NREL National Renewable Energy Laboratory
Innovation for Our Energy Future

Wind/Diesel Power Systems Basics and Examples

E. Ian Baring-Gould,

National Wind Technology Center & Deployment & Industrial Partnerships Centers

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Presentation Outline

An overview of the market status of wind-diesel power systems

- Current status of wind-diesel technology and its application
- System architectures and examples of operating systems
- Recent advances in wind-diesel technology
- Remaining technical and commercial challenges

Kasigluk, Alaska

San Cristobal, Galapagos

Remote Power Systems

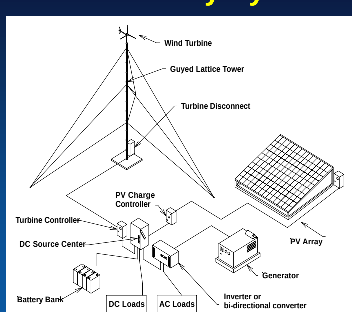
Renewable based power system can be used to supply a wide range of energy needs including:

- **Dedicated use:** Water pumping/ice making.
- **House systems:** Power systems for individual homes, buildings, and load centers.
- **Community Power Systems:** Power systems for a whole community and can include conventional generation, renewable technologies and storage technologies.
  - Community hybrid systems
  - Wind/Diesel systems

Community Scale Hybrid Systems

- Takes advantage of local renewable resources when available in place of diesel produced energy
- Centrally located power plants that distribute AC power to the connected homes.
- Components of wind, PV, biomass, batteries and conventional generators
- Use of batteries when appropriate to store renewable energy for use at night or low renewable times
- Generator used as backup or secondary power supply
- Incorporate larger or multiple generation units to improve operation performance and benefit from quantities of scale benefits
- Relatively mature market, understood technology

Hybrid (Wind, PV, Diesel, Storage) Community System



Lime Village, Alaska

Small community in central Alaska using a solar – diesel hybrid power system as part of an AEA / Sandia National Laboratory PV technology demonstration project

- Average daily load peak of about 15 kW
- Successful technology demonstration
- Currently under monitoring to assess economics and operational characteristics

- 12 kW Solar Array (Siemens & BP)
- 24 kW power converter
- 530 Ahr lead Acid battery bank
- 2 diesel engines

Wind-Diesel Power Systems

- Designed to reduce the consumption of diesel
  - Pits cost of wind power against cost of diesel power
  - Reduces diesel storage needs
  - Reduced environmental impact; fuel transport & emissions
- Used for larger systems with demands over ~ 100 kW peak load up to many MW
- Based on an AC bus configurations using wind turbines and diesel engines
- Batteries, if used, store power to cover short lulls in wind power
- Large potential, varying degrees of maturity with fewer examples
- Obviously requires a good wind resource to be "economical"

Current Status of Wind-Diesel Technology

We have gone beyond conceptual

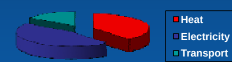
Oil price spike in 2008 have caused many nations and organizations to realistically look at options to reduce dependence on diesel fuel for power generation

Rapidly expanding market for wind-diesel technologies:

- 11 projects operating or in construction in Alaska with 14 additional projects funded
- Operating projects in almost every region of the world
- Expanded interest in Canada, Caribbean and Pacific Islands, and Antarctica

But the challenges continue…

- Electricity is only part of the issue
- Limited education and management infrastructure
- High capital costs
- Lack of understanding of the technology



% of energy usage in the rural community of Akutan, Alaska by sector

What's the Challenge Behind Wind Diesel Power Systems?

By their nature renewable energy is stochastic (uncontrolled) and it varies with the resource.

We like our power very constant and controlled - 60 Hz, 120 V – for our TV's, lights, computers

Turning the variable energy in the wind into constant, consistent energy we can use can be a difficult task – the more energy from the wind, the more complex the task

Wind-Diesel Penetration

One of the critical design factors is how much energy is coming from the wind – called wind penetration – as this helps determine the level of system complexity

$$\text{Instantaneous Penetration} = \frac{\text{Wind Power Output (kW)}}{\text{Primary Electrical Load (kW)}}$$

- Used to understand control requirements
- Reactive power needs, voltage and frequency regulation

$$\text{Average Penetration} = \frac{\text{Wind Energy Produced (kWh)}}{\text{Primary Energy Demand (kWh)}}$$

- Generally calculated on monthly or annual basis
- Total energy savings
- Loading on the diesel engines
- Spinning reserve losses/efficiencies

AC Based Hybrid System

- **Low penetration systems -** Wind acts as a negative load, very little control or integration of wind turbines into the power system is needed .
- **Mid penetration systems -** Wind becomes a major part of the power system but diesel engines still provide much of the system power control. Additional components and limited supervisory control required to assist diesels in maintaining power quality.
- **High penetration systems -** Completely integrated power system with advanced control. Diesel generators shut off when not needed. Limited operational control of system by plant staff.

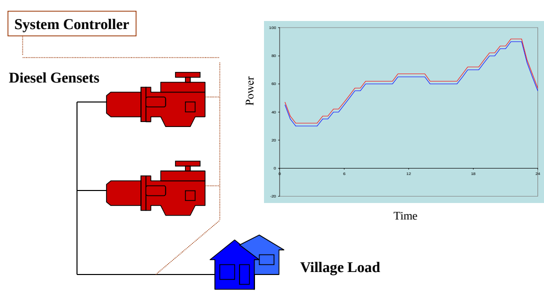
System Penetration

Penetration Class	Operating Characteristics	Penetration	
		Peak Instantaneous	Annual Average
Low	▪ Diesel(s) run full-time ▪ Wind power reduces net load on diesel ▪ All wind energy goes to primary load ▪ No supervisory control system	< 50%	< 20%
Medium	▪ Diesel(s) run full-time ▪ At high wind power levels, secondary loads dispatched to ensure sufficient diesel loading or wind generation is curtailed ▪ Requires relatively simple control system	50% – 100%	20% – 50%
High	▪ Diesel(s) may be shut down during high wind availability ▪ Auxiliary components required to regulate voltage and frequency ▪ Requires sophisticated control system	100% - 400%	50% – 150%

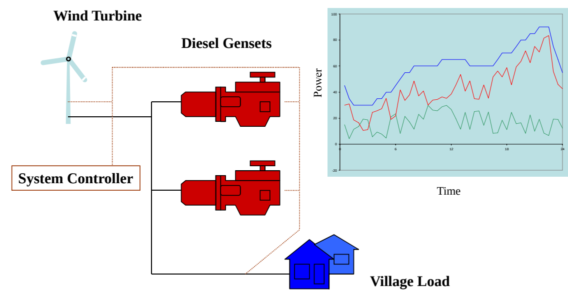
These are really three different systems which should be considered differently

Note: People play loose with the definitions

Diesel Only Power System



Low Penetration wind/diesel system



Low Penetration

- Generally easy integration with existing diesel system, little or no diesel modifications required
- Diesel engines provide all frequency, voltage and reactive power control requirements
- Switch gear would need to be modified to add turbines and turbine control software installed
- Modest fuel savings of up to ~20% possible.
- System support requirements.
  - o Wind turbine maintenance.
  - o No change in staffing or potential increase

Kotzebue, Alaska

- Large coastal hub community in Northwestern Alaska with a population of ~3,100
- Operated by Kotzebue Electric Association
- 11 MW installed diesel capacity
- 2-MW peak load with 700-kW minimum load
- 915-kW wind farm comprised of 15, Entegrity e50, 50 kW; 1 remanufactured V17 75 kW; and 1 NW 100/19, 100-kW wind turbine.
- Instantaneous penetrations regularly above 50%
- Turbine curtailment used to control at times of high wind output

- Wind turbine capacity factor of 13.3%
- **Average penetration of ~5% with wind generating 1,064,242 kWh in 2007**
- Diesel fuel saving of more than 71,500 gal (270,600 l) in 2007
- **Good turbine availability (92.8% 1/02 to 6/04) due to strong technical support**

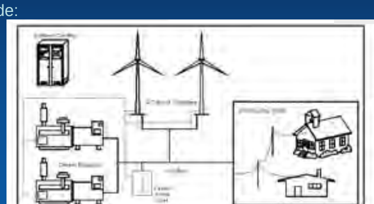
Medium-Penetration Systems

Fairly well developed technology and controls

- Diesel(s) run full-time although the use of modern or low-load diesels improve performance
- Secondary loads are used to maintain diesel loading
- Wind generation can be curtailed, especially during high winds
- Requires relatively simple control system
- Power storage may be used to smooth power fluctuations

Project examples include:

- Toksook Bay, Alaska
- Kotzebue, Alaska*
- Kasigluk, Alaska
- Nome, Alaska
- Mawson Station, Antarctica
- San Cristobal, Galapagos
- Denham, Australia
- Gracious, Azores



Toksook Bay, Alaska

Power system that supplies the ~800 people of the communities of Toksook Bay and Nightmute in coastal Southwest Alaska

- Power system operated by the Alaska Village Electric Cooperative
- Average load just under 370 kW (both Toksook and Nightmute)
- 3 NW100-kW turbines and resistive community heating loads
- Installed in the fall and winter of 2006
- **24.2% average wind penetration with much higher instantaneous penetration**
- Almost 700 MWh generated by wind last year, saving almost 46,000 gal (174,239 l) of fuel
- **First year turbine availability of 92.4% - currently under warrantee**
- **Average net capacity factor of 26.0% from Aug '07 to July '08**

Mawson, Antarctica

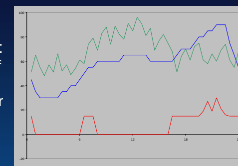
Plant that powers the Australian Antarctica Research Station

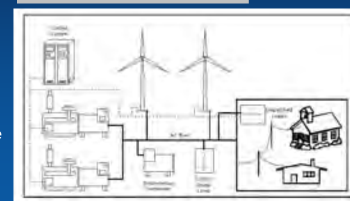
- Installed in 2002-2003
- Four 120-kW diesels with heat capture
- Two Enercon E30, 300-kW turbines
- Flywheel used to provide power conditioning, although a diesel always remains operational
- Electrical demand: 230 kW average
- Thermal demand: 300 kW average
- Total fuel consumption of 650,000 l per year
- **Average penetration since 2002 is 34%**
- **Best monthly penetration is 60.5% in April 2005**
- **Turbine availability 93%**
- Average fuel savings is 29%
- Power station operation Web site: http://www.aad.gov.au/apps/operations

High Penetration without Storage

Very complex system with very few operating examples:

- All diesels allowed to shut off when there is sufficient excess wind in place to cover load
- Synchronous condenser used to control voltage & provide reactive power
- Dispachable and controlled loads are used to maintain power/frequency balance
- Turbine power control likely
- Advanced system control required
- Require a large dispatchable energy sink such as heating





St. Paul, Alaska

Airport and industrial facility on the island of St. Paul in the Bering Sea

- Owned and operated by TDX Power
- **High-penetration wind-diesel system; all diesels are allowed to shut off**
- One Vestas 225-kW turbine installed in 1999 and two 150-kW diesel engines with a synchronous condenser and thermal energy storage
- Current average load ~70kW electrical, ~50kW thermal
- **Since 2003, net turbine capacity factor of 31.9% and a wind penetration of 54.8%**
- System availability 99.99% in 2007
- **In March 2008, wind supplied 68.5% of the facility's energy needs and the diesels only ran 198 hours ~27% of the time.**
- Estimated fuel savings since January 2005 (3.5 years) is 140,203 gal (530,726 l), which at $3.52/gal is almost $500k
- Annual fuel saving between 30% and 40%

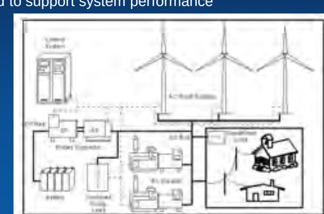
High Penetration with Storage

Very complex system with only a few operating examples:

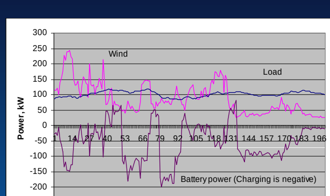
- Typically all diesels allowed to shut off when the wind produces more than needed to supply the load
- Battery or fly wheel storage is used to smooth out power fluctuations while controlling system voltage and frequency when diesels are off
- Dispachable loads are used to productively use extra wind
- Low-load diesels can be used to support system performance
- Turbine power control likely
- Advanced system control required
- Less dependence on large energy sinks for excess wind

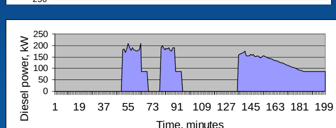
Few project examples but more systems being contemplated

- Coral Bay, Australia*
- Wales, Alaska



Operation with Short Term Storage





Operational data from the power system at Wales Alaska demonstrate system operation

- Battery bank covers short lulls when wind energy can not cover the load
- Diesel started to cover prolonged gaps in wind energy
- Large amounts of excess wind energy is not produced

Coral Bay, Western Australia

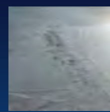
A small settlement of about 200 people on the western coast of Australia with high seasonal load

- **High penetration wind-diesel system using a flywheel and low load diesels**
- Diesels remain on consistently
- Three Vergnet, 275-kW hurricane-rated turbines, a 500-kW PowerCorp flywheel and 7x320-kW low-load diesel engines
- Installed in summer 2007 by PowerCorp Australia in collaboration with Horizon Power and Verve Energy
- ***Average penetration for the first 10 months of operation was 55%***
- **In September 2007, wind supplied 76% of the community's energy needs with instantaneous penetrations consistently above 90%**

Wales, Alaska

Remote coastal community in northwestern Alaska with a population of about 150

- Average load of around 70 kW
- Two AOC 15/50 wind turbines
- High-penetration wind diesel with the ability to operate with all diesels turned off using short-term NiCad battery storage with a rotary converter to control frequency and voltage
- Resistive loads used for heating and hot water
- System has had many problems associated with complexity, maintenance, and confidence of the local population to operate with all diesel engines offline
- Operated by Alaska Village Electric Cooperative with the implementation assistance of Kotzebue Electric Association and NREL



Issues of Power Generation and Transmission

Power Quality of Systems

- Variable renewable penetration of system
- Power flow questions
- Voltage variation on feeder lines
- Level of technology/control existing in diesel plant

If at any time you are not producing enough power, power system will collapse

Elements of Power Quality

- Power reliability: Having power when you should have it.
- Power Quality: Is the power supplied good enough for the needs.
  - **Voltage:** Amplitude of the power wave form.
  - **Frequency:** Maintaining a balance of power supply and demand.
  - **Power Factor maintenance & Reactive Power supply (VAR Support):** All impedance devices require both active and reactive power.
  - **Harmonics Distortion:** The quality of the power that comes down the line and can impact electronic devices

Maintaining High Power Quality

- Maintaining a high level of power quality is dependent on obtaining ways to control what is happening.
- Depends on
  - Configuration: Integrated solid state power power converter and controls, no storage with dump loads
  - Type and age of equipment: Diesel electronic and fuel controls
  - System integration: Overall system control
- There are supply and demand side solutions to this problem

Complication with Uncontrolled Generation

Why are hybrids a complicated control question and need special attention in regards to power quality?

- By their nature renewables are stochastic (uncontrolled) and vary with the resource. The amount of variation and thus the amount required control depends on the renewable resource being used and the power system design
- Wind, river run hydro and solar technologies require adequate control to allow integration and insure power quality

Supply Side Options

Options that affect only the power system as seen from the grid

- Controlled Dump Loads: Fast acting devices that help to balance the generation and load
- Synchronous Condenser: Provides reactive power and controls voltage.
- Power Storage: Flywheels or advanced power converters and small battery bank: Used to assist in managing power flows, power smoothing.
- Active Power Control Devices: Monitor grid condition and act to insure high power quality
- Active Renewable Control: Control power output of the renewable device. Power control or simply turning off some of the units

Active Renewable Control

Control of the offending power generation device to smooth out power output.

- Controlled shut down of renewable devices during high wind or low load periods
- Active power control of renewable technology.
  - Variable speed technology using power electronics
  - Active wind turbine control, variable pitch blades
- Resource smoothing using multiple units
  - smaller turbines spread out over a greater area
- Short and long term forecasting of system power

Demand Side Options

Control options that can be completed on the grid side to support system power quality

- Load Dispatching: Active dispatchable of specific loads and making the distinction between critical and non-critical loads
  - Dispatchable loads like resistance heating
  - Loads shedding where non-critical loads are turned off
  - Protection of sensitive loads
- Capacitors Banks: Installation of capacitors to smooth out rapid system fluctuations and partially correct systems power factor.
- Active Load Control: Replacing large inefficient loads with better or different devices

Active Load Control

This principle may not be applicable in every setting and requires a higher degree of collaboration between the energy supplier and energy consumer

- Specific Use Applications: Working with high energy users to insure that equipment is operating properly. An ounce of prevention is worth a pound of ___
- Water Heaters: In many communities electric water heaters are a large source of energy usage which can be controlled
- Variable Electric Rates: Accounting for the different production costs of energy

System Operation

How complex is it to operate these power systems?

It really depends on what type of system you are talking about…

System Operation

Low penetration systems

- Can be operated as two independent power systems (wind/diesel), though active integration is preferred.
- Operators in full control of power system and use individual unit controls to turn components on and off as needed.
- May have some data monitoring to keep track of what has happened

Coyaique, Chile

- Large regional distribution system
- 3x 660 kW wind turbines
- 4.6 MW of mixed hydro
- 16.9 MW of diesel

- Manually operated through local control center
- Turbines turned off during low load or high wind pereods

System Operation

Mid penetration systems –

- Really must be operated as an integrated power system
- Minimal supervisory control required
- Some components in addition to the diesel used to maintain power quality
- Monitoring becomes more important

San Clemente Island, California

- U.S. Navy island off San Diego
- Diesel powered grid
- 850-950 kW avg; 1,400 kW peak with 775 kW wind

Older diesels require the use of a synchronous condenser to maintain voltage

System Operation

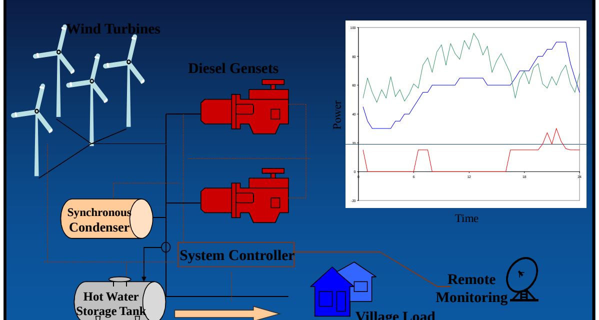
High penetration systems

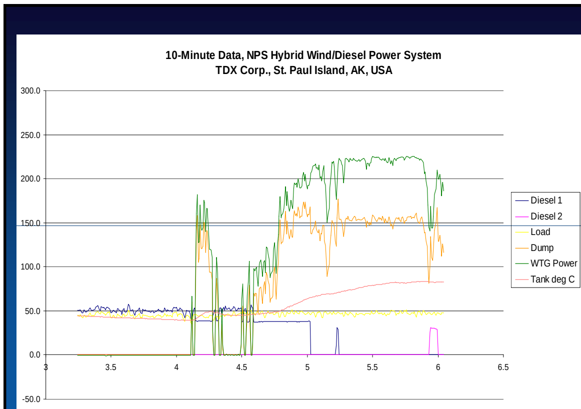
- Really must be operated as an integrated power system
- Advanced supervisory control required
- Individual component controllers oversee specific operation
- Since diesels are turned off, components added to maintain power quality
- Monitoring becomes more important and remote diagnosis generally advised

St. Paul Alaska, USA

- Island in the middle of the Bering Sea
- Implemented by TDX and Northern Power Systems in 1999
- Complex power system controller

Wind/Diesel Hybrid - Fully Integrated





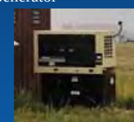
Systems and Components

- Hybrid power systems are made up of separate pieces of equipment that are brought together to form a cohesive power system
- Configuration and component size depend on the load and resource available at site
- Controlling the power systems is a complicated question, both logically and technically, especially as system penetration increases
- Designers must understand the different components and their use

Dispatchable Generators

- Generators that can be turned on with short notice.
  - Diesel, Gas, Natural Gas, Bio-gas
- Usually require a lot of maintenance
- Role depends on system design.
- Wide range of old and new technology
- Wide range of control

40 kW Diesel Generator



10 kW Diesel Generator w/ Fuel tank

Wind Turbines for Hybrids

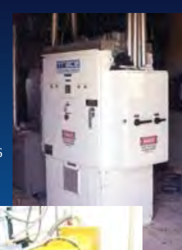
- Range in size from 300W to 750kW
- Large AC turbines for diesel plants
- Small turbines designed for remote applications, generally DC but also AC being developed
- Self erecting or tilt up towers common
- Installed cost $3-6/W with production from $0.10-0.20/kWh

Reconditioned WindMatic

Entegrety e15

Northwind 19/100 B

Hybrid System Power Converters



Trace Tech 100 kW converter

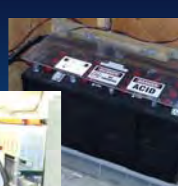
Wales AK 156 kW rotary converter

- Convert energy from DC to AC and back
- Some units contain power system control
- Solid state or rotary systems
- Solid state range in size from 1kW to 300kW
- Rotary systems built to size depending on needs
- Combined with batteries for storage

Xantrax 4kW converter

Batteries

- Many types
  - Lead Acid (deep cycle and shallow cycle)
  - NiCad
- Two uses/sizing:
  - Store energy to cover long periods
  - Store power to cover short periods
- Requires periodic replacement
- Sensitive to environment
- Life dependent on use and the environment



Other Active Power Control

Flywheels - provide short term energy storage while smoothing fluctuations in wind and load

Low load diesels - operate down to below 10% rated power while maintaining control over voltage and frequency

- Allows active control of grid stability
- Allows access to small amounts of instantaneous power
- Generally modular
- Spinning losses
- Long research history, very short operational experience

Power Smoothing and Conditioning

Controlled dump loads, synchronous condensers, and grid conditioners to control system voltage, frequency, and reactive power

- Help to control voltage and balance active and reactive power needs on the grid
- Primarily used when all diesel engines have been shut off
- My provide limited "storage"
- Has a standing loss

Grid Conditioner

Secondary Dispatchable Loads

Transportation

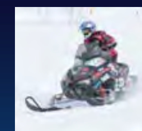
- Snow machines - Not commercially available
- ATVs - Several commercial manufactures
- Trucks and cars - Large variety of light-duty electric and hybrid electric cars and trucks

Thermal loads

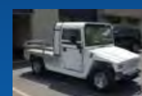
- District heating (water and space) systems
- Dispersed electric heating using ceramic

Water desalination

In many cases, detailed information on dispatchable loads is limited – making assessment difficult



Univ. of Wisconsin Madison modified Polaris



E-Ride electric truck – being tested in Antarctica in 08/09

EVS e-force sport ATV

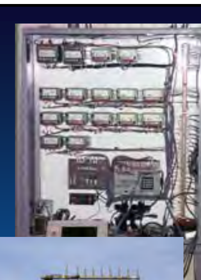
Bad Boy Buggy utility electric ATV in Greenland

System Controls and Switch Gear

- The controller makes everything work together
- Generally have central switch gear/controller and then individual controllers for each component
- Operates at very high speed to monitor system stability while allowing general component control
- Can reduce staffing costs while increasing system performance
- Controllers are not created equal – just because they say something is "wind ready" does not mean that it is

Monitoring and Remote Access

- Remote access allows oversight of system performance
- Enables real time system interrogation and troubleshooting even when off site
- With expert analysis system reduces maintenance and down time
- Small incremental cost

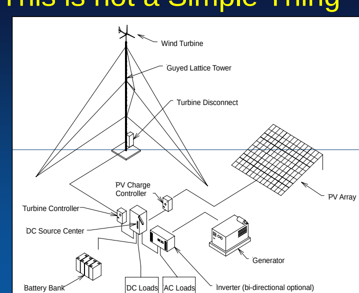


That looks simple – doesn't it?

The design and implementation of power systems is a complex matter and although the models (and initial presentations) make it look simple, it is never that easy.

Every power system is complicated, some much less than others but you do need to think about the design and how it will be implemented.

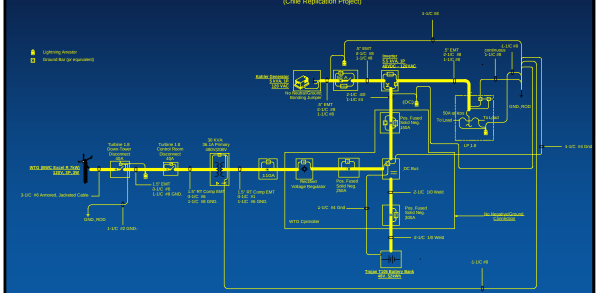
This is not a Simple Thing



"Simple" DC based small power system

Power system schematic

Site 1.8 One-Line Electrical Diagram for BWC Installation
(Chile Replication Project)



Other Integration Issues

In many cases it makes sense to implement wind as part of a complete system up-grade

- Complications with old diesel and controllers to integrated and automated operation
- Need for more space in the power house
- Modification to existing switch panels
- Integration with existing thermal loops

Adds to the cost and becomes much more complicated and time consuming

Conclusions

- There are a lot of options / configuration of hybrid power systems using local renewable resources to reduce the dependence on imported fuels for rural electricity generation.
- Its not only the cost of imported fuels that need to be considered - the cost of fuel storage, transportation, and potential environmental impact should be assessed as well.
- Options for larger communities include advanced diesels and control, locally derived bio-fuels & renewable technologies.
- Projects should be implemented with the support of the whole community and as part of energy education/efficiency campaigns.
- Several very successful wind-diesel projects have been implemented in arctic areas, but every project is not successful
- Social sustainability issues dominate over technical ones
- Its never as easy as it seems

Renewable power systems, specifically wind-diesel, can be implemented successfully in remote areas

National Renewable Energy Laboratory
Innovation for Our Energy Future

Questions?

E. Ian Baring-Gould
National Wind Technology Center & Deployment & Industrial Partnerships Centers
303-384-7021
Ian.baring-gould@nrel.gov