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?

- 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

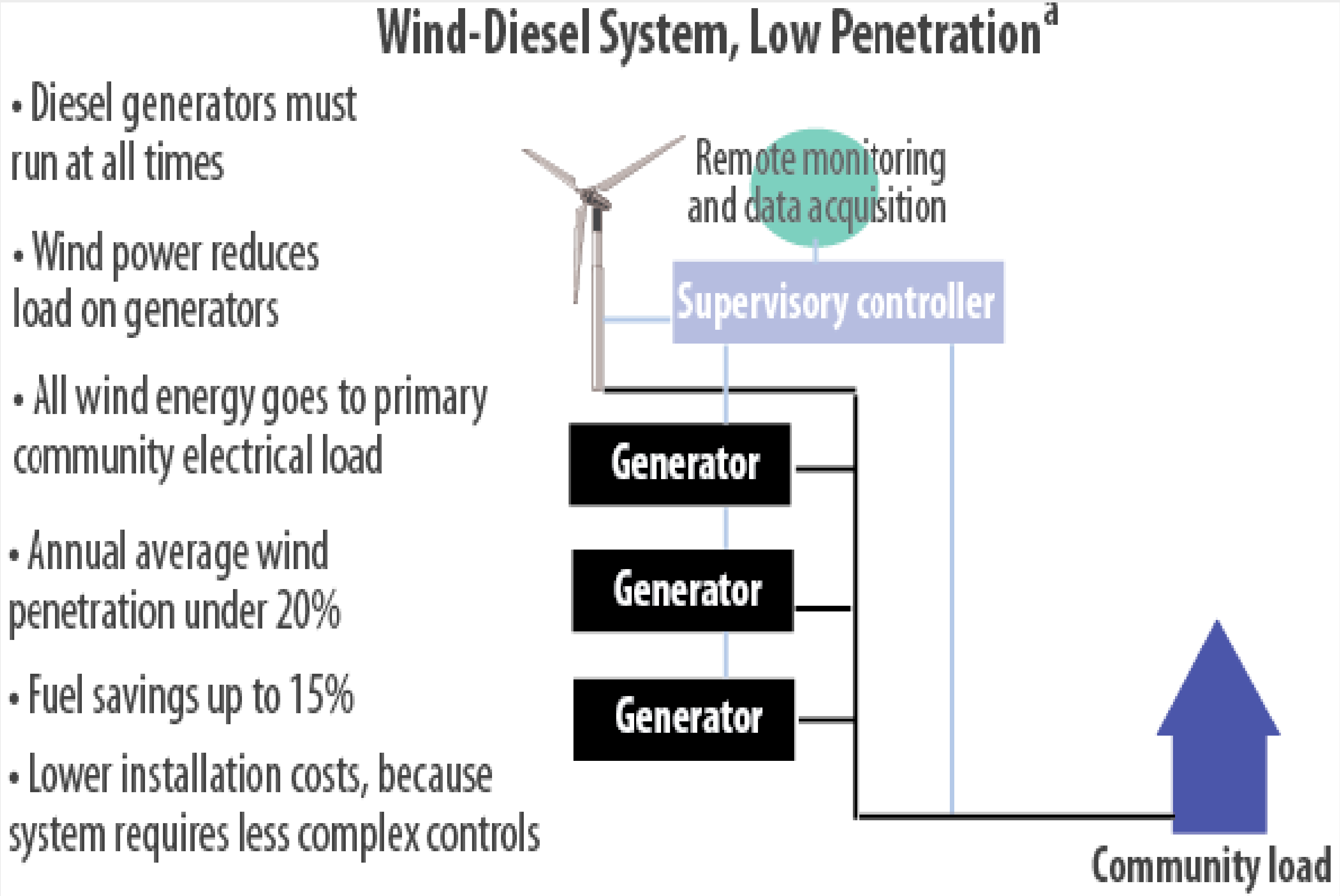
Supply side

- 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

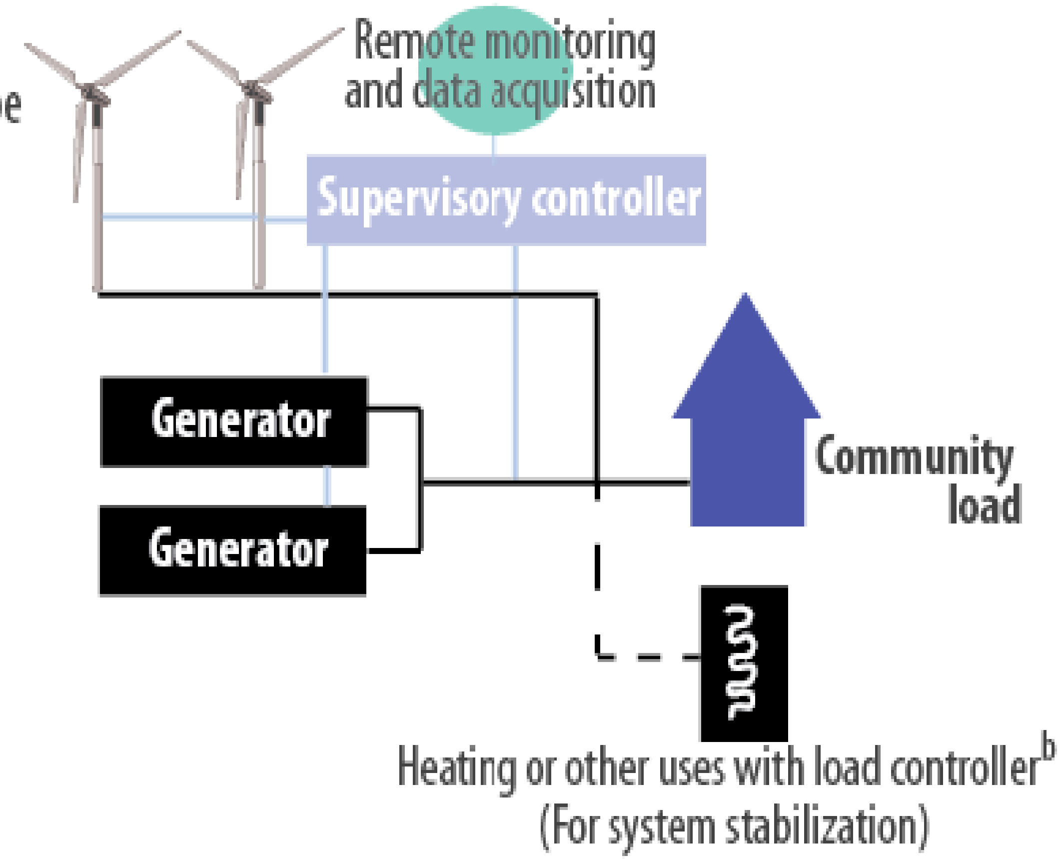
Very Low and Low Penetration W-D Configuration



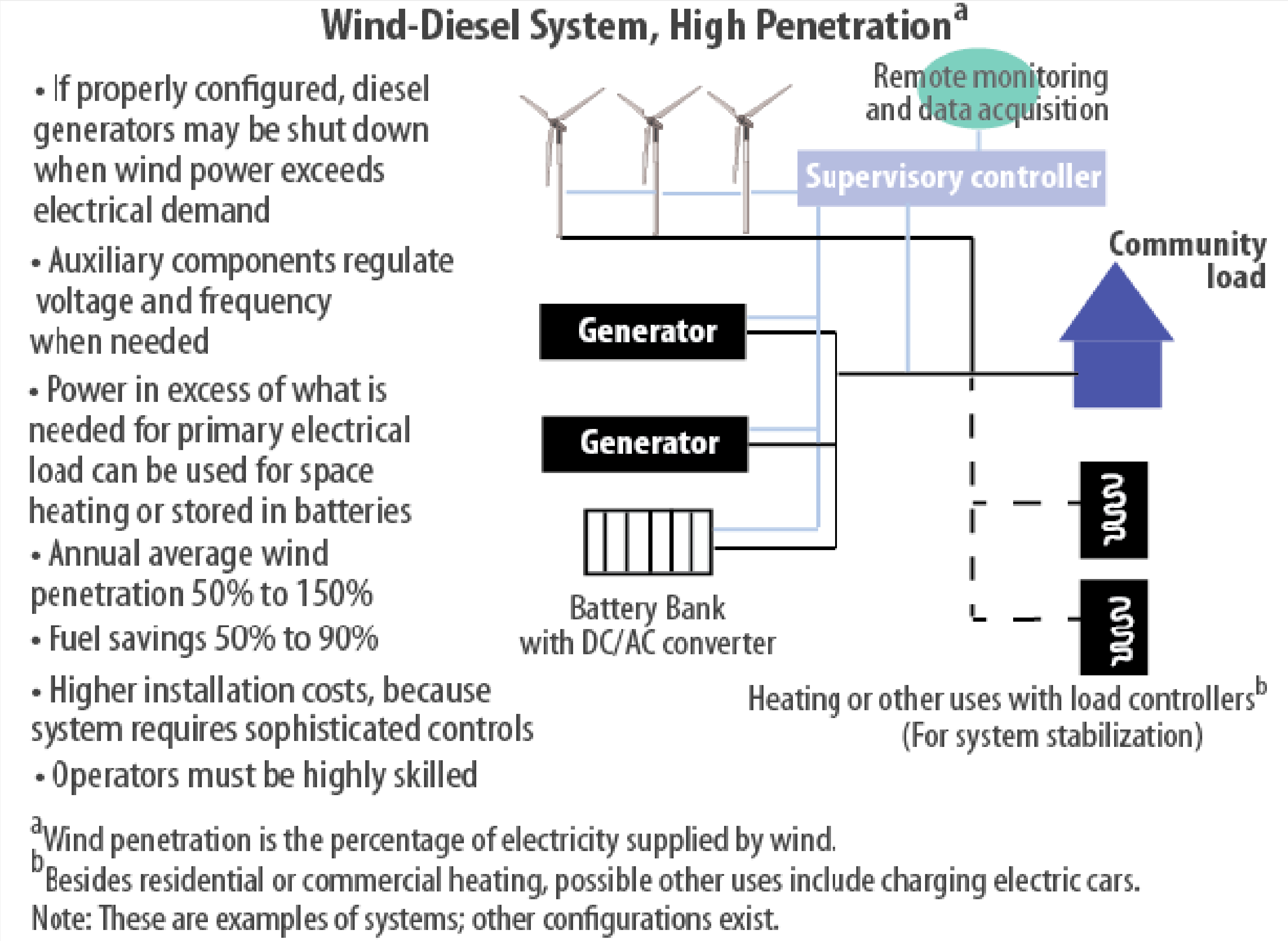
Medium Penetration W-D Configuration

Wind-Diesel System, Medium Penetration[a]

- 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



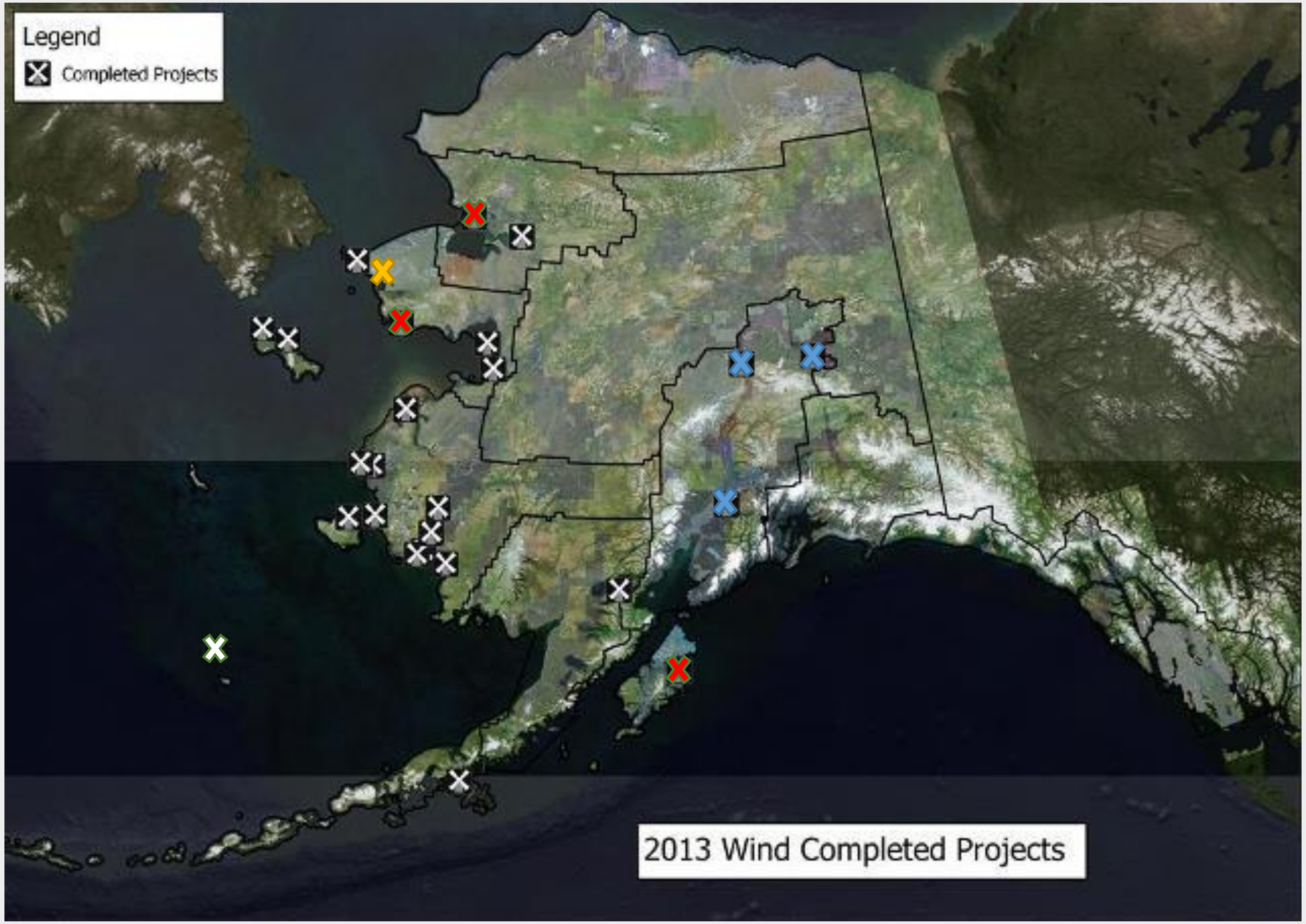
Typical Alaska Rural Energy Project

- 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, Tuntiluliak,
  - Unalakleet, Wales (non-operational)
- Military base
  - Tin City LRRS

Village Wind-Diesel Wind Turbine Options

- 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

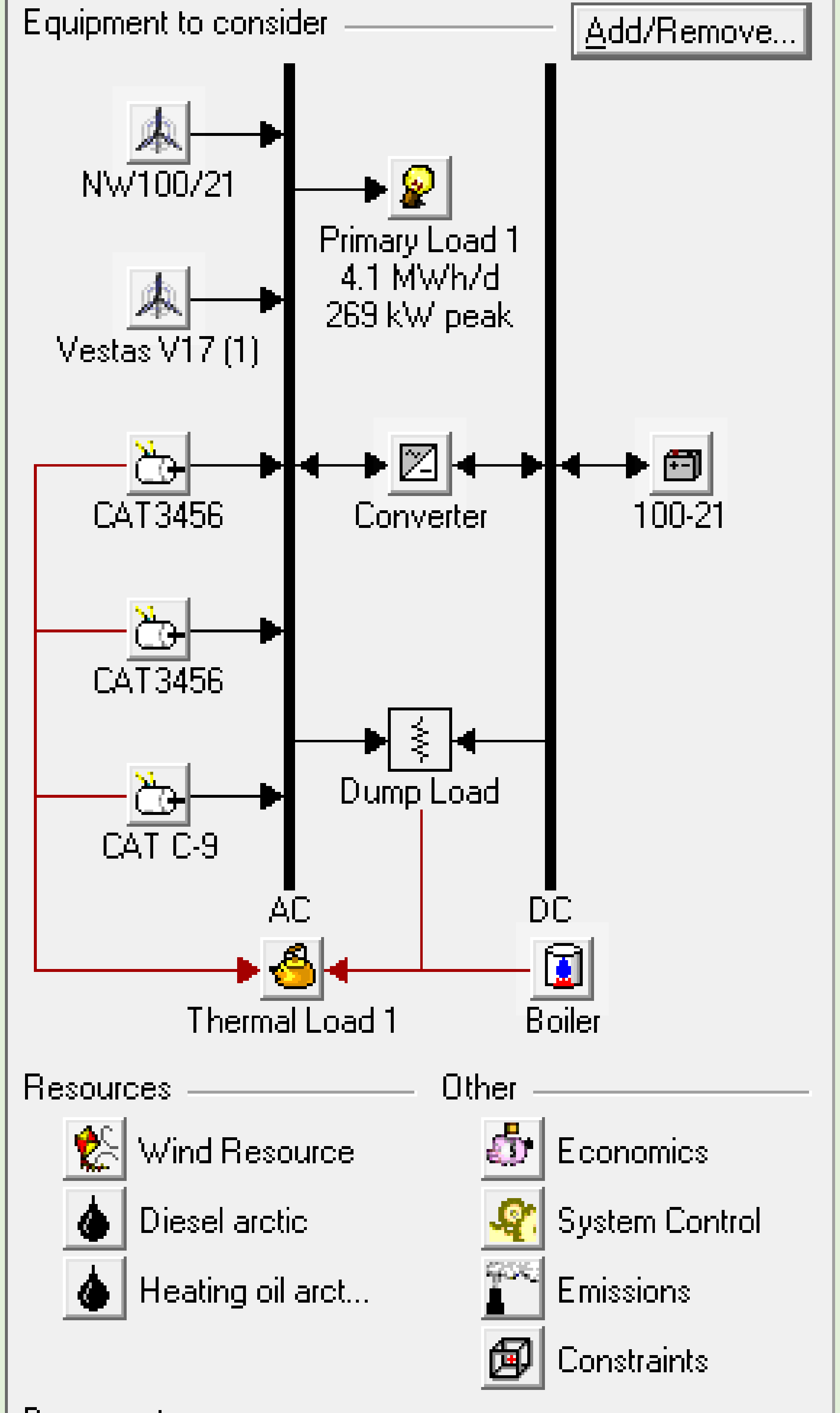
Note: these tools can also be used to model other renewable energy options

  - Solar
  - Hydro

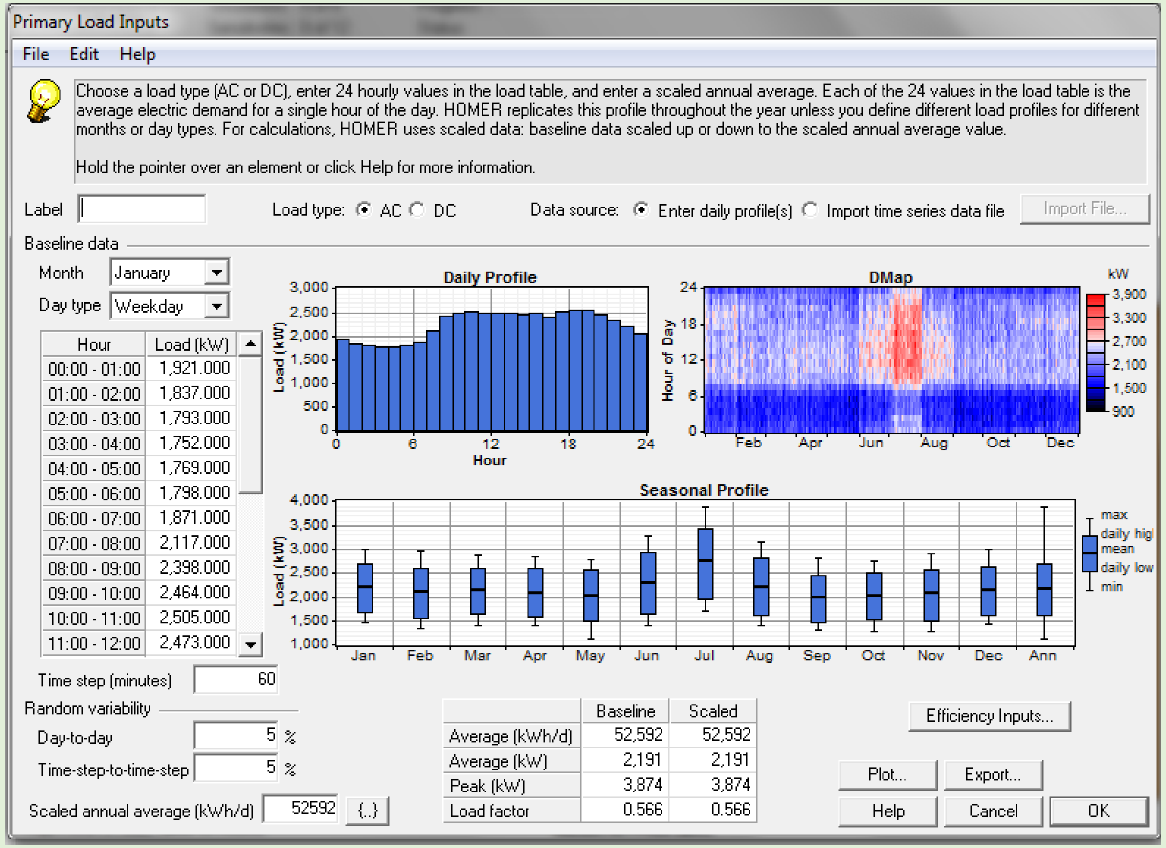
HOMER software

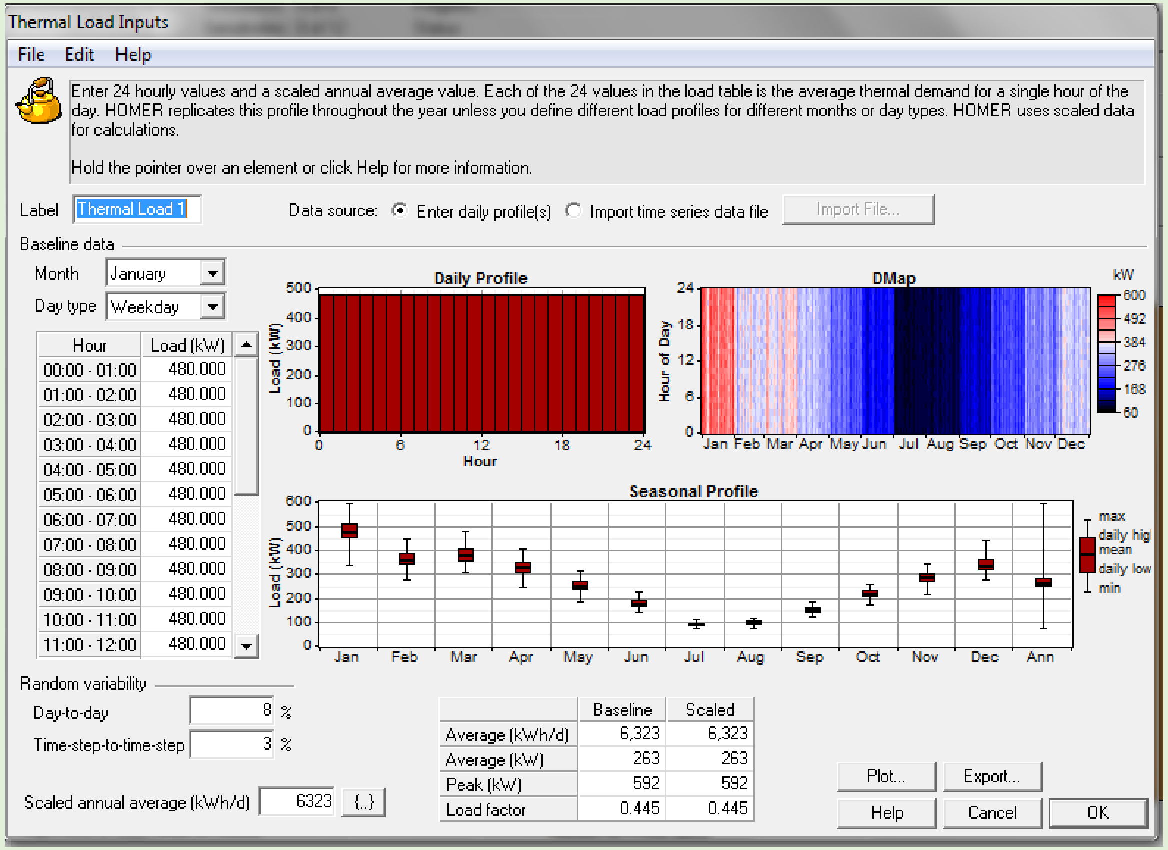
- Designed by U.S. Dept. of Energy’s National Renewable Energy Laboratory (NREL) for village power program
- Now licensed to HOMER Energy in Boulder, Colorado, USA
- Distributed generation design – on and off grid
- Economic and technical feasibility of renewable energy options
- Optimization and sensitivity 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

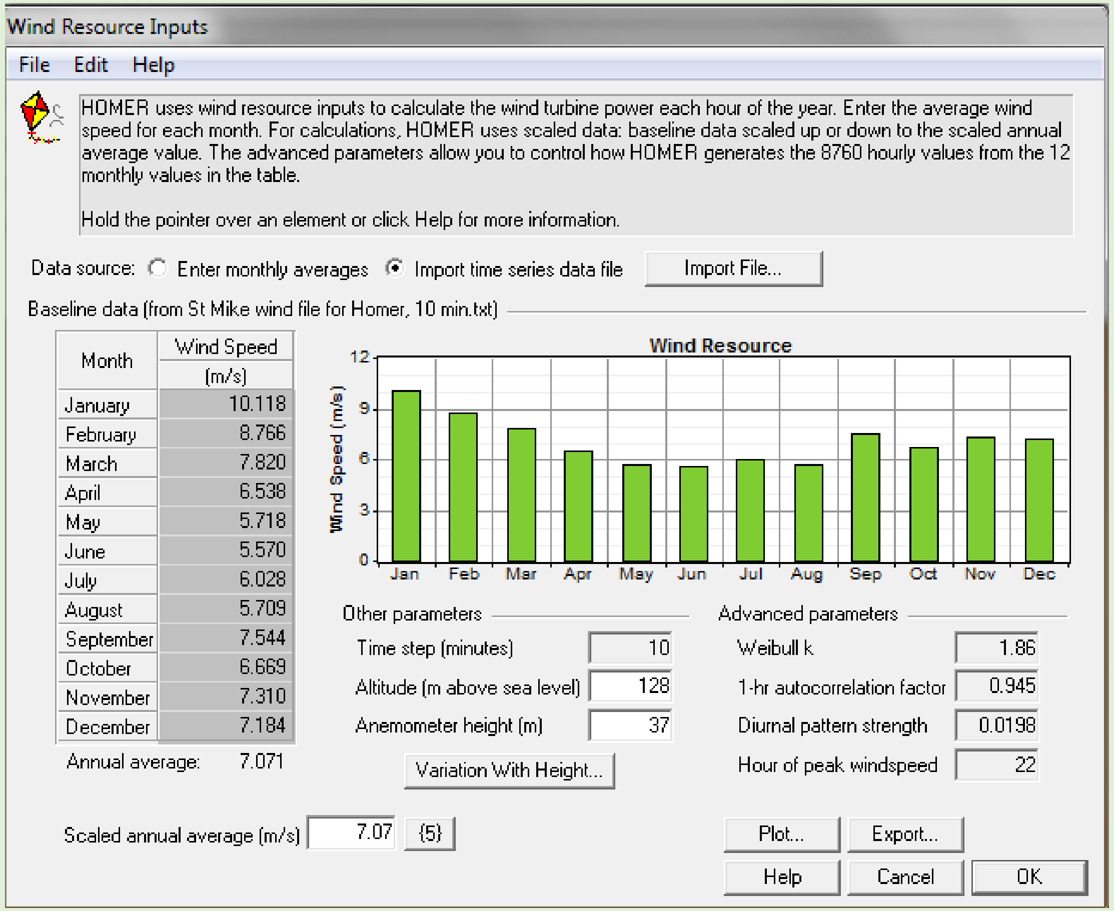


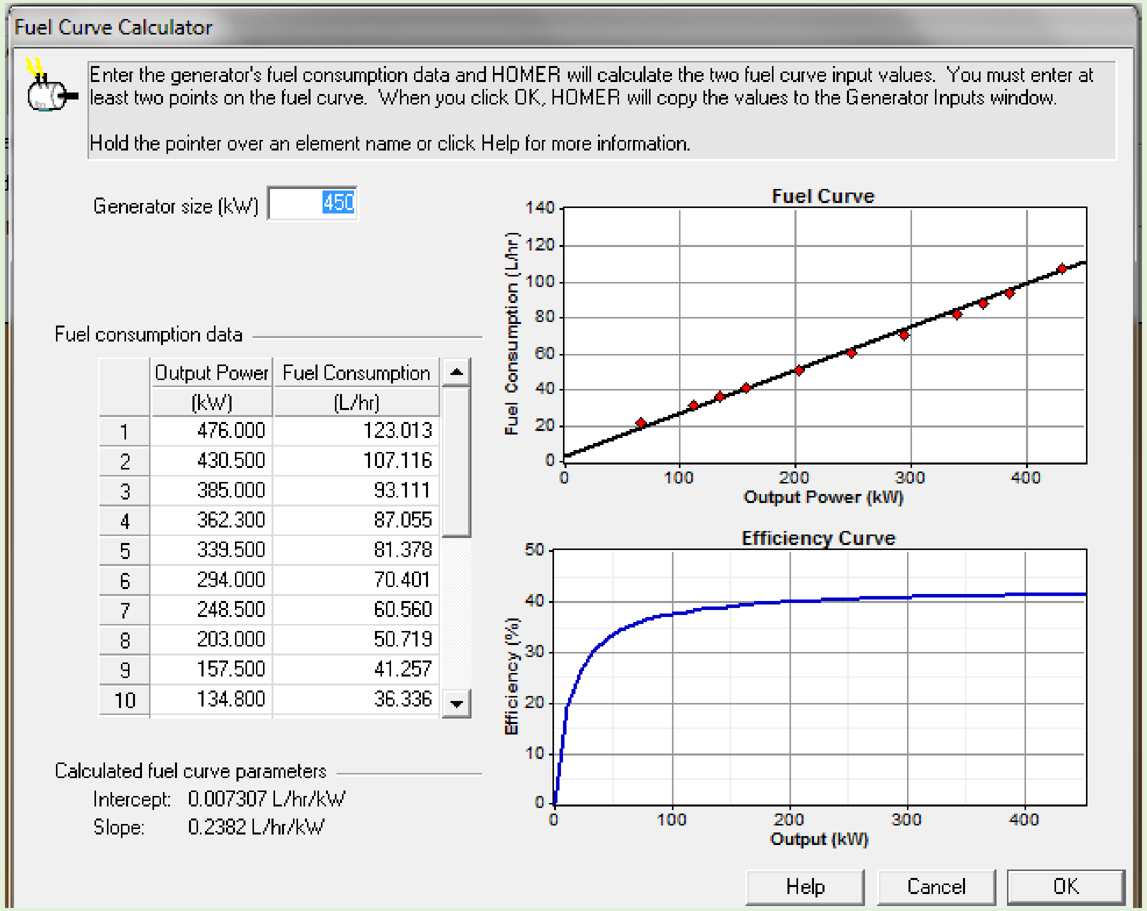
Import/synthesize electric and thermal load



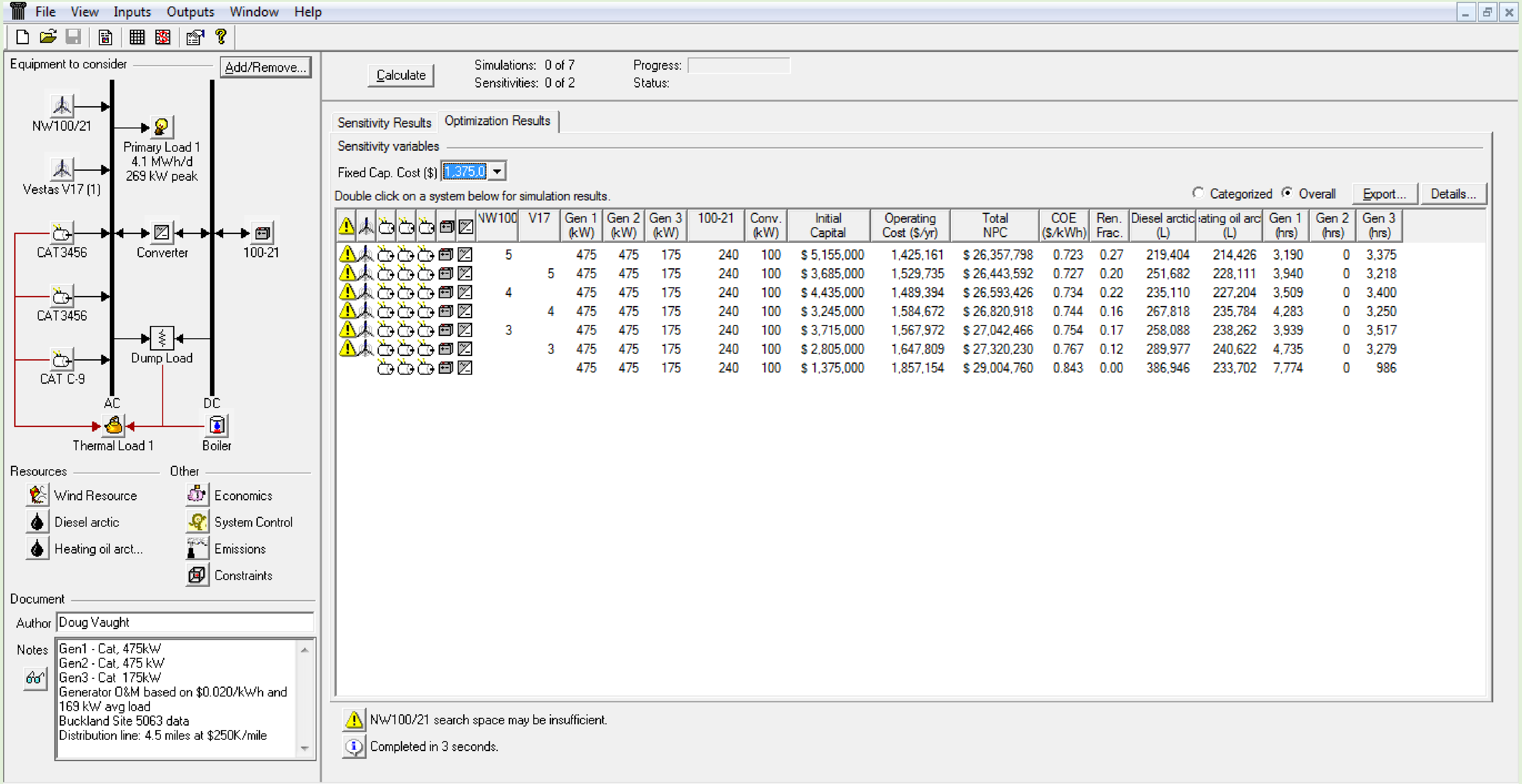


Import wind resource and diesel fuel curves



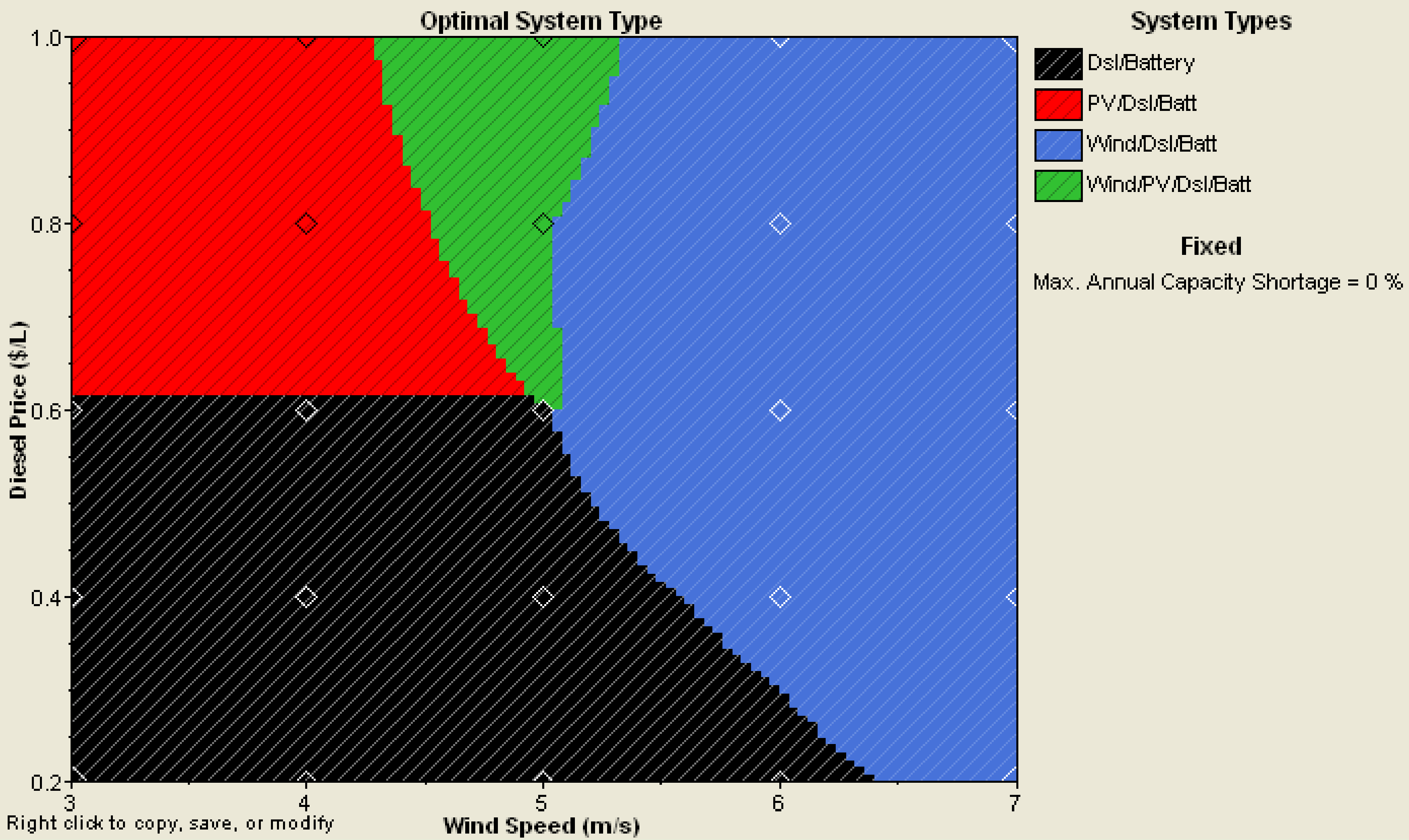


HOMER economic optimization output



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)	ating oil arc (L)	Gen 1 (hrs)	Gen 2 (hrs)	Gen 3 (hrs)
5		475	475	175	240	100	$ 5,155,000	1,425,161	$ 26,357,798	0.723	0.27	219,404	214,426	3,190	0	3,375
	5	475	475	175	240	100	$ 3,685,000	1,529,735	$ 26,443,592	0.727	0.20	251,682	228,111	3,940	0	3,218
4		475	475	175	240	100	$ 4,435,000	1,489,394	$ 26,593,426	0.734	0.22	235,110	227,204	3,509	0	3,400
	4	475	475	175	240	100	$ 3,245,000	1,584,672	$ 26,820,918	0.744	0.16	267,818	235,784	4,283	0	3,250
3		475	475	175	240	100	$ 3,715,000	1,567,972	$ 27,042,466	0.754	0.17	258,088	238,262	3,939	0	3,517
	3	475	475	175	240	100	$ 2,805,000	1,647,809	$ 27,320,230	0.767	0.12	289,977	240,622	4,735	0	3,279
		475	475	175	240	100	$ 1,375,000	1,857,154	$ 29,004,760	0.843	0.00	386,946	233,702	7,774	0	986

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

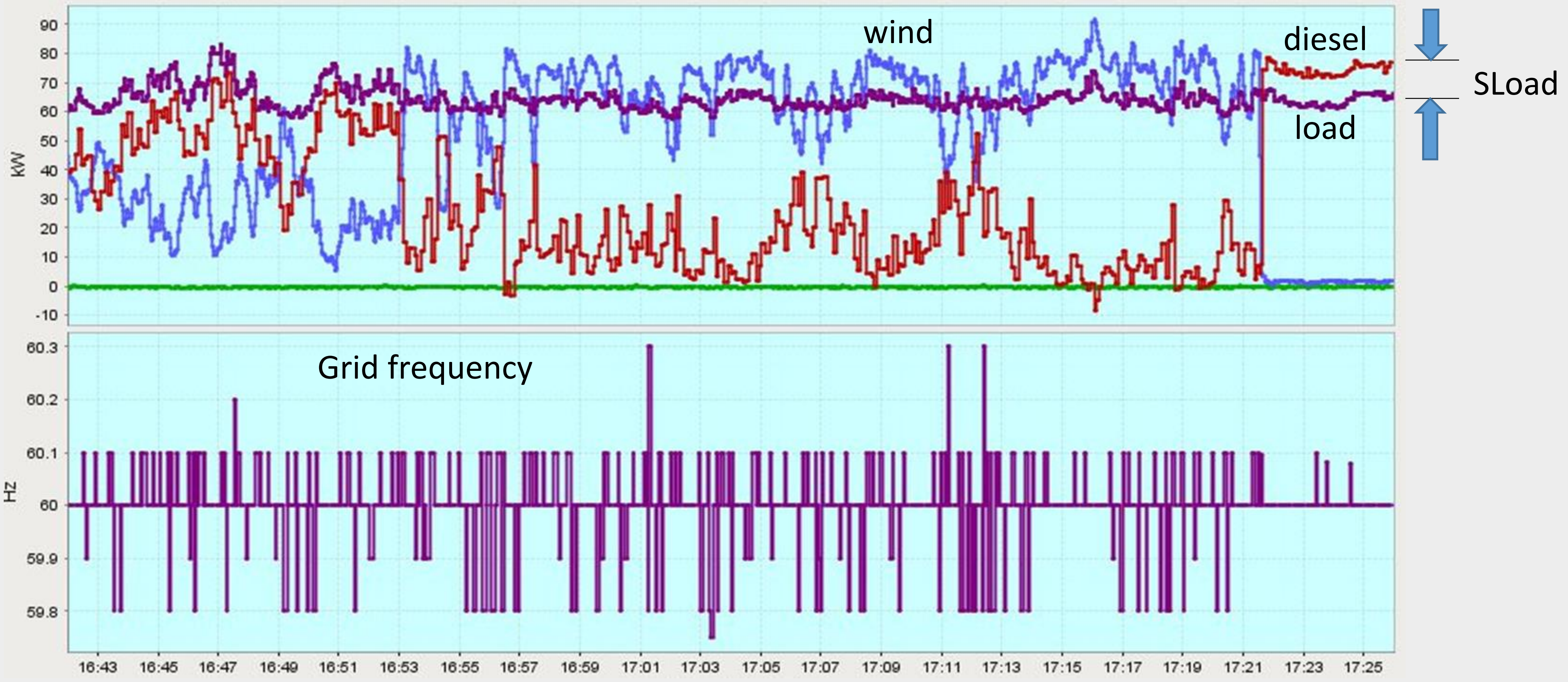
Power Dashboard – Enhancing the Process

- ***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

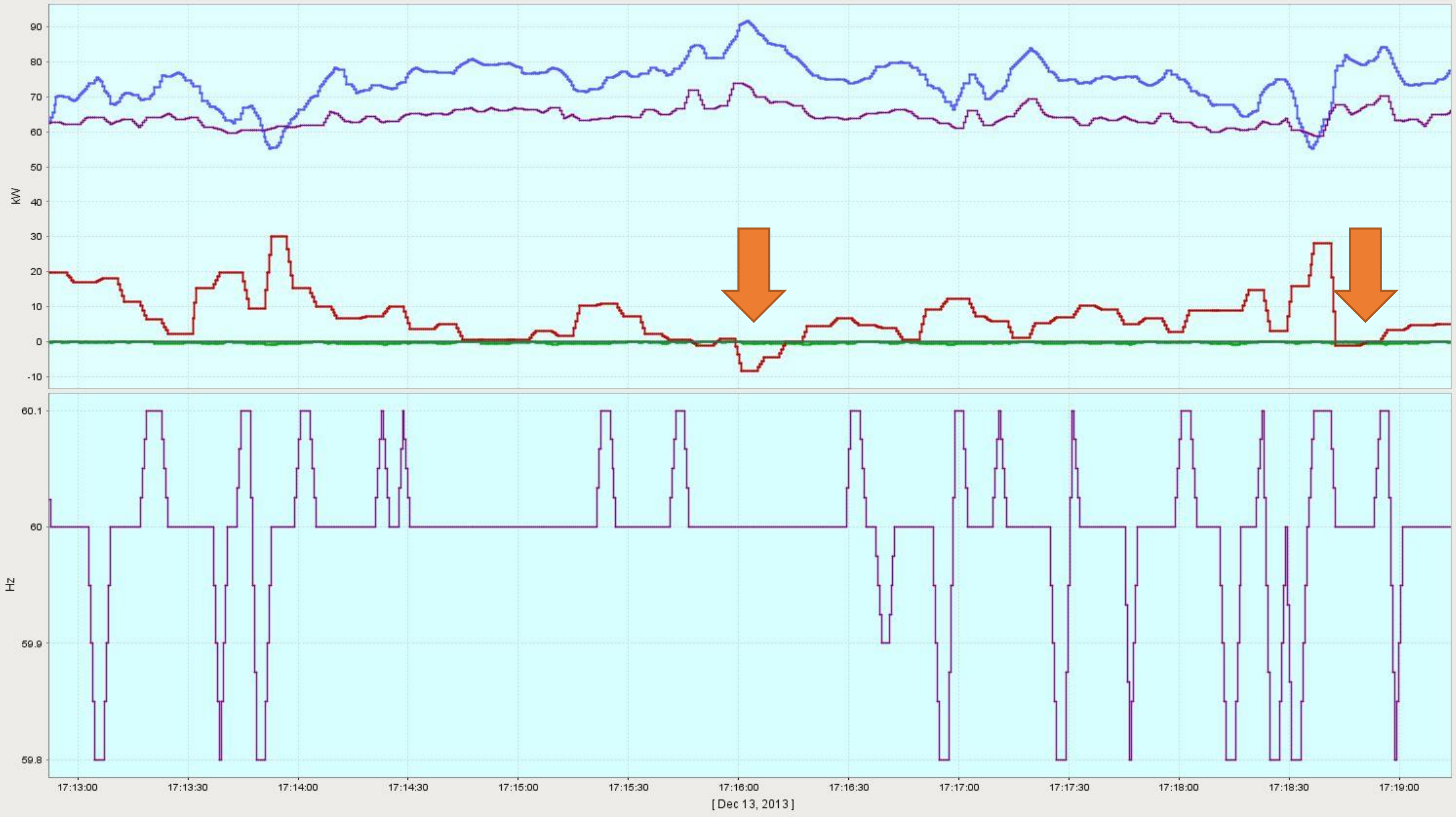
Motivations for Power Dashboard to Model Isolated Grid Wind-Diesel

- 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)

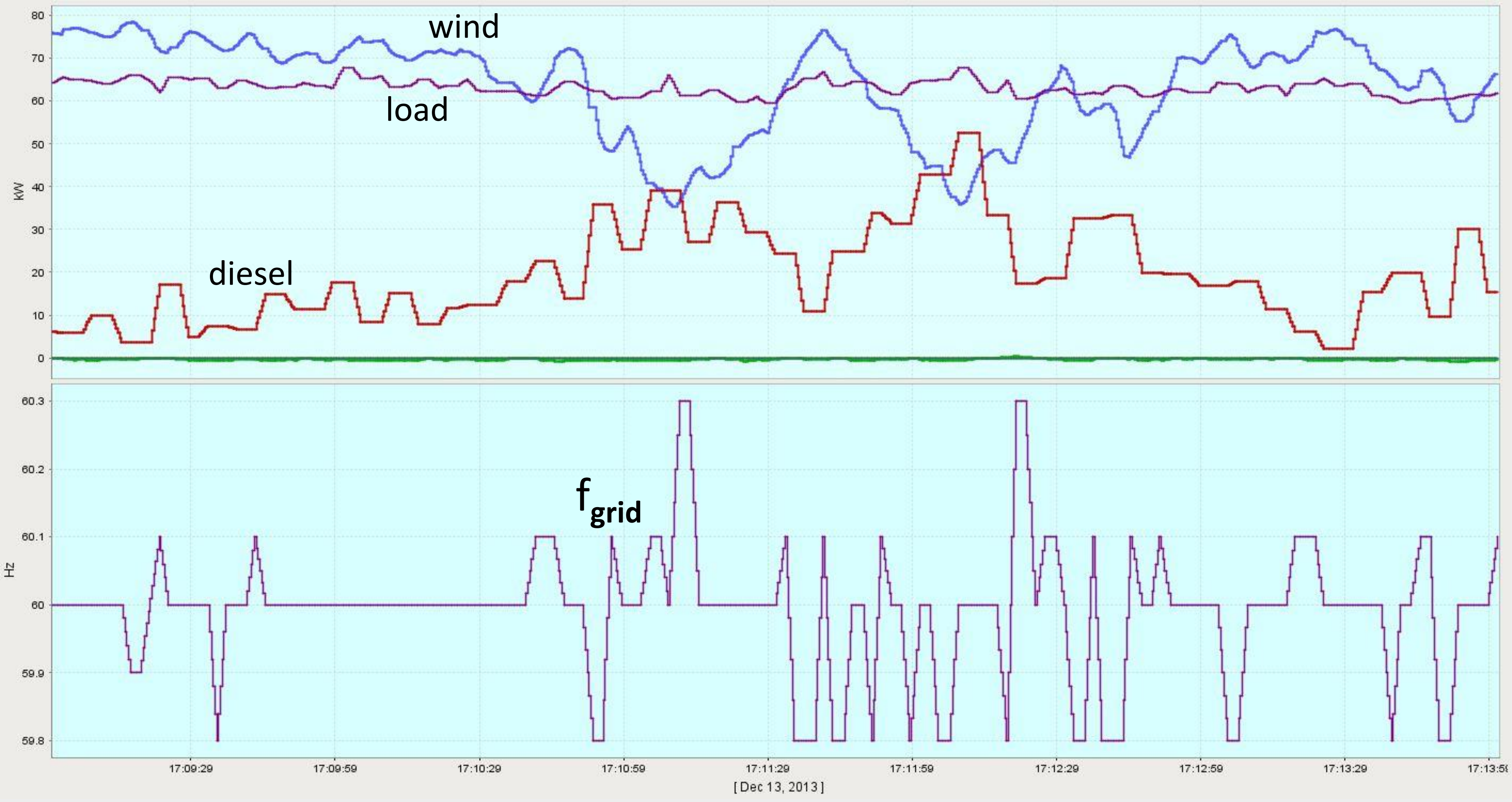
Dynamic Nature of Isolated WD System



Snapshot of Unwanted Diesel Operation



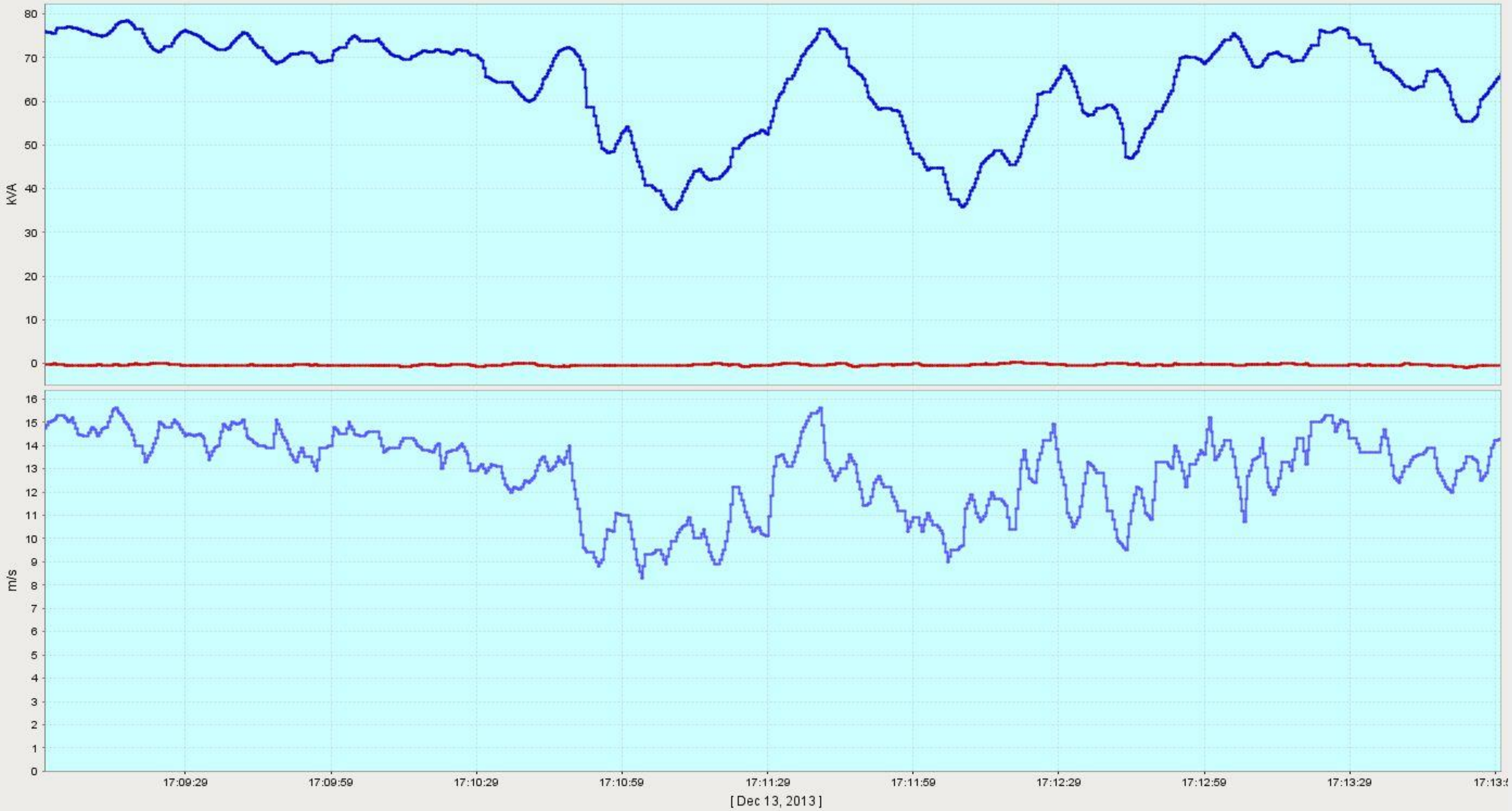
Snapshot of diesel & turbine – 5 min interval



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 <u>are</u> 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

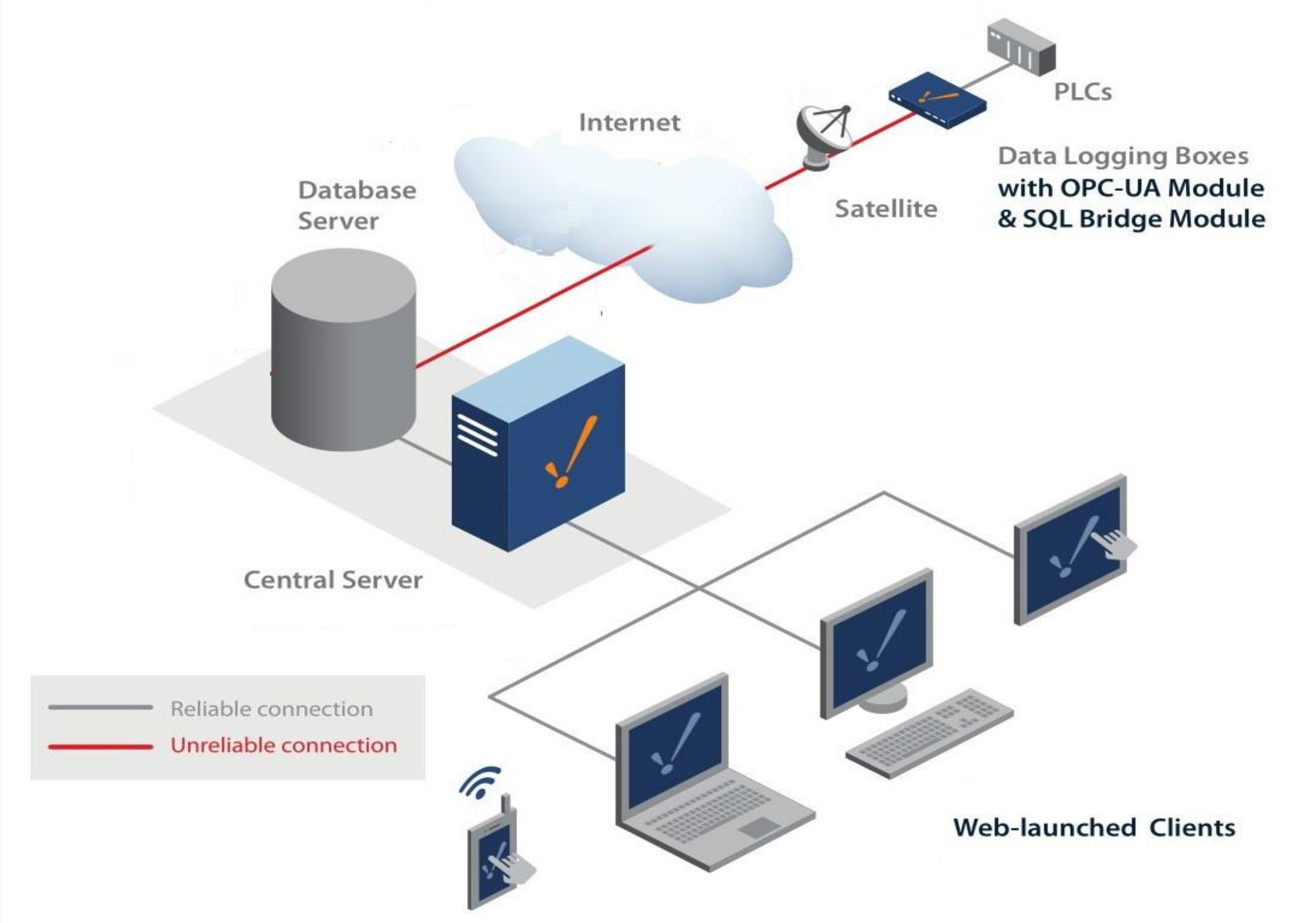
Design phase

- 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

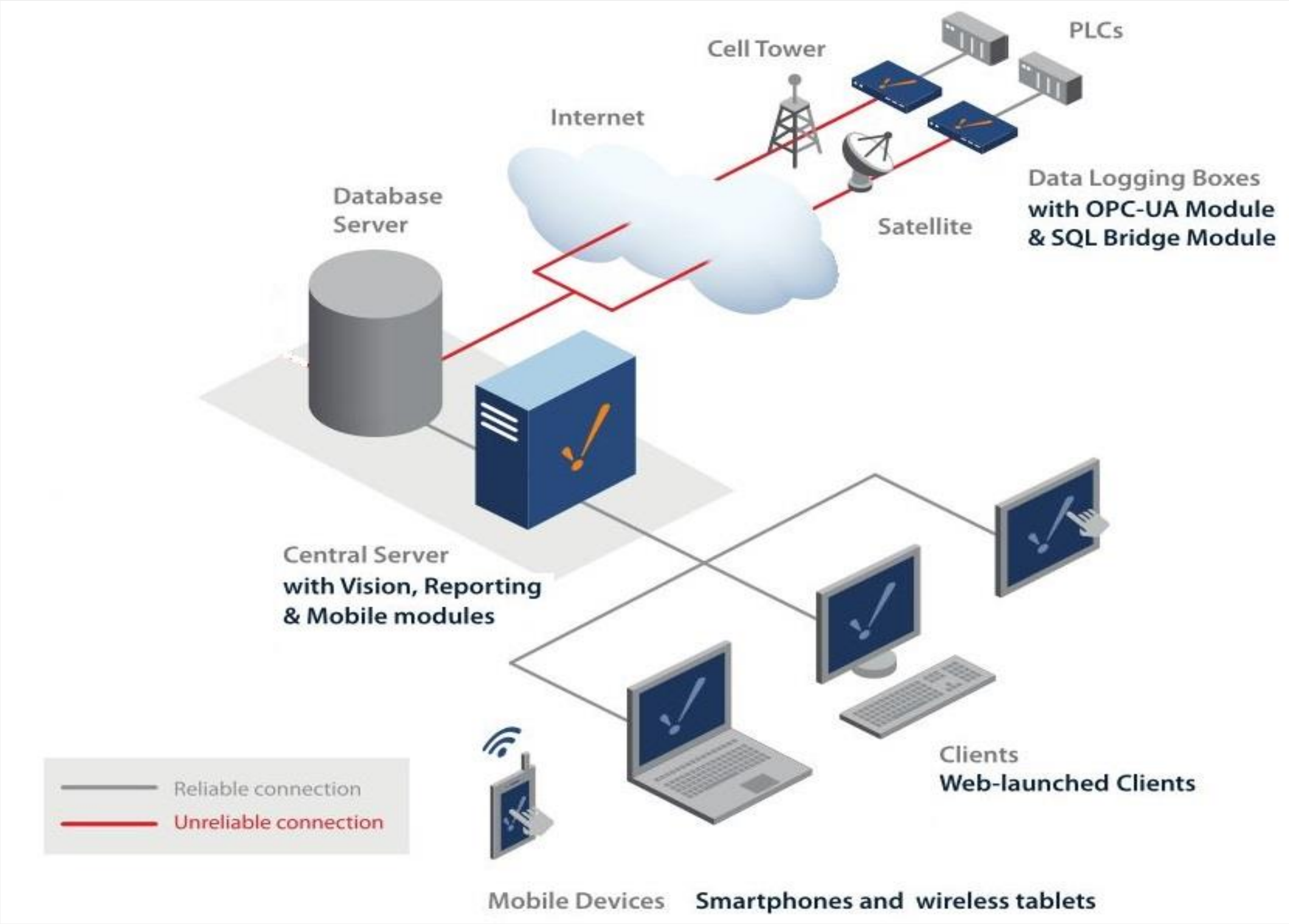
Operational phase

- 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

Solution >>>	>>> Problem
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!