Off-Grid Wind Hybrid Power Systems Components and Architectures

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WEATS

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Session Overview

- Provide an overview of renewable based power systems for rural areas.
- Describe renewable power penetration and the basic design of wind/diesel power systems
- Provide examples of power systems that have been installed.
- Review common power system components and their purpose

Session Goals

Provide a basic understanding of renewable based hybrid power systems so that attendees will be able to understand these power system options

Key Messages

Hybrid power systems are an economic reality that can be used to limit or reduce the dependence on diesel fuel and may provide power to remote communities at a lower life cycle cost that other traditional alternatives.

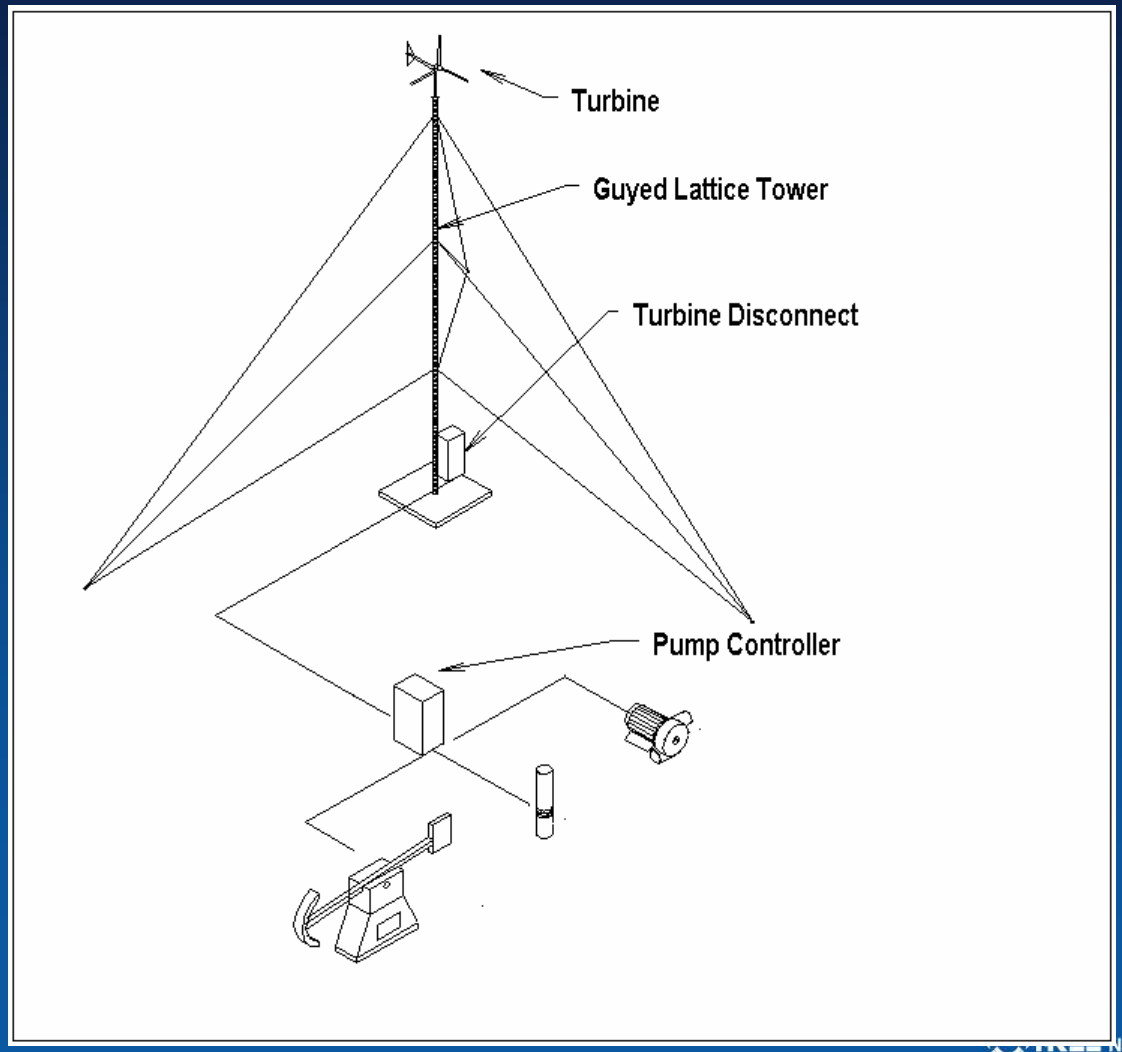
Stages of Remote Power Systems

Renewable power system can be used to cover a wide range of needs.

These include:

- **Dedicated use:** Water pumping/ice making.
- **House systems:** Power systems for individual buildings, dispersed generation.
- **Community Power Systems:** Power provided to a large community with large loads
- **Wind/Diesel Systems:** Large communities with large loads

Direct connect Water Pumping



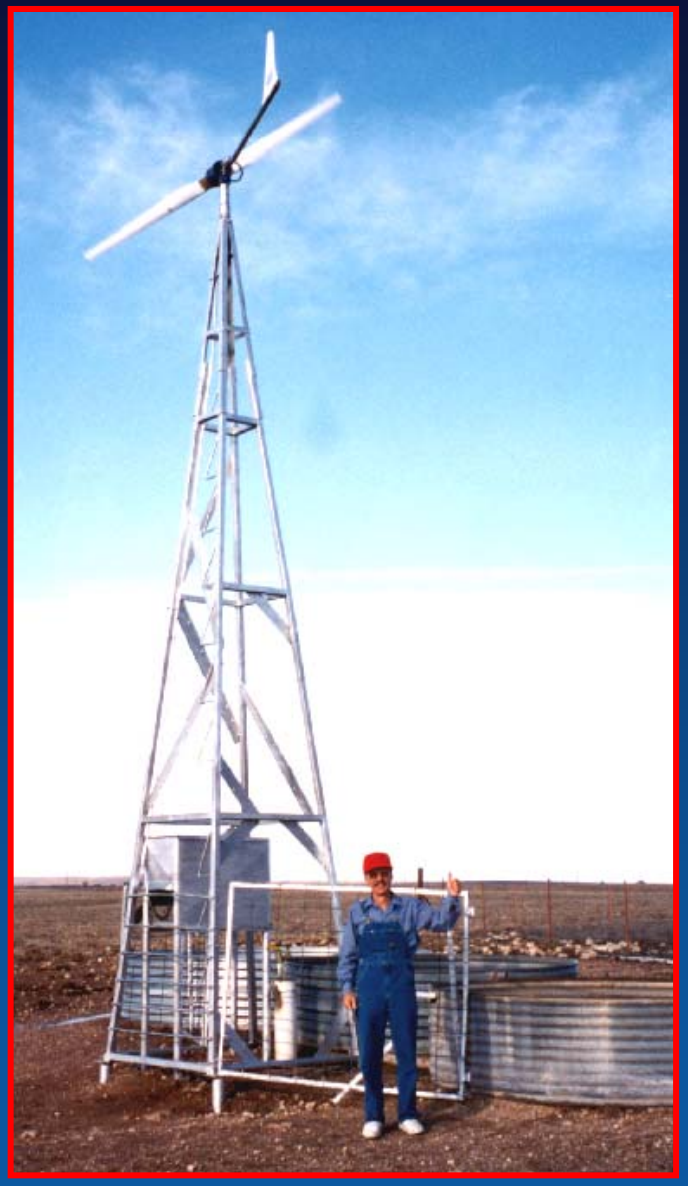
Agricultural Water Pumping

- Livestock watering at the Bledsoe Ranch Colorado, USA
- PV, Mechanical wind and diesel backup solves problems with seasonal variations in resource

NEOS Corporation

Direct Water Pumping

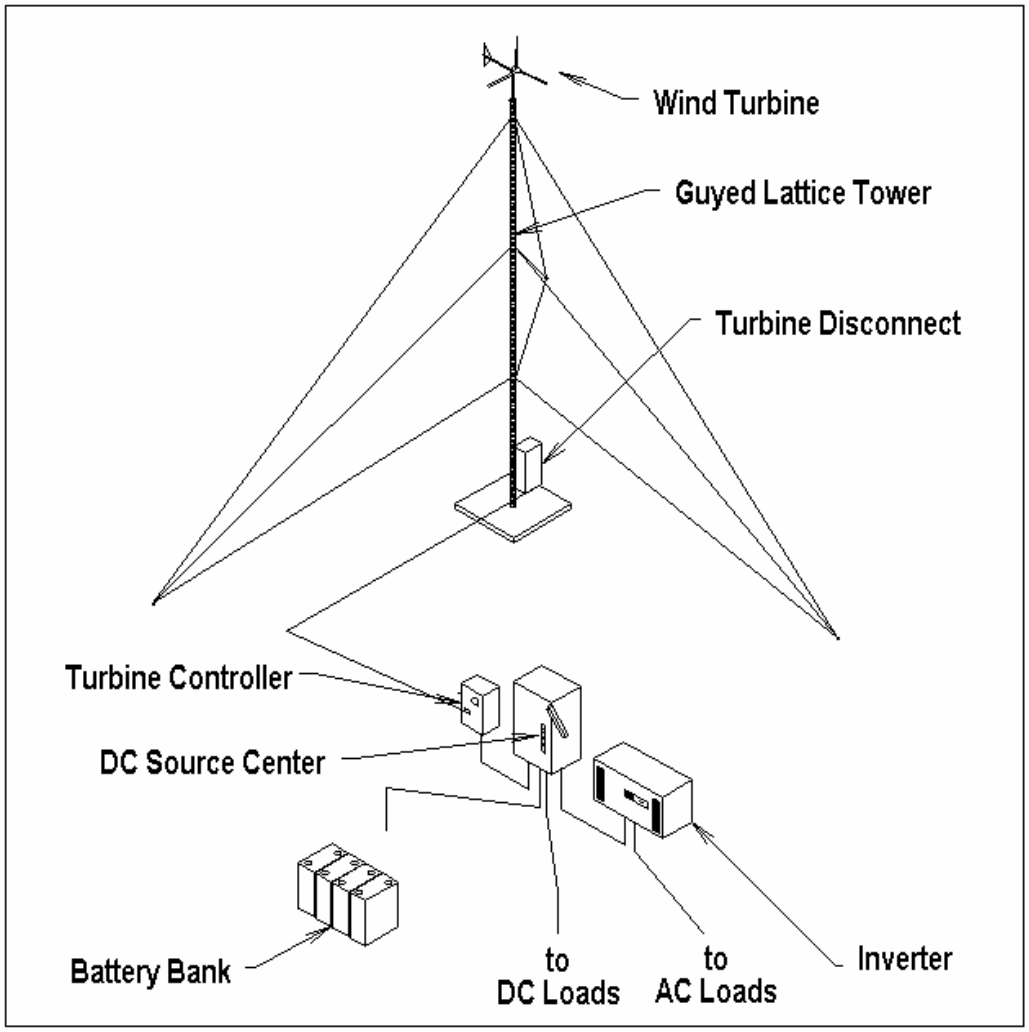
- Ranch near Wheeler, Texas
- Water-pumping for 120 head of cattle
- Whisper 1000 wind turbine,
  1 kW, 9-ft rotor, 30-ft tower



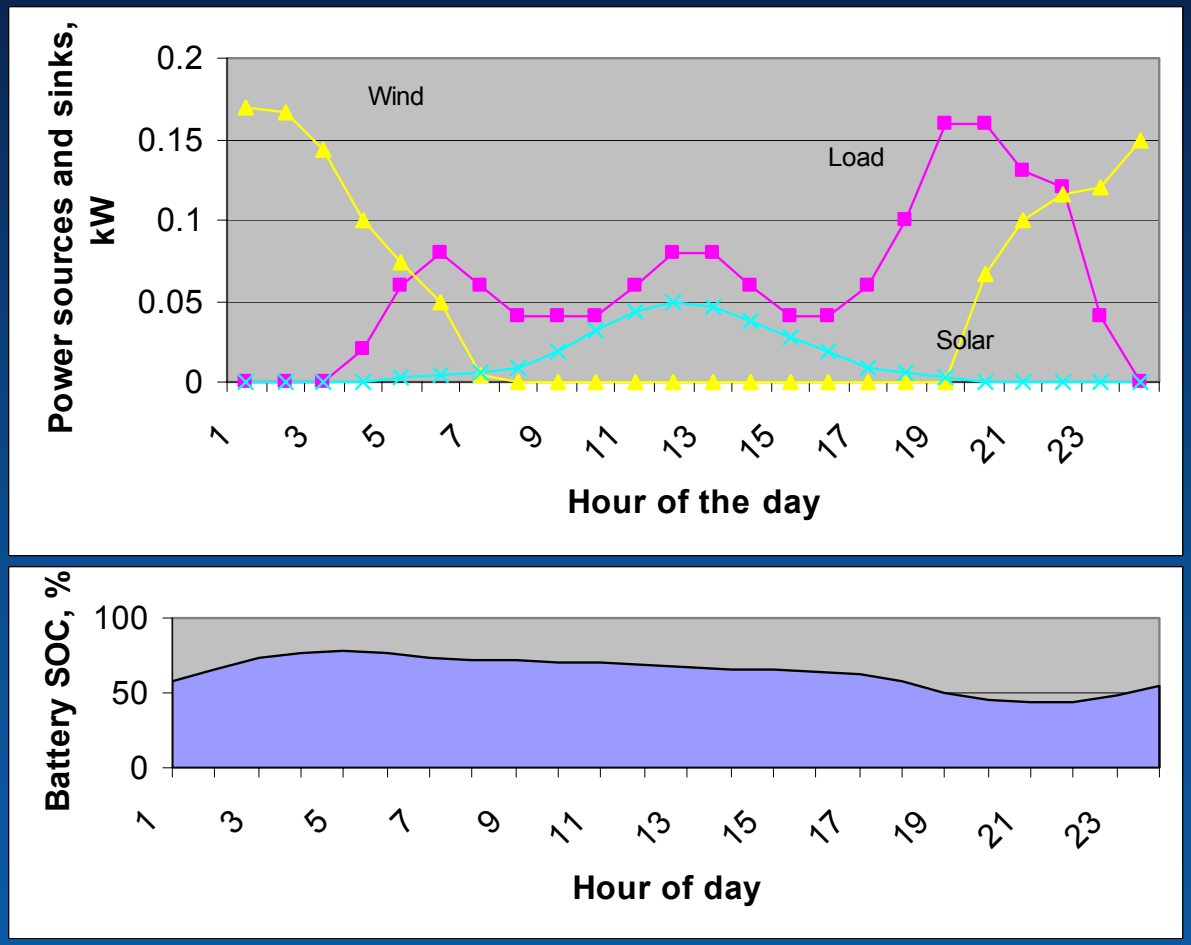
Small Power Systems

- Systems do not have a dispatchable backup generator like most hybrids
- Very simple architecture:
  - Turbine, PV, Disconnects, Batteries
  - DC Loads or AC power through an inverter
- Primarily PV dominated for small loads, wind has potential at larger loads.
- In many instances a combination of PV and wind make most sense
- Can vary in size, power output

Single Source System Architecture



Energy Flow for a Small Hybrid



Solar Home System

- **Provide entry level of service**
  - Lighting, radio
  - DC service
- **Expandable in size, >20W**
- **Cost ~$700 for small unit**
- **Developed market**

Wind/PV Home Systems

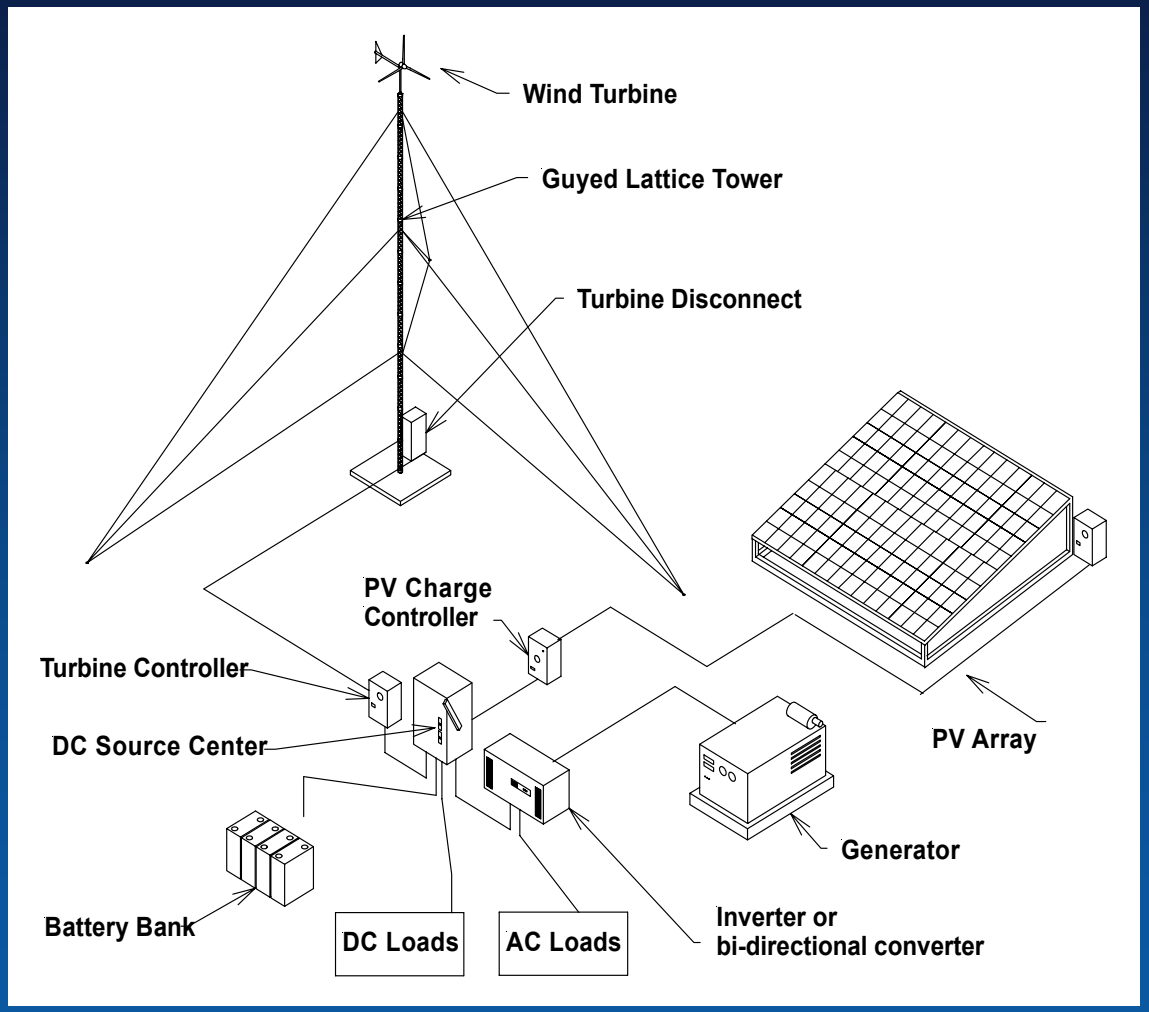
- Provide more energy
- AC Power
- Higher output
- Lower $/kW

Inner Mongolian wind/PV system

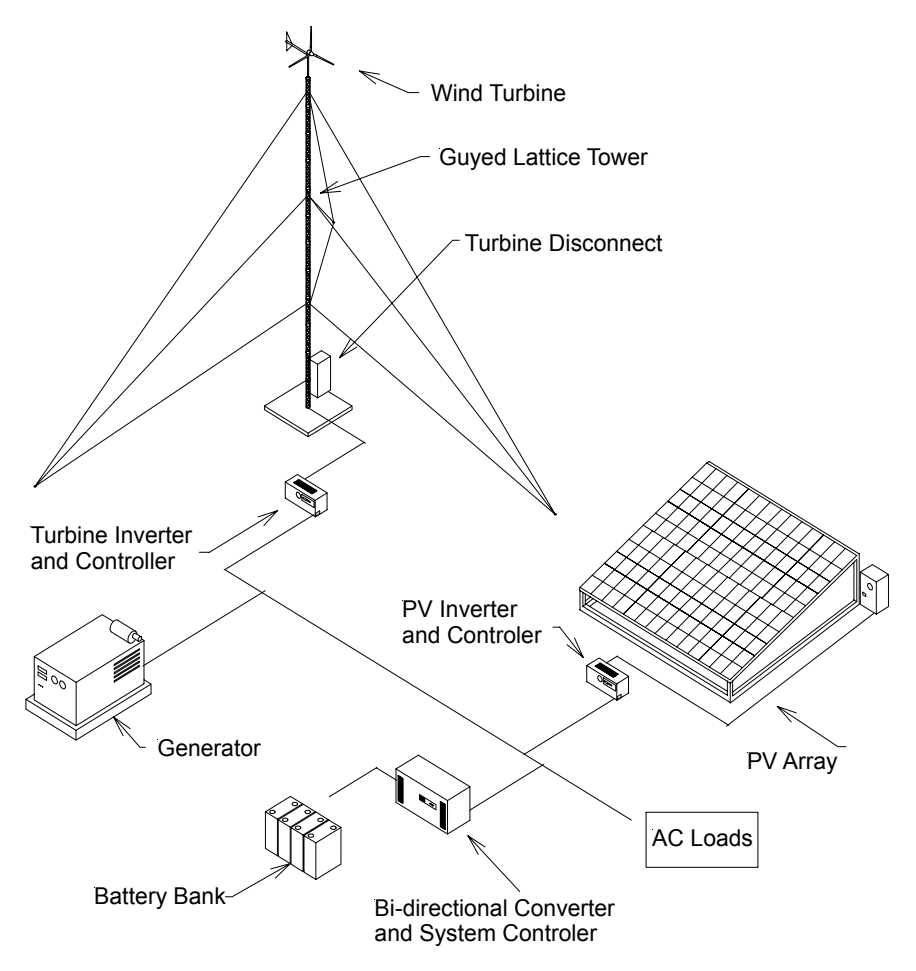
Village Scale Power Systems

- Larger, village scale power systems use centrally located power plants and distribute AC power to the connected homes.
- Single point of service and maintenance
- Usually use larger or multiple generation units to improve operation performance and benefit from quantities of scale benefits
- Act very much like small power utilities
- Provide “grid” style power

Village System Architecture (DC)



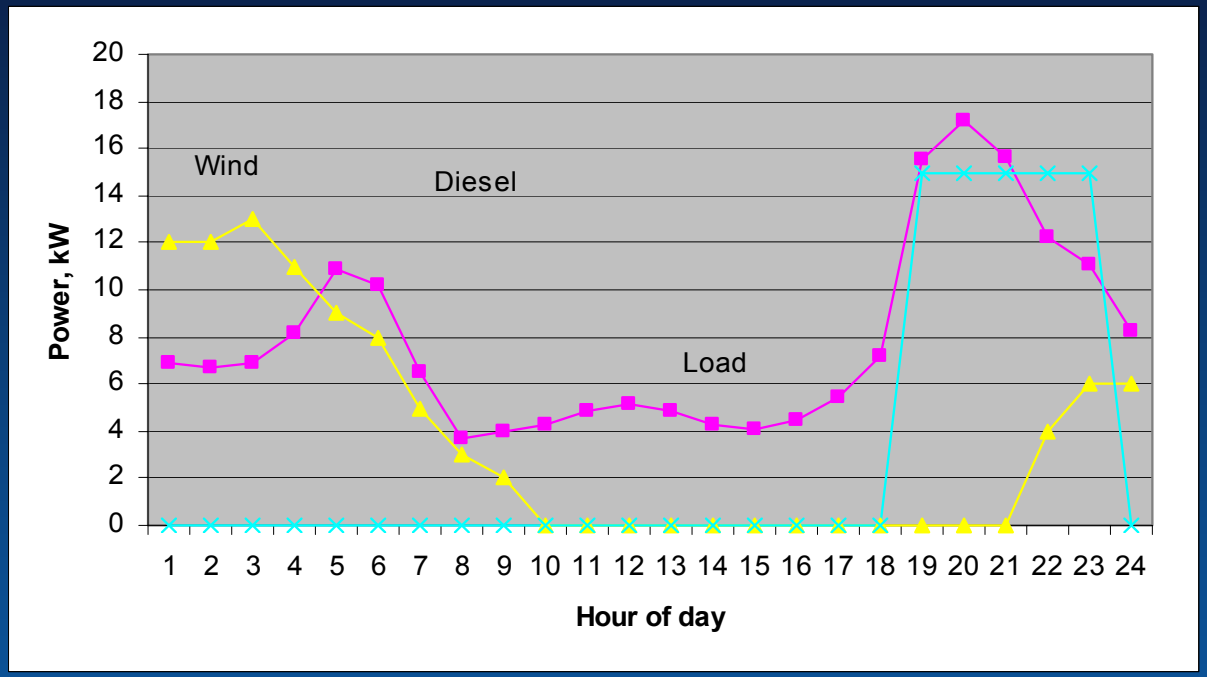
Micro-grid System Architecture (AC)

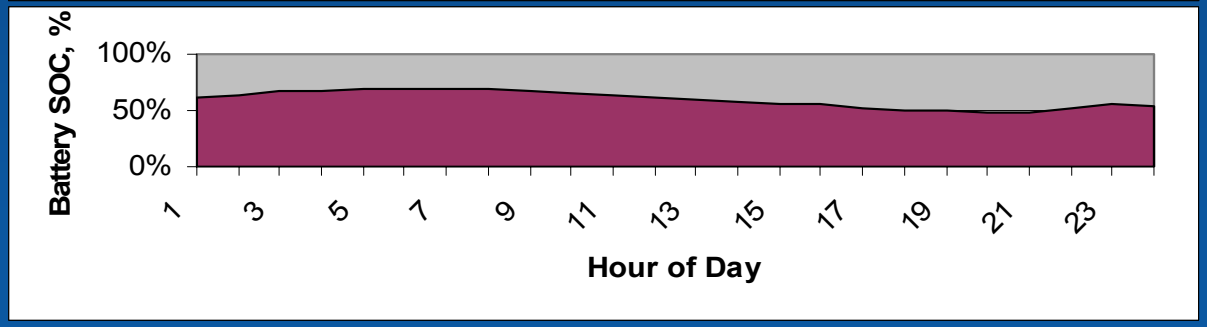


Micro-Grid Power Systems

- Supply communities with demands from ~100kWh/day load (15 kW peak load) up to ~700 kWh/day (75 kW Peak load)
- Components of wind, PV, biomass, batteries and conventional generators
- Generally provide AC
- Use of batteries to store renewable energy for use at night or low renewable times
- Generator used as backup power supply
- Mature market

Parallel System





Both diesel and inverter needed to cover the maximum load.

Both units run together.

Woodstock, Minnesota

- Wind farm maintenance shop and office
- Electric loads include lighting, PC, and shop tools
- Passive solar day-lighting, corn used for space heat
- Installed cost $6,800 in 2001 (grid extension alternative: $7,500)
- 1200 ft^2 shop, 900 ft^2 office
- Whisper H40 wind turbine, 900 W, 35-ft tower
- PV panels, 500 W
- 24 VDC battery, 750 Ah
- 4-kW inverter, 120 VAC single phase

Santa Cruz Island, California, USA

- Remote Telecommunications station
- Power System
  - PV array
  - Two wind turbines
  - No Backup generator
- Vary costly access/site visits
- Remote operation and monitoring of system

Northern Power Systems

Mt. Newall, Antarctica

- Science Foundation Station project
- Repeater and Seismic monitoring station
- Power System
  - **3.3 kW PV array**
  - **Diesel generator**
  - **HR3 wind turbine**

Northern Power Systems

Isla Tac, Chile

- Island community with Health post, school and 82 homes
- Power System:
  - 2x7 kW wind turbine s
  - Flooded batteries
  - 2 x 4.5 kW inverter
  - 16 kWA backup gas generator

Subax, Xinjiang, China

- Small community of 60 homes in very remote part of Western China
- Power System
  - 2 BWC excel (8kW) turbines
  - 2 15 kVA Inverters
  - 4 kW PV
  - Low Maintenance battery bank
  - 30kVA diesel generator

Dangling Rope Marina, Utah, USA

- Remote National Park Center
- 160 kW PV / Propane generator hybrid system

San Juanico, Mexico

Remote fishing community of 400 people with tourism

Power System

- 17 kW PV
- 70 kW wind
- 80 kW diesel generator
- 100 kW power converter/controller

Advanced monitoring system

Wind-Diesel Power Systems

- Larger systems with demands over ~ 100 kW peak load us to many MW
- Based on an AC bus configurations
- Batteries, if used, store power to cover short lulls in wind power
- Both small and large renewable penetration designs available
- Large potential mature with fewer examples
- Due to cost - PV generally not used

Penetration

There are many different potential configurations for Wind – Diesel power systems, one of the critical design factors is how much energy is coming from the wind – called wind penetration

Instantaneous Penetration:

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

- Voltage and frequency control
- Reactive power

Average Penetration: (generally a month or a year)

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

- 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. Additional components and limited automated control is required to insure that power quality is maintained. Little operational control required though may be used.
- **High penetration systems -** Completely integrated power system with advanced control. Limited operational control of system by plant staff

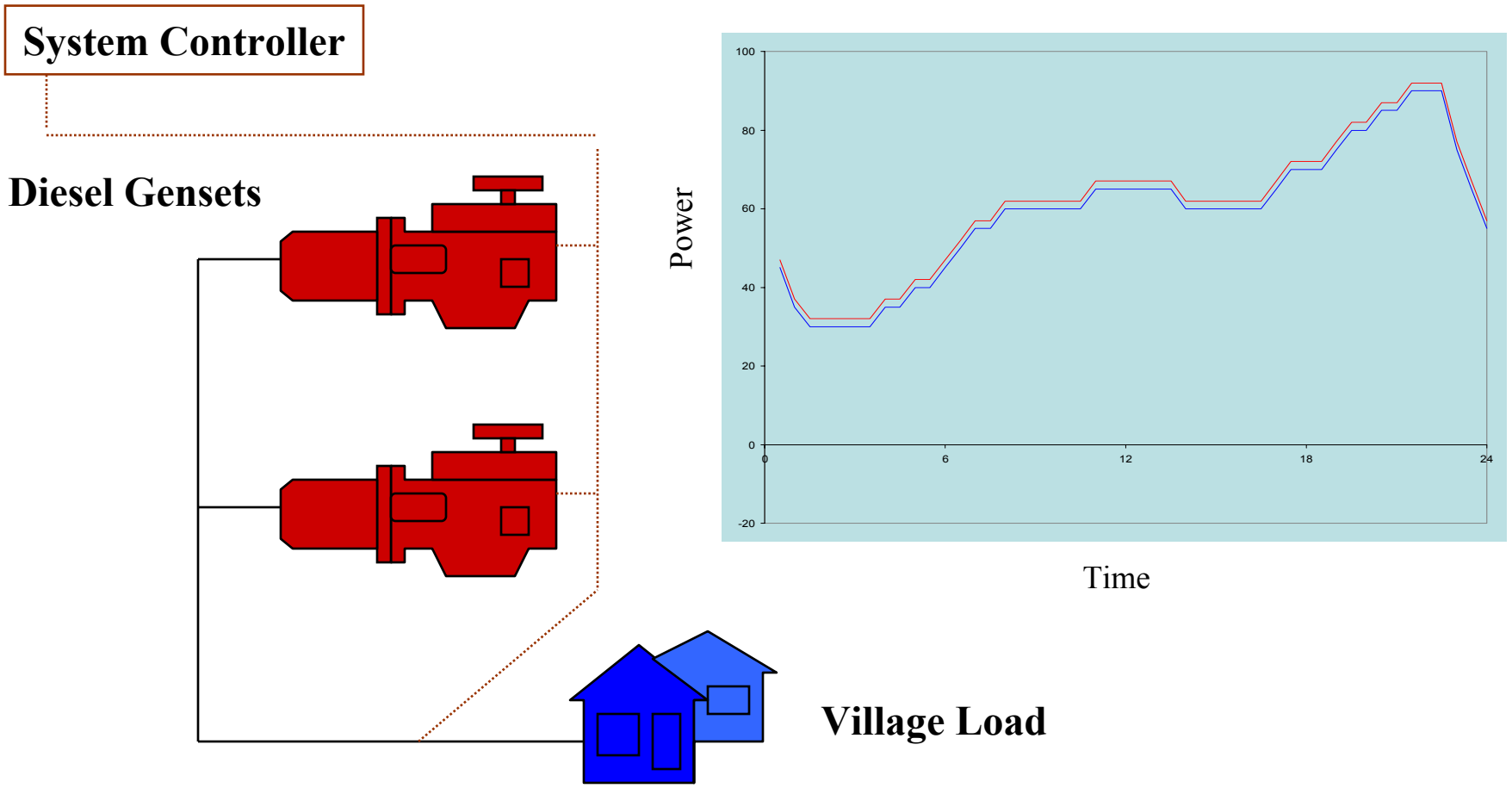
System Penetration

	Low	Medium	High
Peak Instantaneous	<50%	50 – 100%	100 – 400%
Annual Average	<20	20 – 50%	50 – 150 %
Commercial status	Fully utilized	Well proven Fully commercial Multiple use	System prototype Operating
Examples	Denmark, Greece	San Clemente, CA Kotzebue, Ak Coyaique, Chile	St. Paul Wales Ak

These are really three different systems which all should be considered differently

Note: People play loose with the definitions

Diesel Only Power System

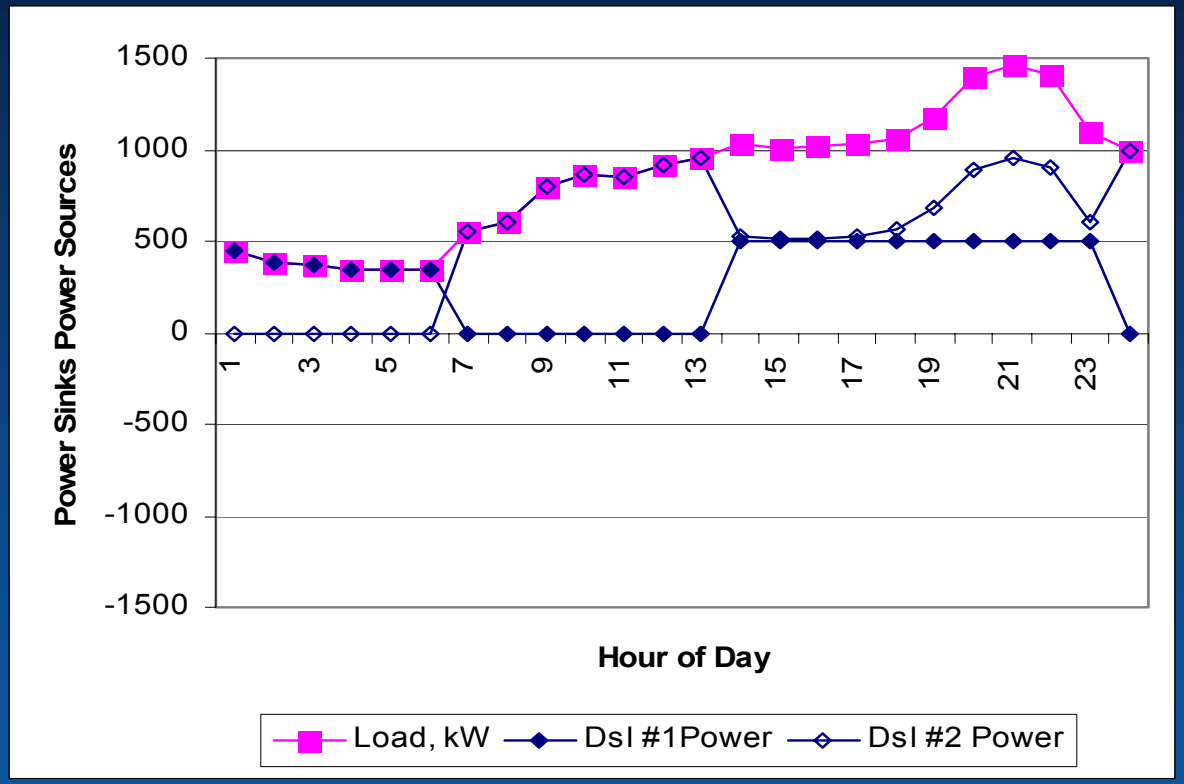


Multiple Diesel Plants with Control

In multiple diesel systems the diesels may be dispatched to take advantage of size and load.

Generally requires automatic diesel control.

Favorable in power systems with renewables

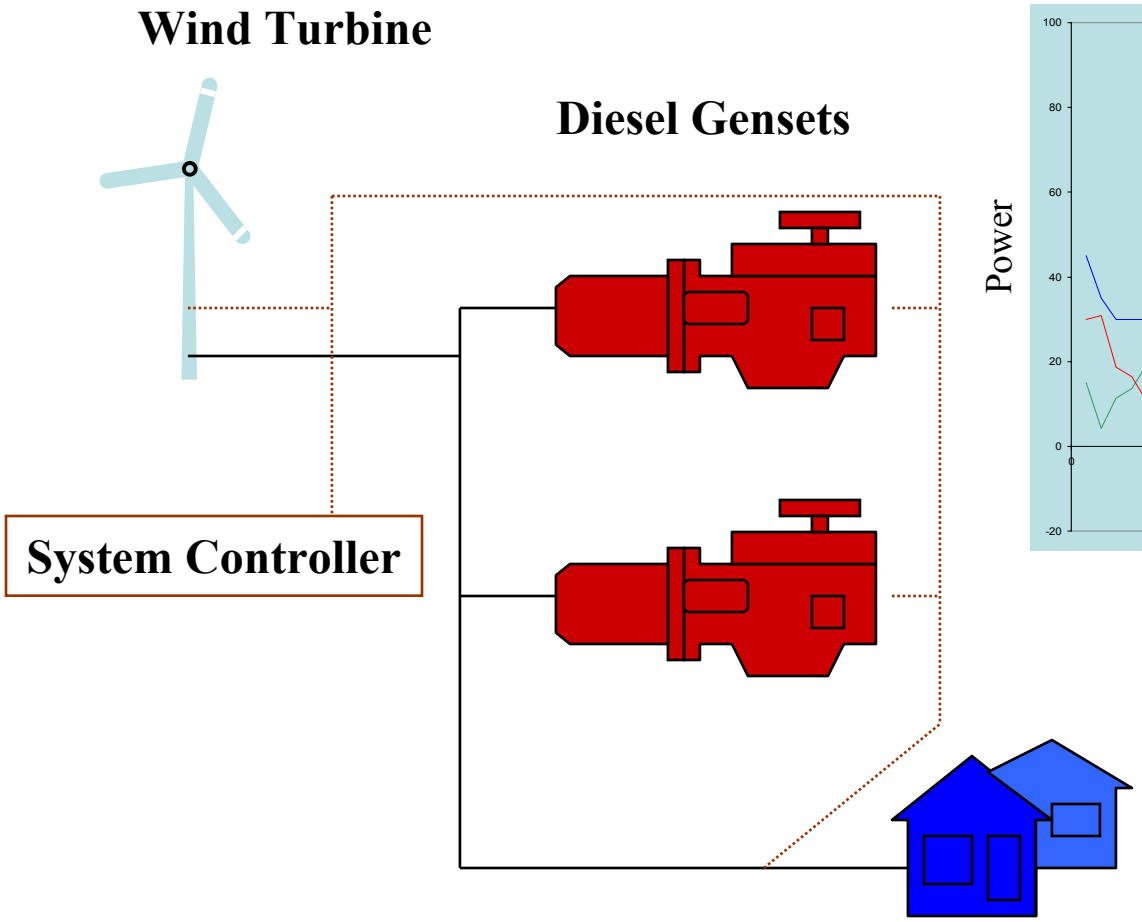


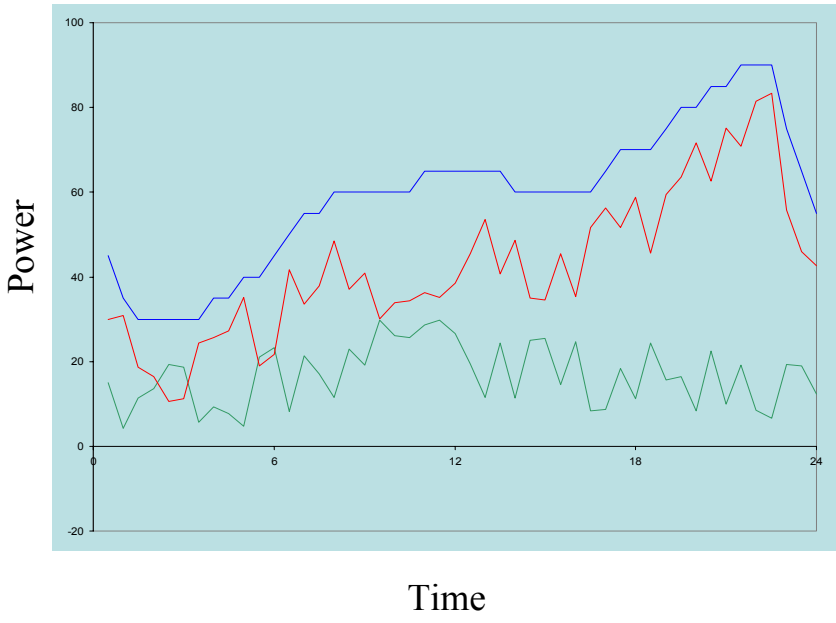
Potential use of a 500 and 1000 kW diesels

Low Penetration

- Capital cost of between $1,000-1,500/ per kW of wind capacity, excluding diesel units and plant BOS
- Easy integration with existing diesel system, little or no diesel modifications required
- Modest fuel savings of up to ~20% possible.
- System support requirements:
  - Wind turbine maintenance.

Low Penetration wind/diesel system





Kotzebue, Alaska

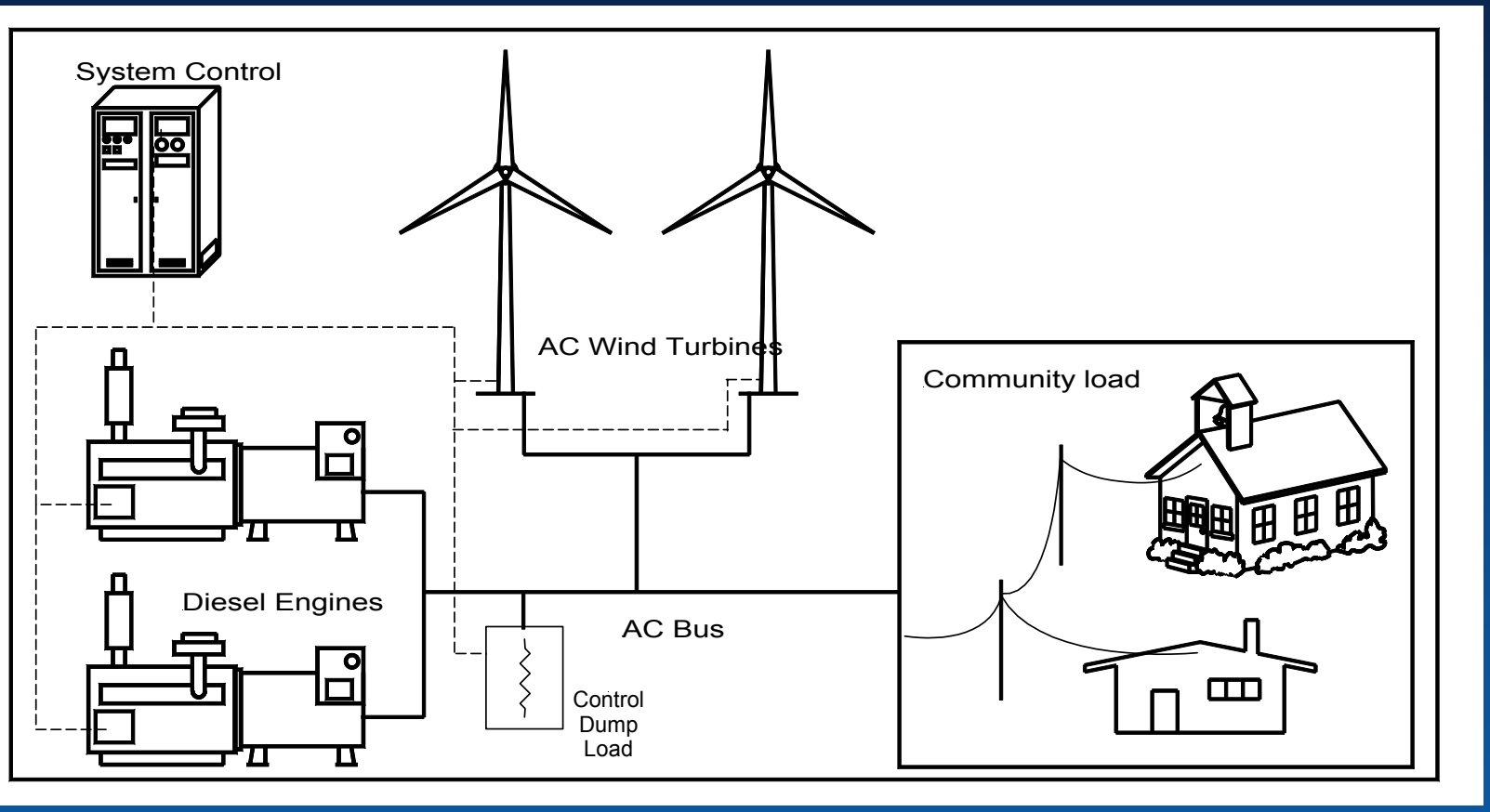
- 11 MW remote diesel power station in Northern Alaska
- 2 MW peak load with 700kW minimum load
- Installation of 10 AOC 15/50, 50 kW wind turbines and 1 NW 100, 100kW wind turbine
- KEA, Island Technologies, AOC

Coyaique Power System

- 3x 660 kW wind turbines
- 4.6 MW of mixed hydro
- 16.9 MW of diesel

- Manually operated through local control center

Medium Penetration W/D Schematic



Medium Penetration

- Capital cost of between $1,500-2,500 per kW of wind capacity, excluding diesel units and plant BOS.
- Some diesel controls modifications necessary
- Automated diesel operation desirable
- Usually must install/integrate secondary loads to regulate minimum diesel loading.
- Requires relatively simple supervisory control
- Rudimentary control of wind turbine output recommend
- Greater fuel savings possible, up to ~40%
- Additional support requirements:
  - Wind turbine maintenance
  - Secondary load maintenance
  - Ongoing assessment to insure system maintains adequate control of system power quality.

San Clemente Island, California

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

Plant Details

- Four generators
- 3 NEG-Micon 225 kW turbines

Yearly impact -

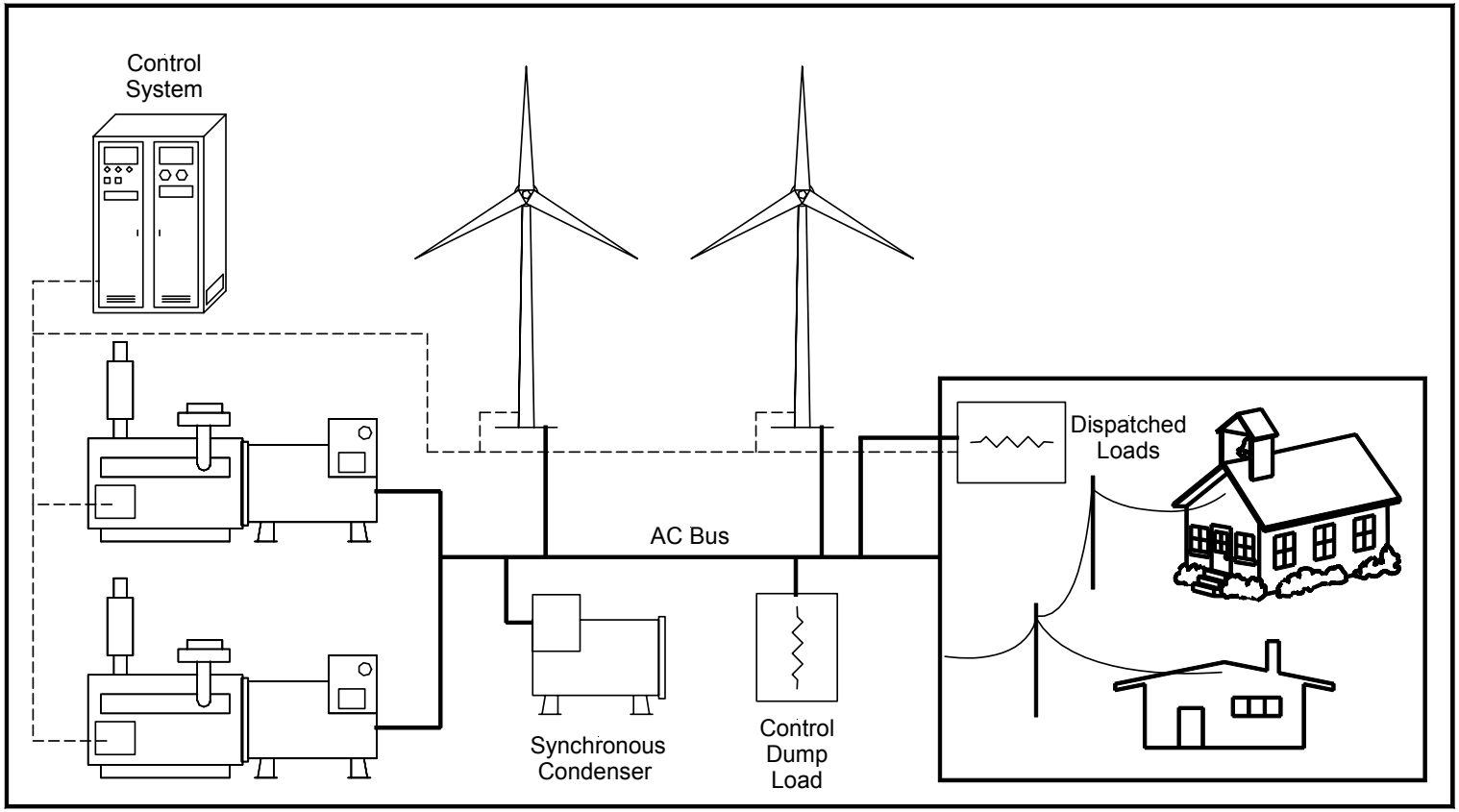
- $97,000 fuel savings
- 871,785 Ton CO2 avoided

Selawik, Alaska

- Small Alaska Village Electric Cooperation community in northern Alaska
- Installation of 4 e15, 50 kW wind turbines and dump loads
- Part of a diesel plant retrofit project

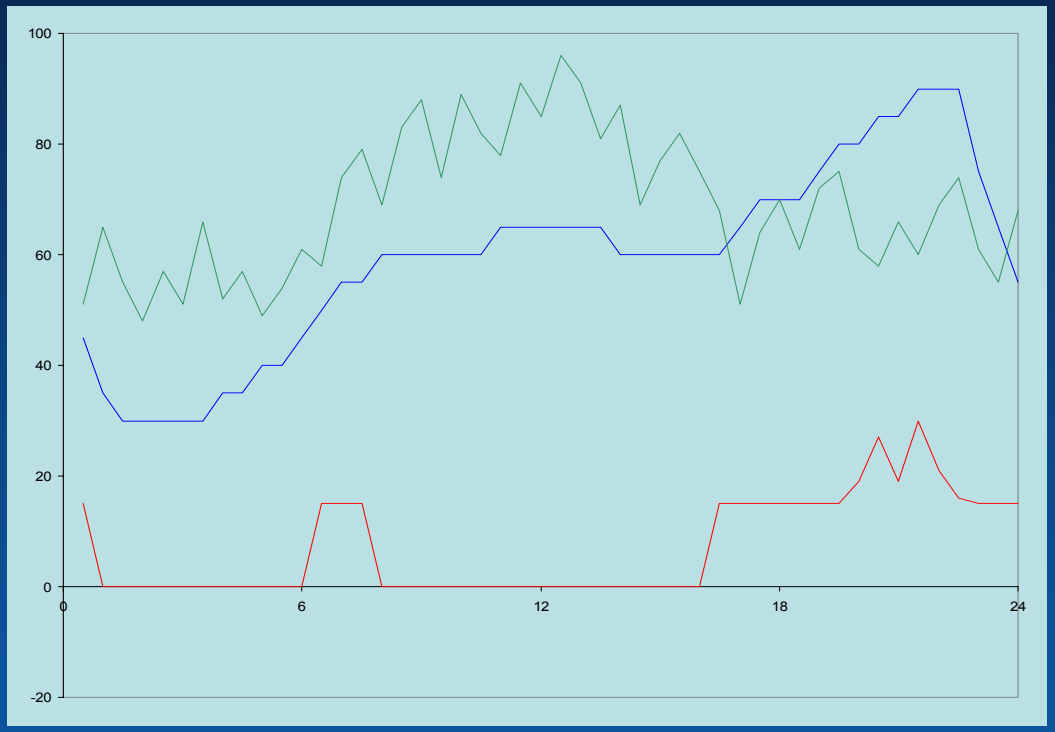
AVEC, Entegrity, Sustainable Automation

High Penetration w/out storage



Wind Diesel without Storage

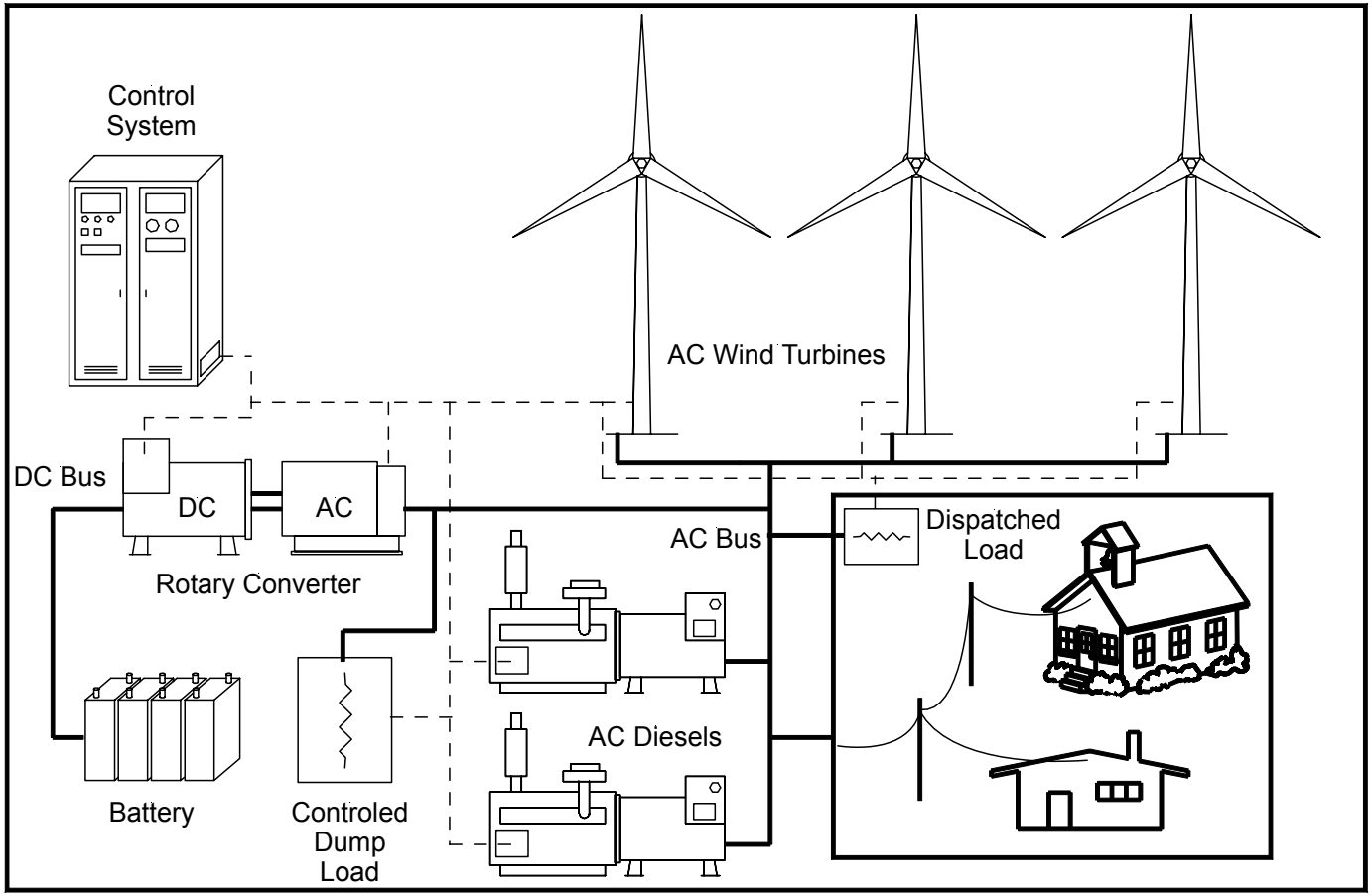
When the wind power is larger than the load by some margin - Diesel is shut off.



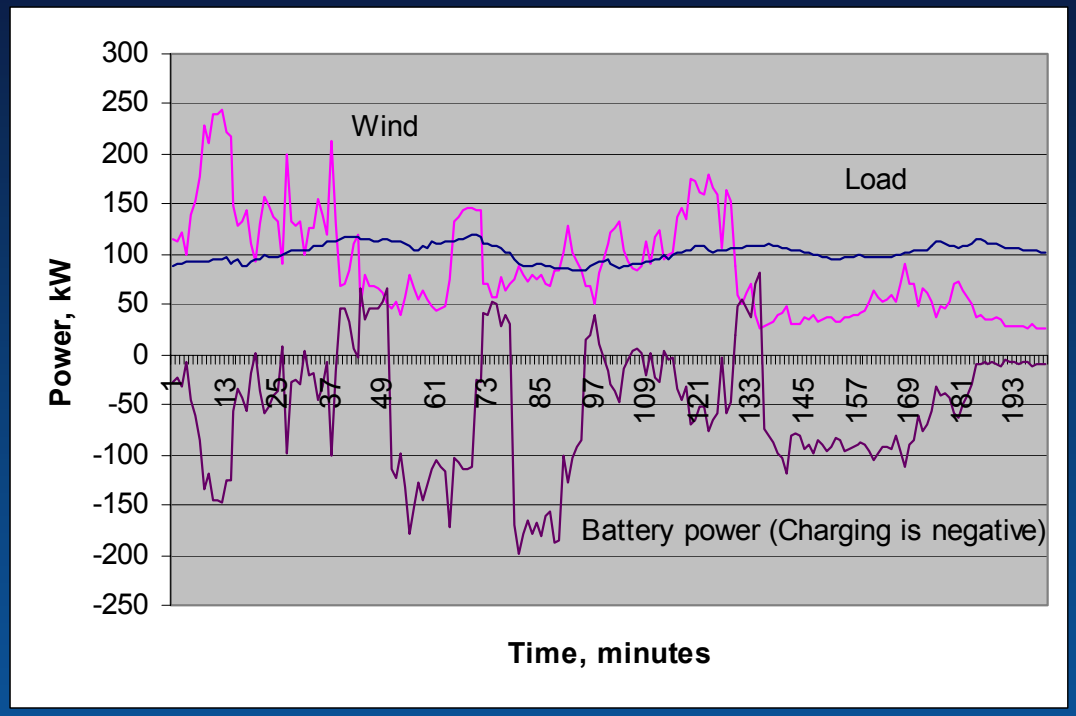
- Frequency controlled by dump load
- Voltage controlled by condenser

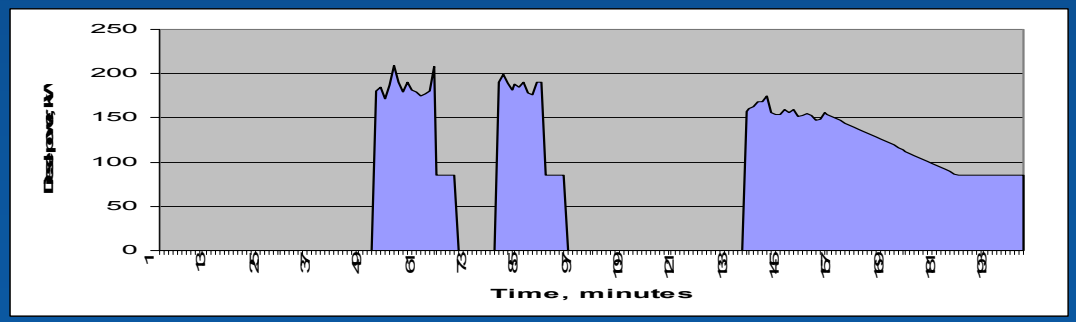
Red = Diesel
Blue = Load
Green = Windpower

High Penetration W/D Schematic



Wind/Diesel with Short Term Storage





- Diesel used to provide power to system when the wind can not cover load.
- Battery used to fill short gaps in or to start diesel

High Penetration W/D Principles

- Use of wind allows all diesel engines to shut down, reducing fuel consumption and operation hours
- System controller continually monitors power system and dispatched equipment as needed to maintain system integrity
- Very technology dependent system architecture, requires a high degree of technical sophistication
- Some level of automated operation is required
- Should include a fail safe operation strategy so that system can run on diesel's alone if specific components are not operational

St. Paul Alaska, USA

Island in the middle of the Bering Sea
Peak load of 160kW
Cost of Power, ± $0.21/kWh
Waste energy used for heating
TDX and Northern Power Systems

Wales, Alaska

High penetration system

- Remote community in Northern Alaska
- 80kW average load with 130kW of wind power
- Short term battery storage
- Resistive loads used for heating and hot water
- Problems with maintenance and operation
- AVAC, KEA and NREL

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.
- Must understand the components

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

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

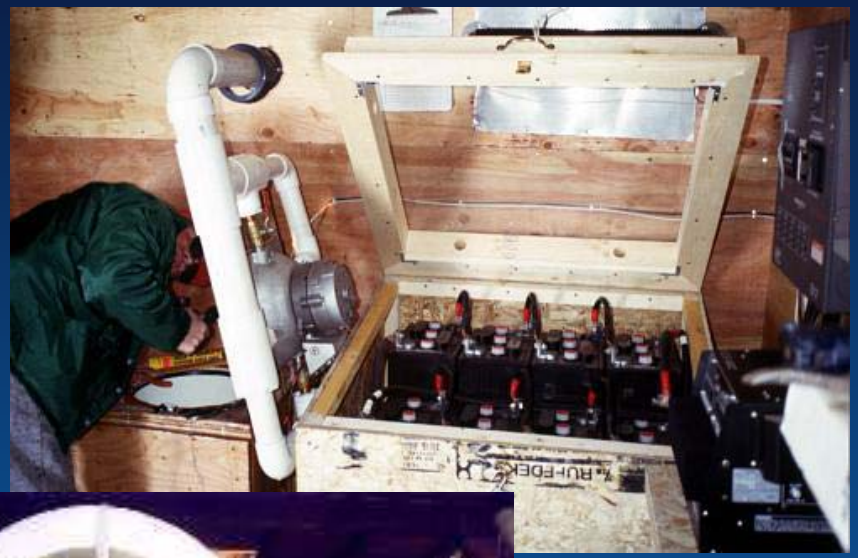
Photovoltaics

- Applicable for small, remote applications
- Installation cost of ~$10/W, LCC of $0.22/kWh
- Low maintenance requirements
- Quite accepted internationally
- Not used commonly in large applications but there are some examples

PV on Active Tracker

Micro and Run of River Hydro

- Applicable for areas with a dependable resource.
- Lower head systems available
- Run of river up to 50kW pre-commercial
- Generally larger infrastructure cost



Micro Hydro facility at remote ranch

UEK 50kW flow turbine

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

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

Flywheel

Low Load Diesel

- 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

- 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

75 kW Synchronous Condenser

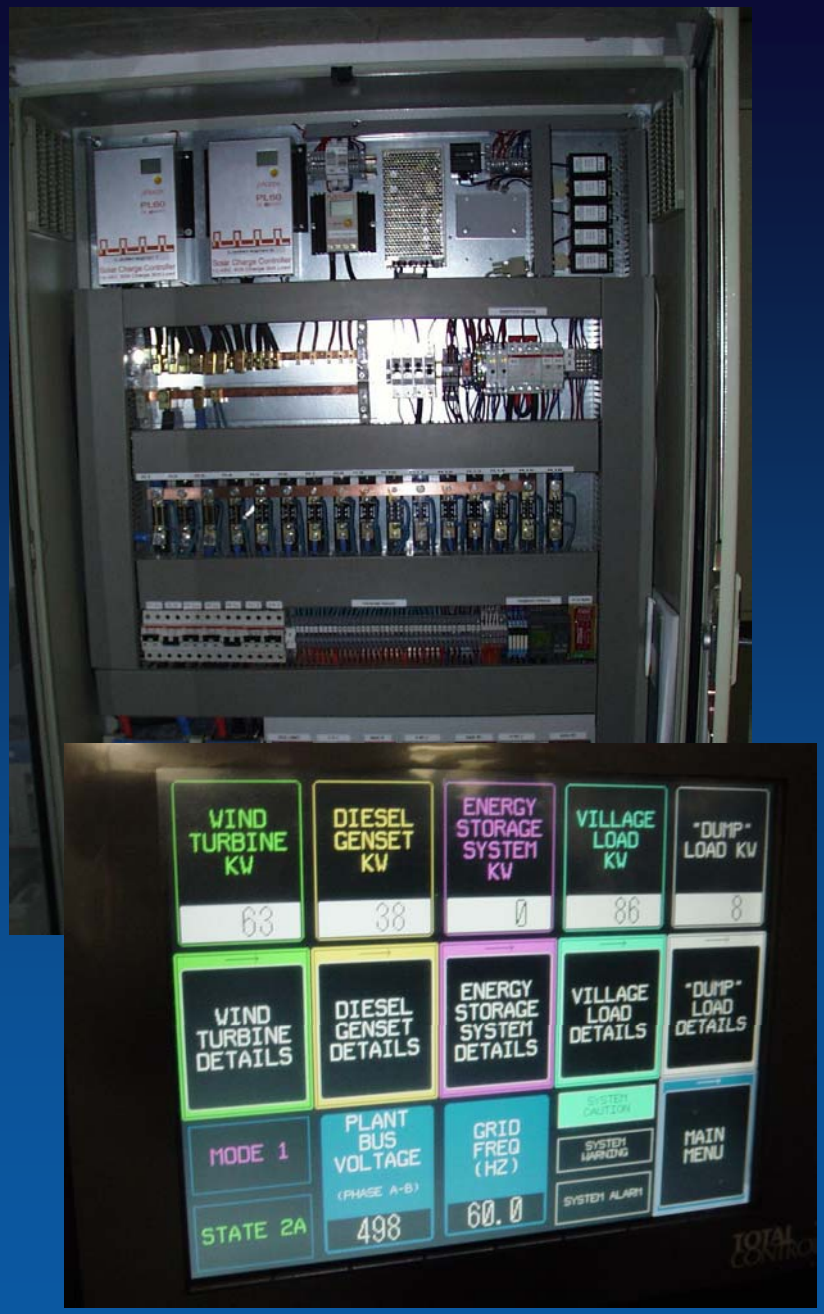
Dump Loads and Community Heating

- Remove excess energy from the grid
- Help to control frequency
- Made of resistive heating elements and some control
- Two uses
  - Dispatched to provide heating (excess wind)
  - Used as one aspect of the grid stability control (fast acting)

100 kW dump load

System Controls

- The things that make everything work together.
- Individual components and central control
- High speed (behind the scene) and general control
- Can Reduce staffing costs and increase service



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

Conclusions

- Renewable based rural power systems can help supply energy to rural needs in a clean, inexpensive way that does not burden the national economy
- There are many different options for providing power, detailed assessment is required to understand which is applicable for you
- Configuration depends on many factors
- Social issues dominate over technical issues

Renewable power systems have
a place in rural development