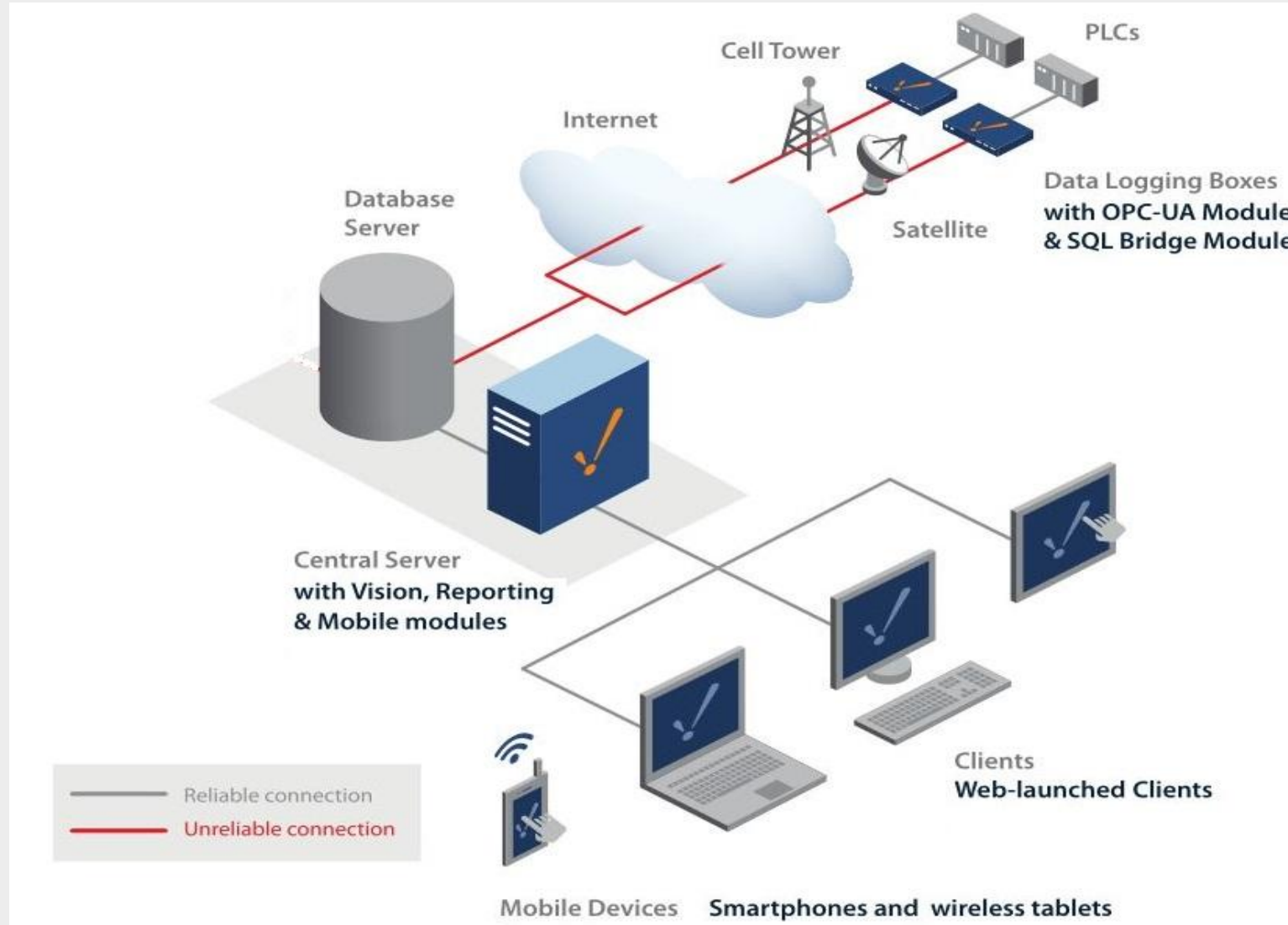
## Operational phase

- SCADA functionality, continued database
- Preventative maintenance, scheduling, and system optimization/fine tuning

# Data Collection – Single Remote Power Plant



# Example Architecture of Multiple Remote Power Plants



# Summary of Power Dashboard's solution to wind-diesel development

| <b>Solution &gt;&gt;&gt;</b>           | <b>&gt;&gt;&gt; Problem</b>                            |
|--|--|
| Consistent high rate data collection   | Legacy modeling tool gaps                              |
| Comprehensive equipment monitoring     | Lack of awareness of equipment status                  |
| Internet age architecture              | Difficult data communication                           |
| Remote access to engineering expertise | Scarcity of qualified personnel in the field           |
| Analysis of historical data            | Preventative maintenance and troubleshooting           |
| Remote diagnostics                     | High travel cost to visit remote sites and communities |

Thank you!

