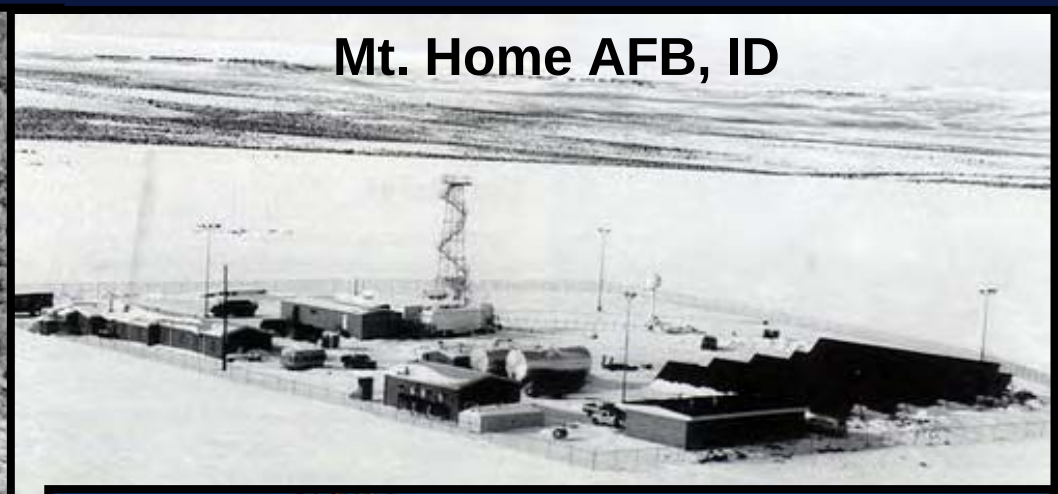
NAEMI Renewable Energy Analysis & Economics Training Workshop

Roger Taylor
TEP Manager
National Renewable Energy Laboratory

Hybrids

Hybrid Power Systems are Not New



Hybrid Power Systems

- Hybrid power systems use local renewable resources to provide power.
- Community hybrid power systems can range in size from small household systems (100 Wh/day) to systems supplying a whole area (10's MWh/day).
- They combine many technologies to provide reliable power that is tailored to the local resources and community.
- Potential components include: PV, wind, micro-hydro, biomass, batteries, conventional generators, and direct load control.

Agricultural Water Pumping

- Livestock watering at the Bledsoe Ranch Colorado, USA

- PV, Mechanical wind and diesel backup solves problems with seasonal variations in resource

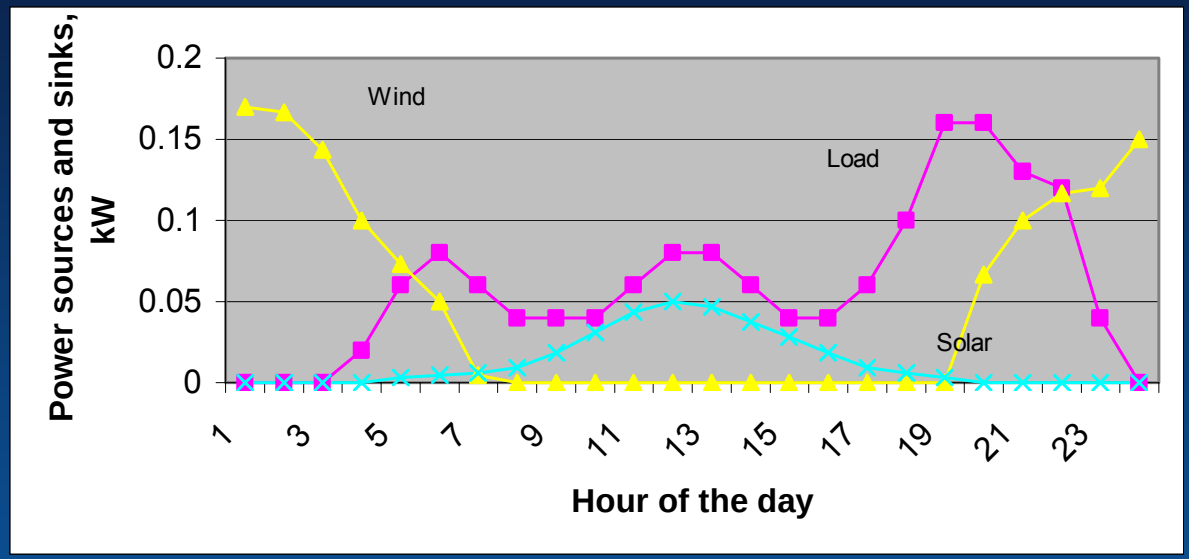
NEOS Corporation

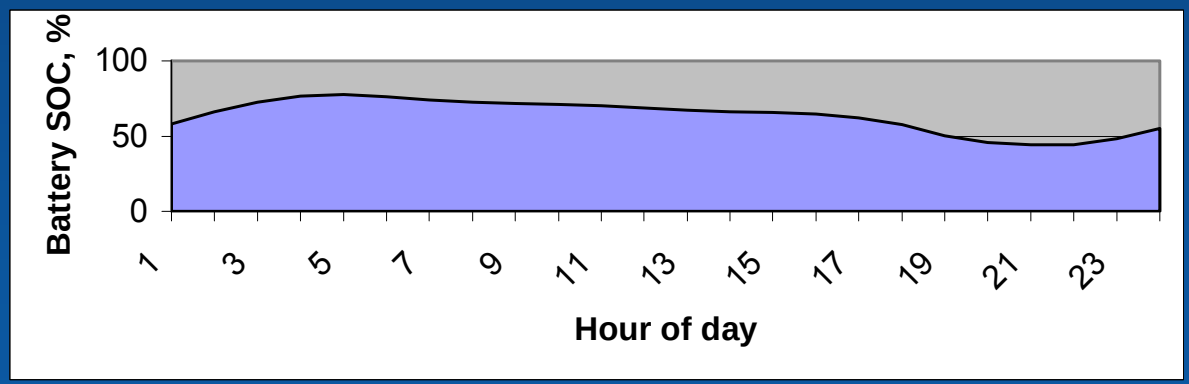
Home Power Systems

- **Systems do not have an automated backup generator like most larger 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**

Inner Mongolia, Wind/PV Home Systems

Energy Flow for All-Renewable Hybrid





Single Home Systems/mini-grids

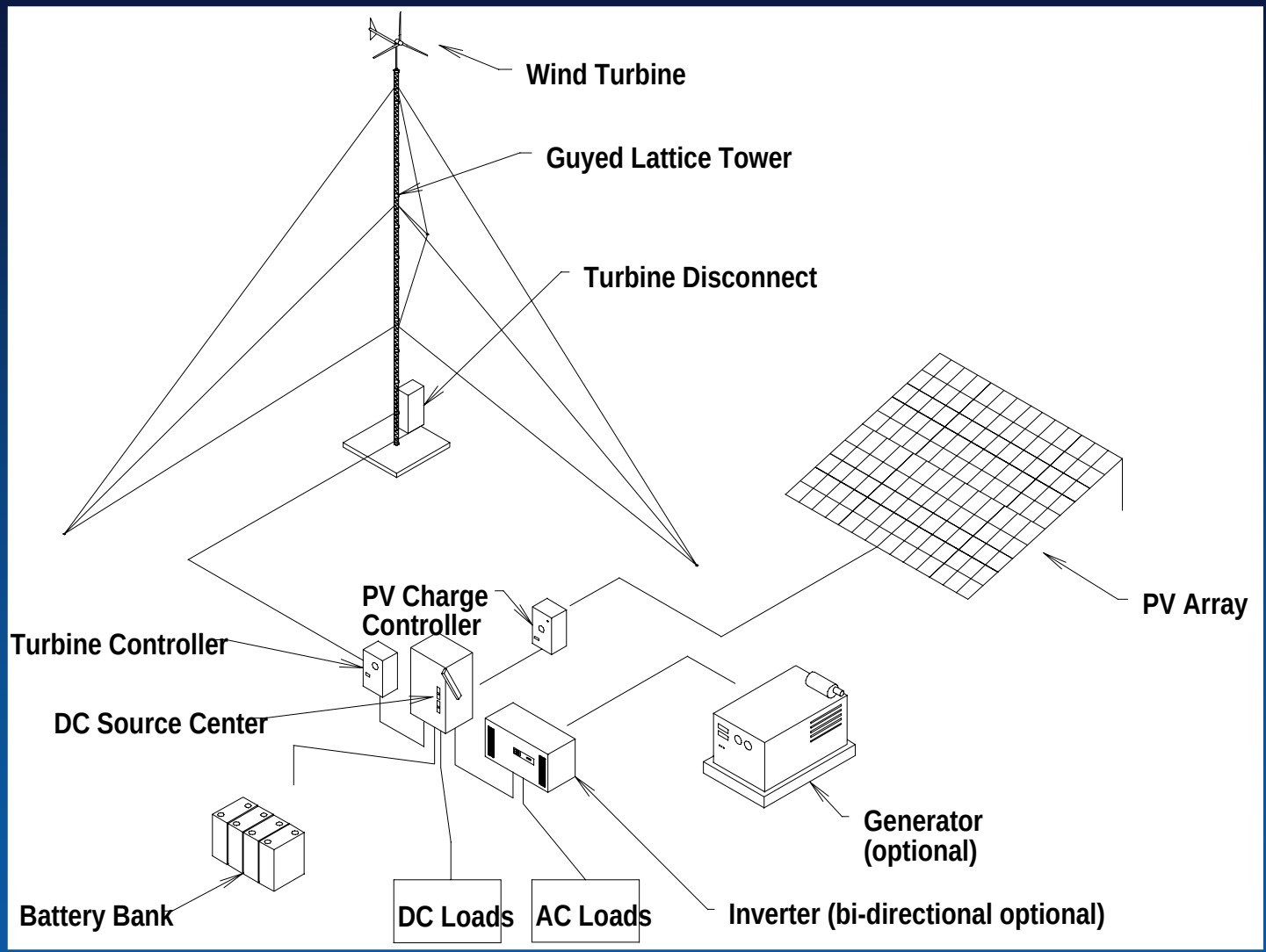
- Chipepte, Mexico
  - Windseeker 503
  - 1000Ah, 12V, “No maintenance” Battery Bank
  - < 100W DC Loads
- Pez Maya, Mexico
  - 2 AIR Marine 403 turbines
  - 1000Ah, 12V, “No maintenance” Battery Bank
  - 1100W inverter
  - power to a small mini-grid for homes and cottages

Pez Maya

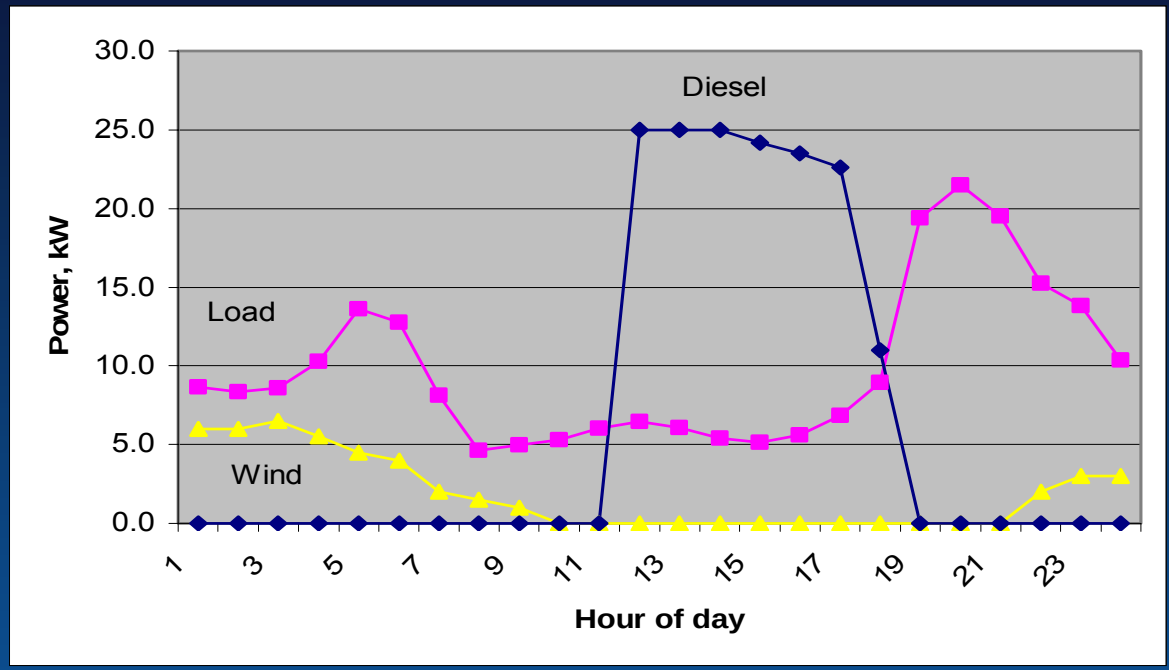
Community-Scale Power Systems

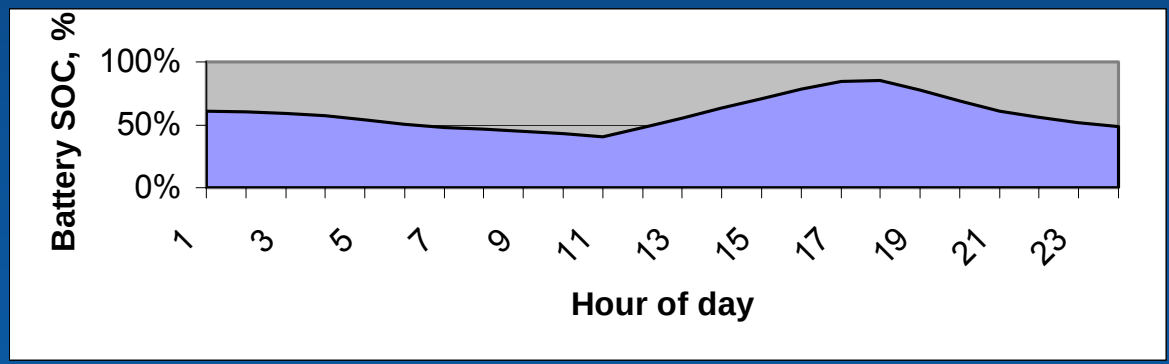
Centrally located and used by the whole community or area through connection to a common distribution system

Typical System Architecture



Energy Flow for Small Wind-Diesel Hybrid





Sunwize Power System

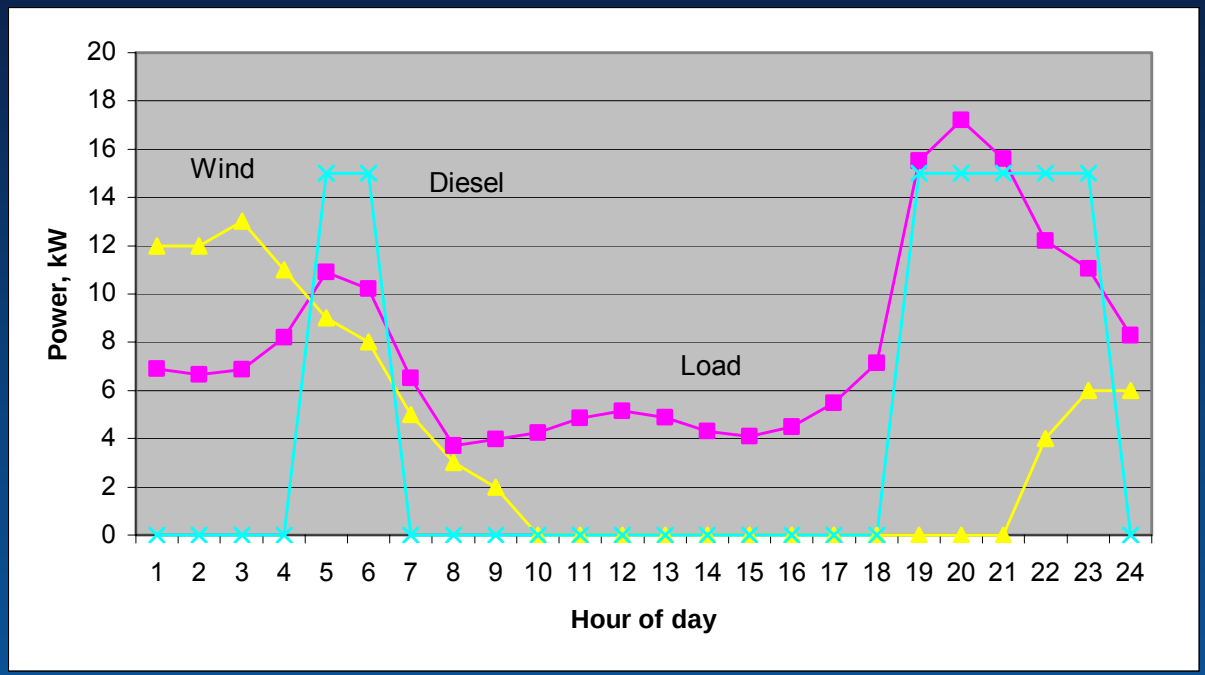
- Whisper 3000 wind turbine
- 1.8 kW PV (Siemens)
- 5.8 kW diesel generator
- 25.6 kWh battery bank
- 2-SW4048 4kW inverters

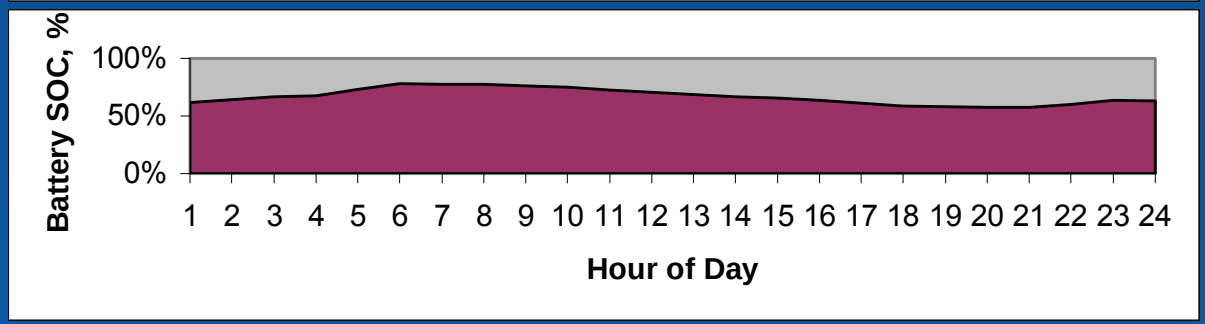
Santa Cruz Island, California, USA

- 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

Parallel System - Smaller Diesel

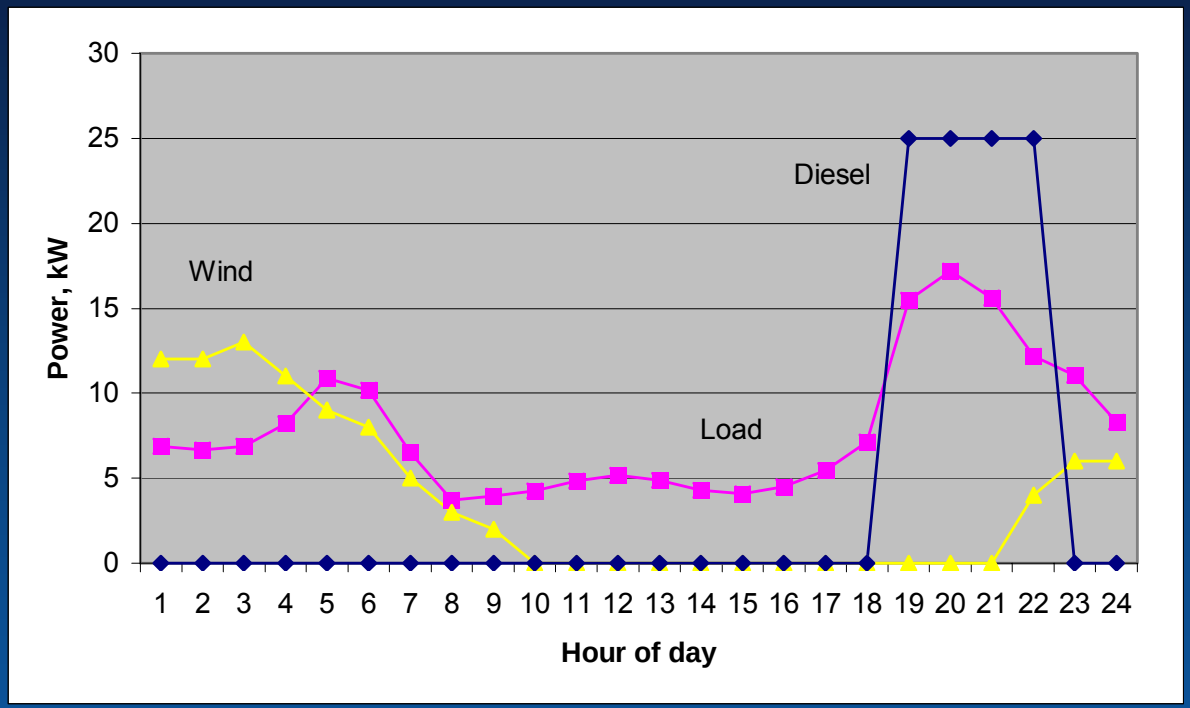


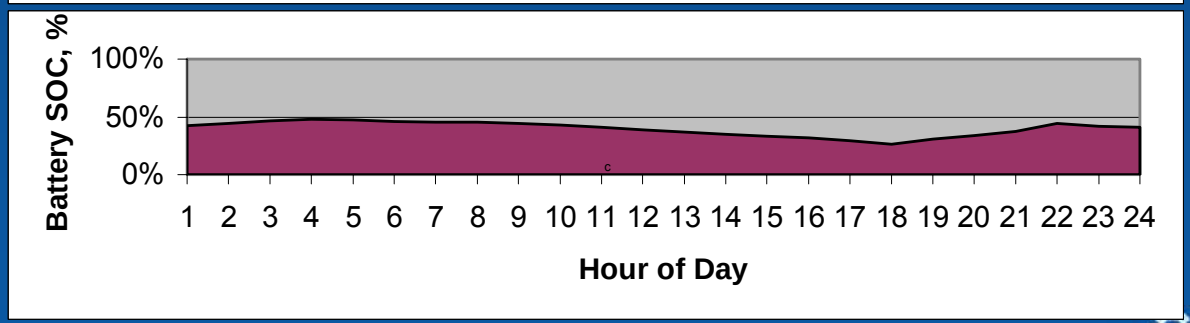


Both diesel and inverter needed to cover the maximum load.

Both units run together.

Switched System - Larger Diesel





Both diesel and inverter sized to cover the complete load. Only one runs at a time.

National Parks

Dangling Rope Marina, Lake Powell, UT (160 kW PV/Propane)

Remote Village of Xcalac, Mexico

Now Running on Diesel Only

60 kW Wind, 12 kW PV, 40 kW Inverter

Remote Village of Joanes, Brazil

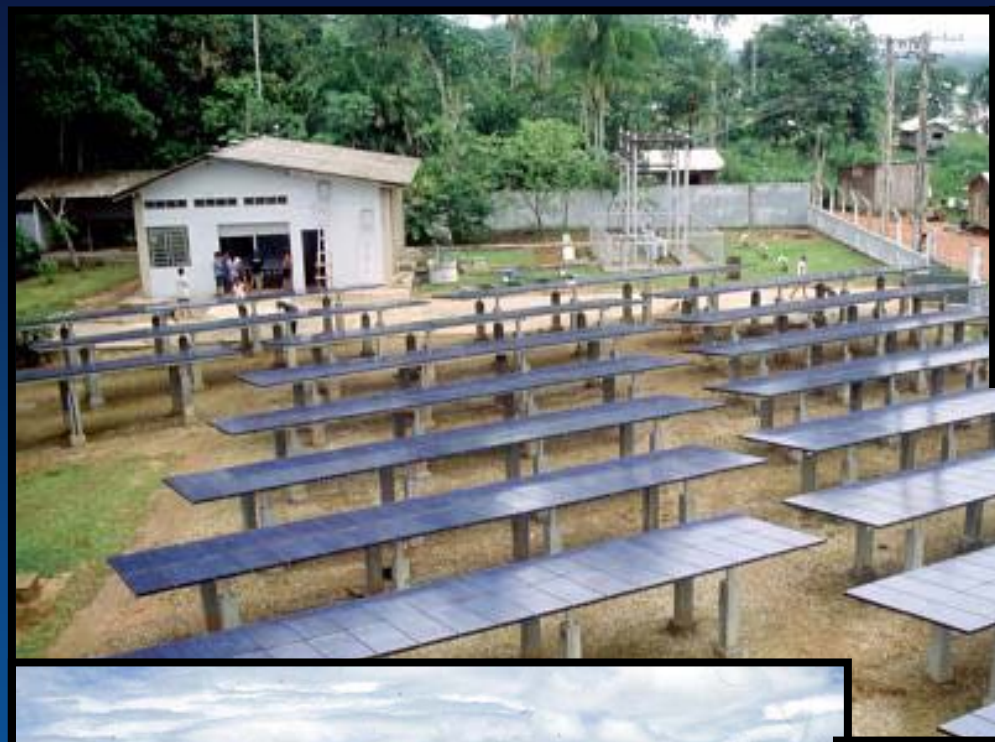
Remote village the Island of Marajo

50kW Power System
- PV array
- Four wind turbines
- Backup generator

Northern Power Systems

Power system used to support local grid

Remote Village of Campinas, Brazil



50 kW PV
50 kVA Inverter
300 kWh Batteries

Remote Village of San Juanico, Mexico

Remote fishing & tourism community of 400 people

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 loads up 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
- Provide conventional AC power

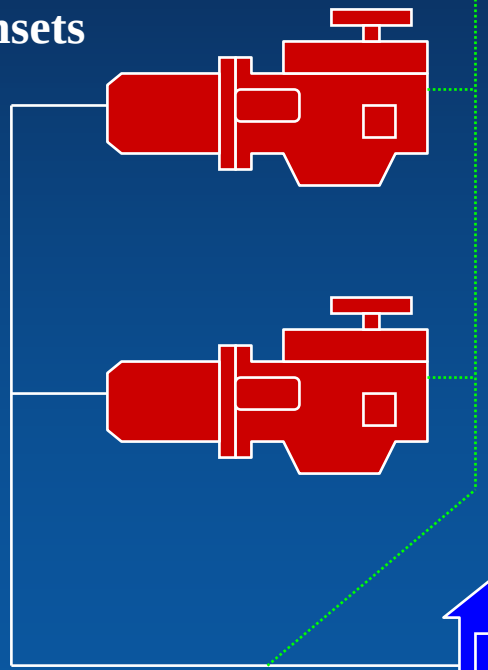
Wind-Diesel System Penetration Ranges

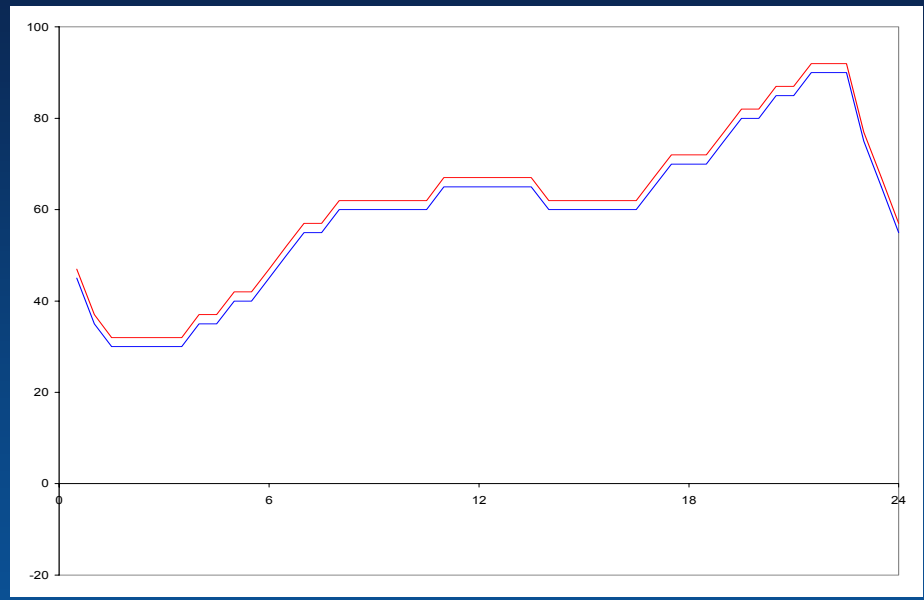
	Low	Medium	High
Peak Instantaneous	<50%	50 – 100%	100 – 400%
Annual Average	<20	20 – 50%	50 – 150 %
Commercial status	Fully utilized	Well proven Fully commercial Multiple use	System prototypes Operating
Examples	Denmark, Greece	San Clemente, CA Kotzebue, Ak Coyaique, Chile	St. Paul Wales Ak

Diesel Only Power System

System Controller

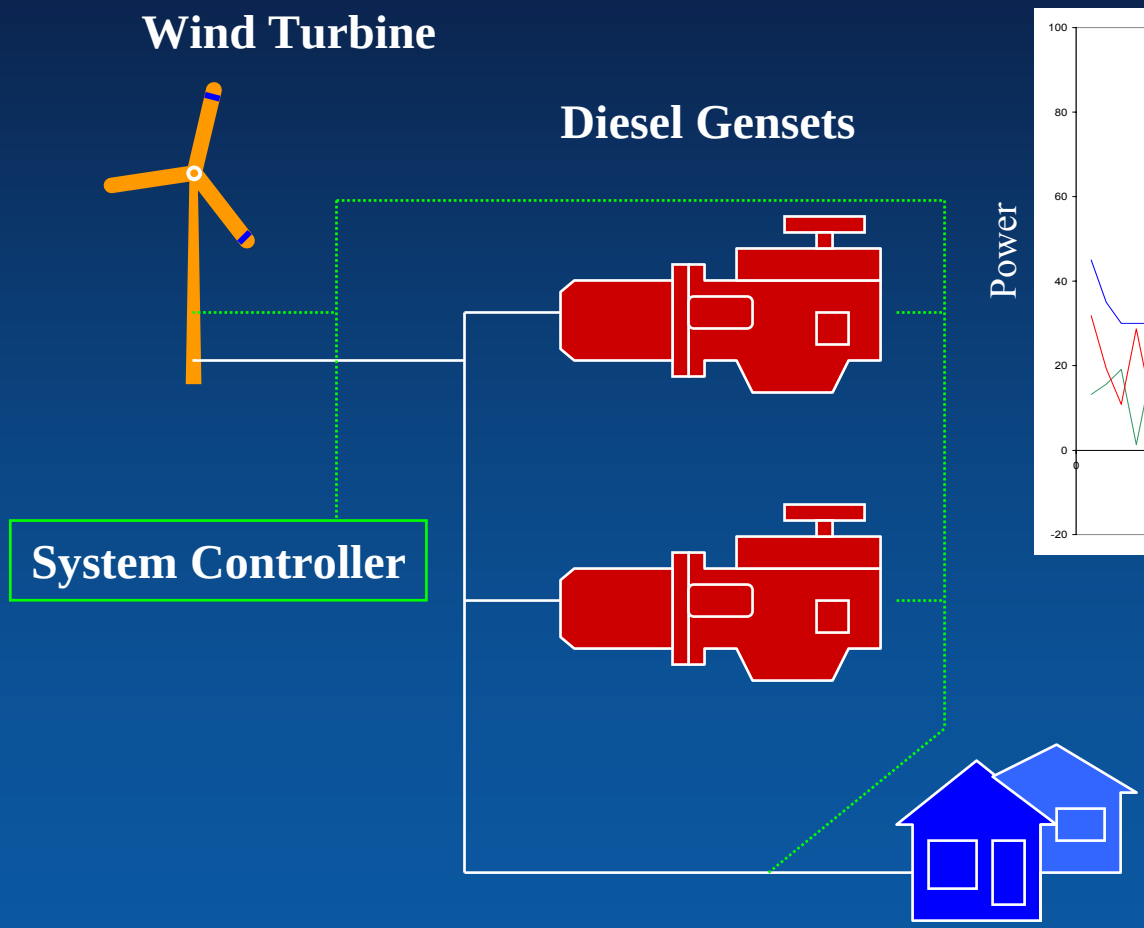
Diesel Gensets

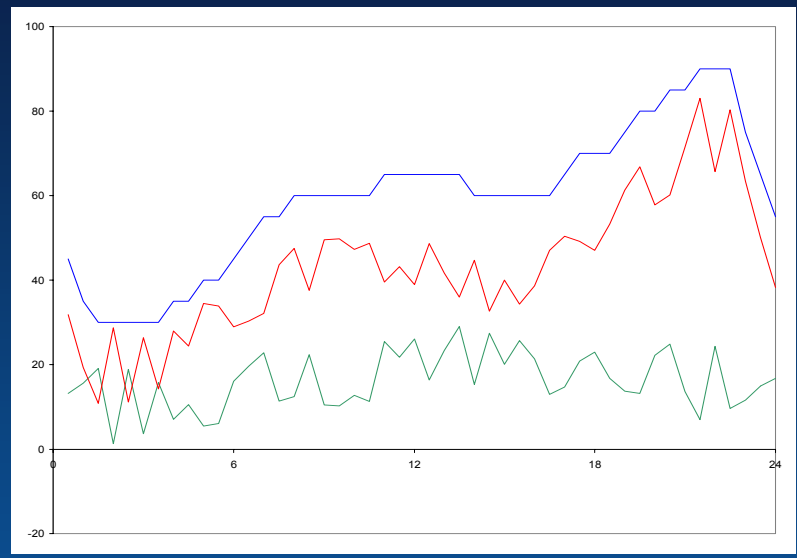




Village Load

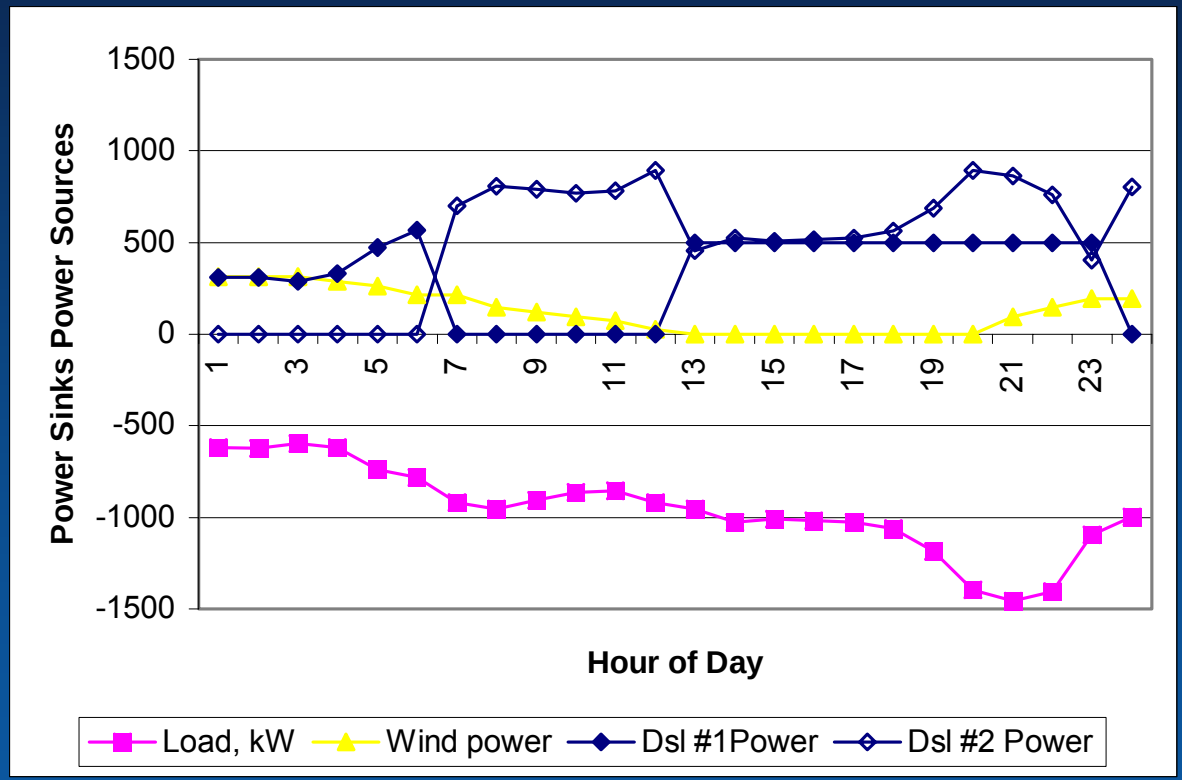
Low Penetration Wind/Diesel System





Multiple Diesel Plants with Control

In multiple diesel systems the diesels may be dispatched to take advantage of the renewable energy. Requires automatic diesel control.



Ascension Island

Four NEG-Micon 225 kW turbines installed in 1996.

- U.S. Air Force installation on British island in mid-Atlantic ocean.
- Prime diesel generation with rotary interconnect to British 50 hertz system

Coyaique, Chile

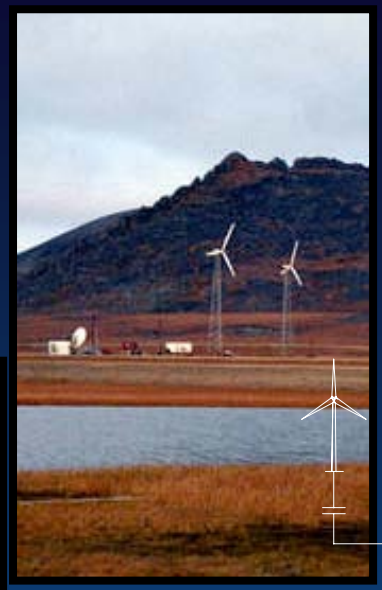
- Isolated Community
- Private Utility
  - 2 MW Wind, 4.6 MW Hydro, 16.9 MW Diesel
- Remote installation

EDELAYSEN S.A.

saesa
LA LUZ DEL SUR

High Penetration Wind Diesel System
Wales Alaska

High Penetration System
Wales Alaska



Wind Turbines
(Induction, Stall-Regulated)
2 X 65 KW = 130 KW

Diesel #1
142 kW

Diesel #2
75 kW

Diesel #3
148 kW

DC

AC

Battery Bank
240 VDC, 130 Ah
~30 kWh

Rotary Converter
156 kVA

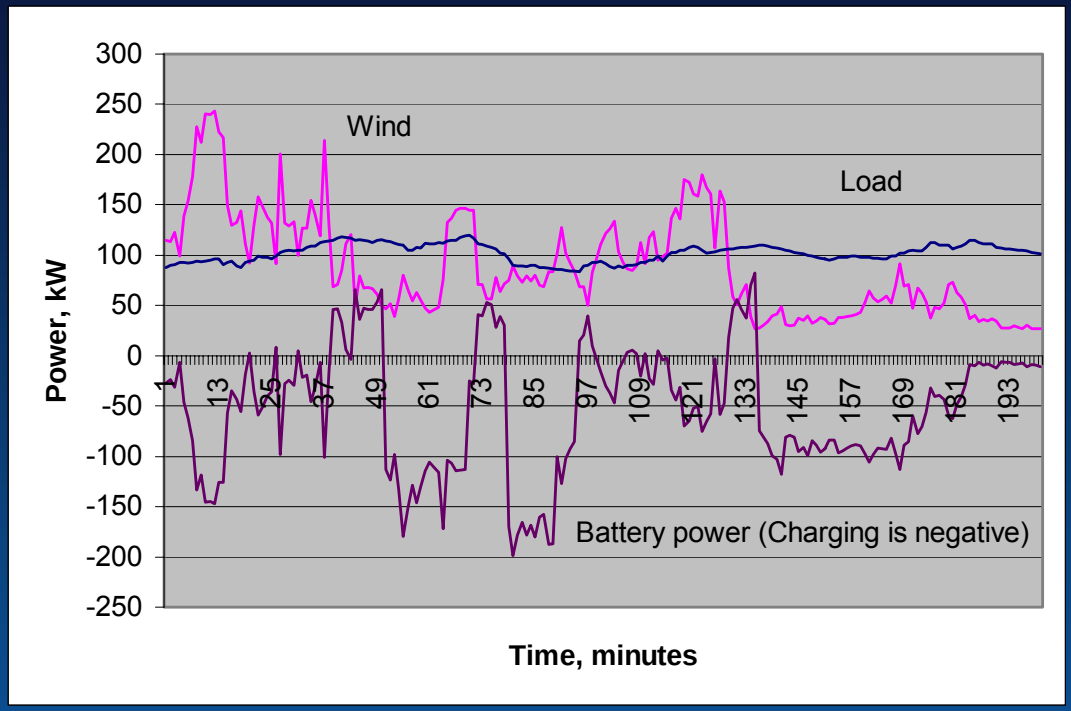
Secondary Load Controllers

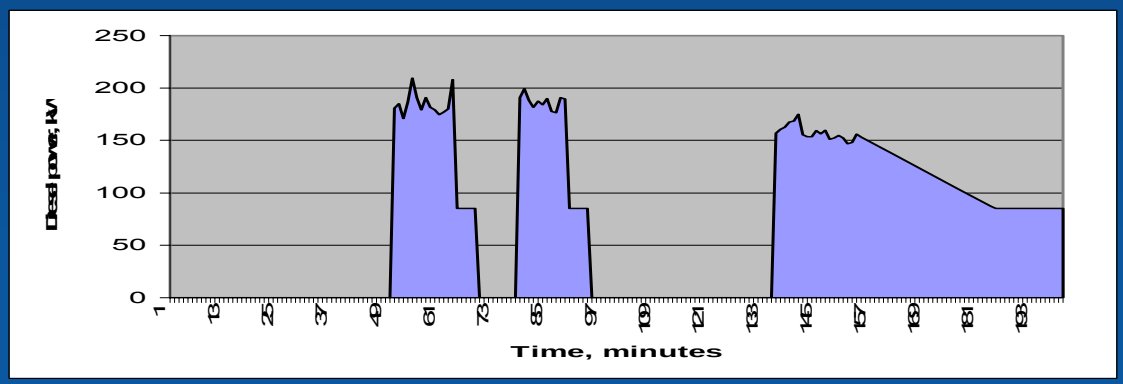
School Heating System

Resistance Heaters

Diesel Plant Hydronic Loop

Wind/Diesel with short term storage





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

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

St. Paul Power System

- 225 kW Wind Turbine
- 2 x 150 kW Diesel Gensets
- Digital Engine Controls
- NPS Components
  - System Controllers/ RemoteView™
  - Synchronous Condenser
  - Heating and Thermal Plant
  - Integrated Shelter
  - Dump Load Regulator

Key Points of Large Hybrid Systems

- Differences in Energy Storage
  - Long term energy storage: Larger battery bank to transfer energy from one time to another. Order of hours.
  - Short term energy storage: Energy used for very short periods to provide grid stability and allow controlled diesel engine starting. Order of minutes.
- Power Quality issues
- System Control
  - DSP based advanced control is required

Power Balancing Alternatives

- Control wind generation: mechanical pitch control, electronic control, individual machine switching in multiple machine windfarms.
- Dispatchable Loads: Installations of controllable incremental loads like resistance heating to consume extra power.
- Load shedding where non-critical loads are temporarily shut off to quickly reduce system load.

Conclusions

- Many options for the configuration of hybrid systems - Depend on load, resource, and costs.
- Medium penetration wind-diesel systems are operating in various isolated locations around the world. Instantaneous wind penetration levels exceeding 50% of load are common.
- Several high penetration systems, with and without energy storage, have been successfully demonstrated.
- High penetration systems are capable of prolonged diesel-off operation.

Village Power Hybrids
Simulation Models for Options Analysis