Integration of Wind / Diesel Power Systems

Ian Baring-Gould
Bethel, Alaska

Session Overview

- Describe different designs of wind-diesel power stations
- The key issues for hybrid power system integration
  - Mechanical (component integration)
  - Electrical (system stability)

Session Goals

Provide a deeper understanding of wind / diesel power systems and component integration.

Key Messages

The design and integration of power systems is a complex matter and although the models make it look simple, it is never that easy.

The Complication is with Uncontrolled Generation

By their nature renewable generation are stochastic (uncontrolled) and vary with the resource.

The amount of variation and thus the amount of system control to handle the variation depends on the

1. Renewable resource being used
2. The load
3. Power system design

Different Integration Issues

There are two general types of integration issues – mechanical and electrical

- Mechanical: The connecting of different devices within the power system and making them work together
- Electrical: Insuring that the power system power quality is sufficient to meet the needs of the customers

Mechanical Integration Issues

The first rule of thumb is:

If you are going to implement a medium to high penetration wind / diesel power system, expect to do it as part of a complete diesel plant upgrade.

It is not required, but there are many things that need to be considered in retrofitting an existing plant with wind (or other renewables)

Building Design and Space

Adding new equipment can take up a lot of space

- Switch gear
- Grid stability equipment
- Control boxes
- Spare parts

Building design may be problematic

- Heating
- Layout
- Living arrangements

Making Sure the Equipment Can Talk

- Supervisory Control
- Component Controls
  - Diesels
  - Wind turbines
  - System stability devices
- Controlled thermal loads
  - May be installed in other buildings
  - Switching speed
  - Outside control

Upgrading Diesel Controls

Diesels will need to operate in an automatic fashion, which may require the upgrading of the diesel controls, but allow for manual operation if needed

- Automatic startup and synchronization
- Load sharing
- Speed control

Retrofit of existing diesel units can be complicated

- Age of unit
- Governor design
- Fuel system
- Compatibility, such as generator pitch
- Space constraints within the power house and on the diesels themselves

Best if this does not have to be done on location (live diesels, parts etc)

Plant Synchronization

In many older (and smaller) plants only one diesel is run at a single time.

Allowing more than one diesel to operate can be quite a problem, even following the addition of new controls

- Governor design
- Generator compatibility – pitch
- Fuel system feed and return lines
- Cooling system configuration and pumping

Automated start and control capabilities will likely result in more diesel starts, most unattended, which may require the revamping of the diesel start system and starter battery.

Cooling System

Current diesel plants have many different types of cooling systems – some integrated, some not, but all provide primary heat to the power plant and sometimes other buildings as well.

In almost all cases the operation of the diesels provide more than enough heat for the plants needs, but in high penetration systems we would like to shut off the diesels

- Plant goes from heat surplus to heat deficit.
- To allow fast starting of the diesel engines, diesels in fast start mode must be kept warm

May require revamping of the cooling systems

- Implementation of electric boilers to allow use of wind energy
- Allow specific engine cooling systems to be separated
- Better energy management
- Different or conflicting pumping requirements.
- Heat efficiency of plant buildings may need to be considered

Assessing the Costs

One must determine the true cost of performing the upgrades and modifications to the existing plant. To do this, one must consider not only the costs of parts and labor, but various other costs and risks as well, including:

- the cost of doing engineering designs that may only apply to this one installation
- the difficulty of doing fabrication and installation work in the field
- the risk of design and installation error
- the loss of revenue and customer good will associated with outages necessitated by diesel plant rework
- the risk of delays to the project if the plant requires extensive rework

Integration of System Electronics

Integration of a power system means that the plant must insure high Power Quality during and following the change

- 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

Types of Power Quality

- System stability - reliable power: Having power when you should have it.
  - Unscheduled blackouts
  - System failures
  - Voltage and frequency within acceptable limits
  - System power factor not overtaxing power system
- The level of harmonic distortion -is the power being delivered usable?
  - Changing structure of the power
  - Sub-cycle quality of the power

System Stability

Driven by maintaining system voltage, frequency and reactive power supply.

- **Voltage:** Currently uses an active controller on the diesel. Alternatives are a synchronous condensers or a battery bank and solid state or rotary power converter.
- **Frequency:** A balance of power supply and demand, controlled by the throttle of the diesel. Can be solved through the use of dump loads or power converters.
- **Power Factor:** Balancing active and reactive power as needed by the inductive motors and electronics on the system. Capacitor banks, motors or advanced solid state power converters.

Power Harmonics

- A matter of the type and quality of the electronic equipment employed in the design of the power systems.
- Requires fine tuning of the power system during installation, very dependent on equipment being used
- Should be insured as part of the testing and system commissioning
- Will required continued supervision and maintenance
- More impact on high tech or sensitive loads

PQ in Large Hybrid Systems

- With power generation on the AC bus. 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
- Supply and demand side solutions to this problem

Supply Side Options

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

- Dump Loads: Fast acting resistors to balance the generation and load.
- Dispatchable loads: Block heaters to use excess energy.
- Synchronous Condenser: Provides reactive power and controls voltage.
- Advanced power converters and small battery bank: Used to assist in managing power flows, power smoothing.
- Active renewable control: Control power output of the renewable device.

Demand Side Options

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

- Distinction between critical and non critical loads
  - Dispatchable loads like resistance heating
  - Loads shedding where non-critical loads
  - Protection of sensitive loads
- Installation of capacitors to smooth out rapid system fluctuations and partially correct systems power factor.
- Replacing large inefficient loads

Wind Turbine Issues

- More smaller turbines are better than one large one
  - Smother power production
  - Higher impact of turbine reliability
  - but you do have space issues
- Turbine Size will likely be dictated by site conditions but smaller turbine (50-300 kW) will provide
  - Easier shipment and installation
  - Require smaller maintenance operations and facilities

Types of Power Systems

There are many different types of power systems that all depend on:

- The load
- The renewable resources
- What amount of diesel do you want to offset

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)

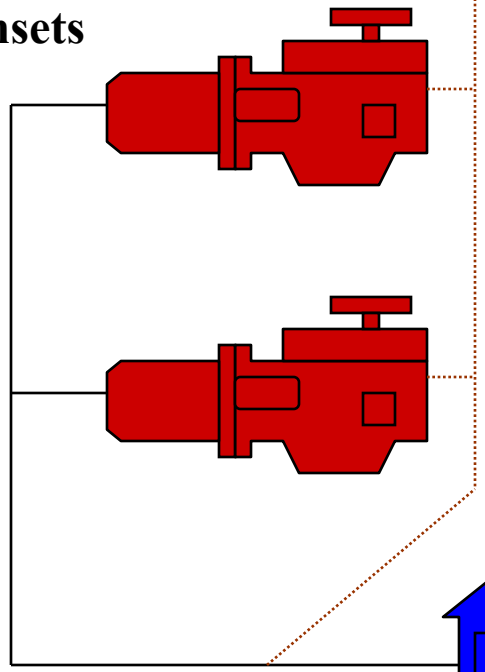
$$\text{Average Penetration} = \frac{\text{Wind Energy Produced (kWh)}}{\text{Primary Energy Demand (kWh)}}$$

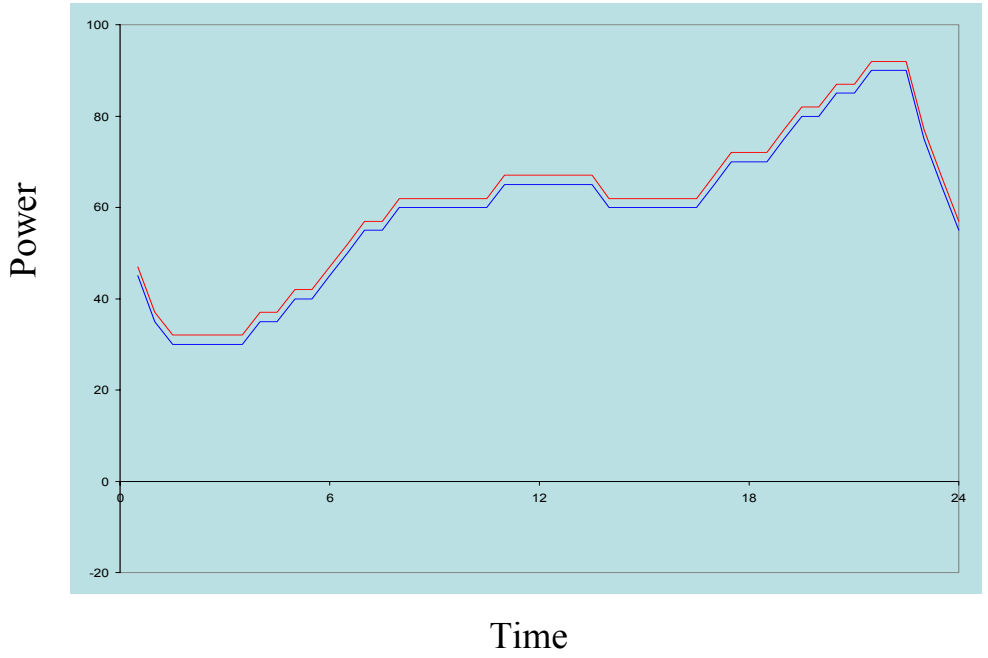
- Total energy savings
- Loading on the diesel engines
- Spinning reserve losses/efficiencies

Diesel Only Power System

System Controller

Diesel Gensets



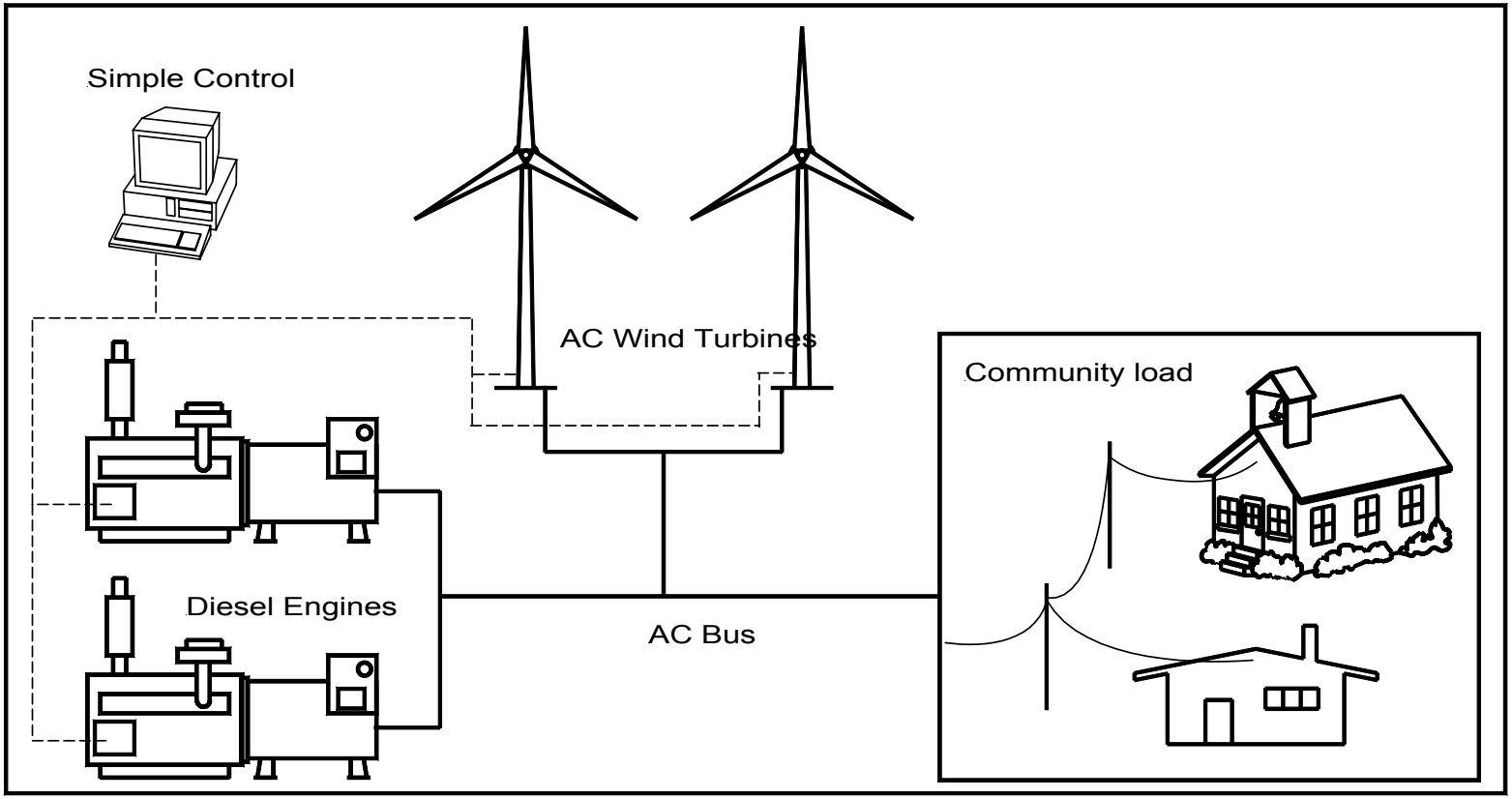


Village Load

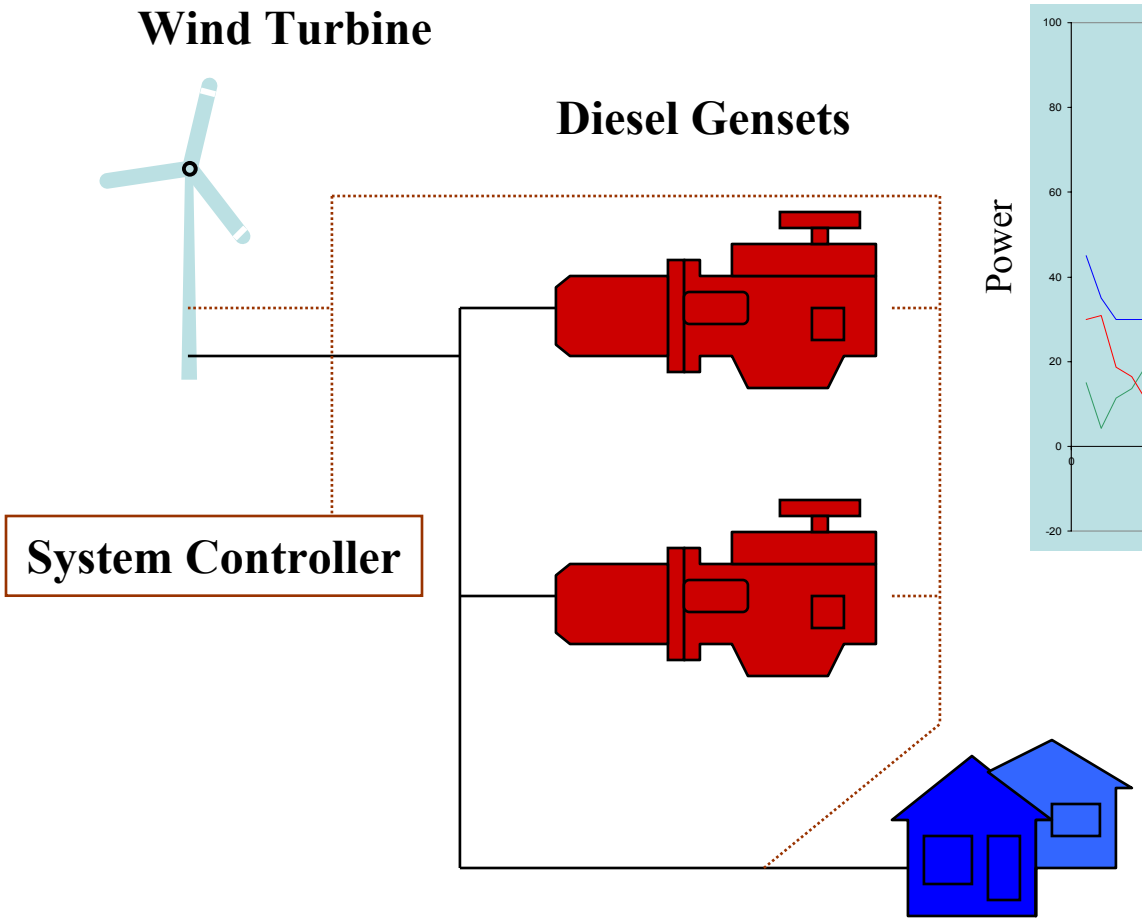
Low Penetration W/D Specifications

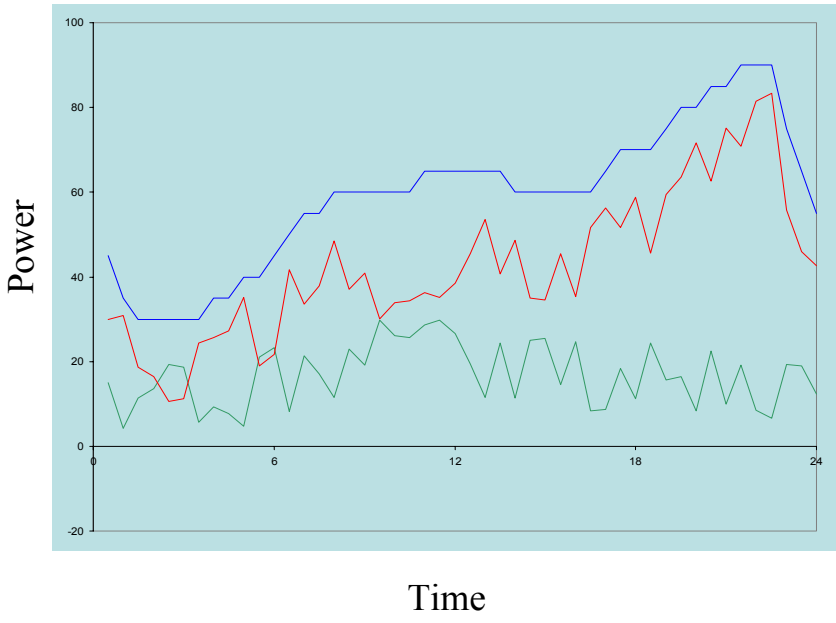
- Equipment
  - Wind turbine or series of turbines
  - Dump load could be include to smooth out power fluctuations
  - Capacitor bank used correct power factor if needed
- Control
  - Wind turbine monitoring
  - Power control of wind turbines possible but not required
  - Minor controls to allow remote turbine shut down in extreme cases

Low Penetration W/D Schematic



Low Penetration wind/diesel system

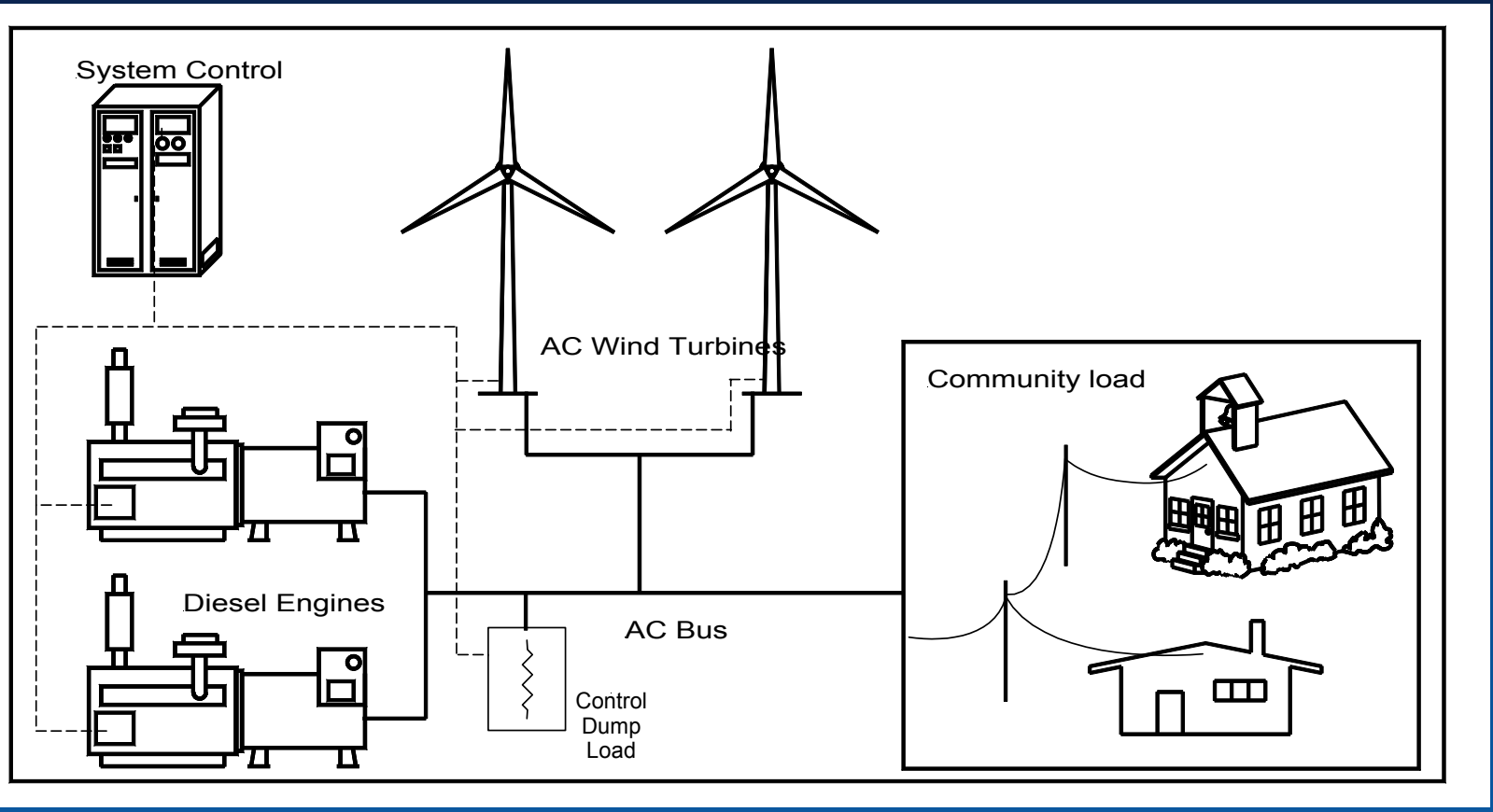




Medium Pen W/D Specifications

- Equipment
  - Wind turbine or series of turbines
  - Dump load to smooth out power fluctuations
  - Dispatchable loads to reduce loading on diesels and help control system frequency - May have capacitor bank
- Control
  - Wind turbine controls
  - Power control of wind turbines possible but not required
  - Diesel control
  - System controller to maintain system stability and dispatch primary diesels and wind turbines as needed
  - Some power forecasting may be implemented

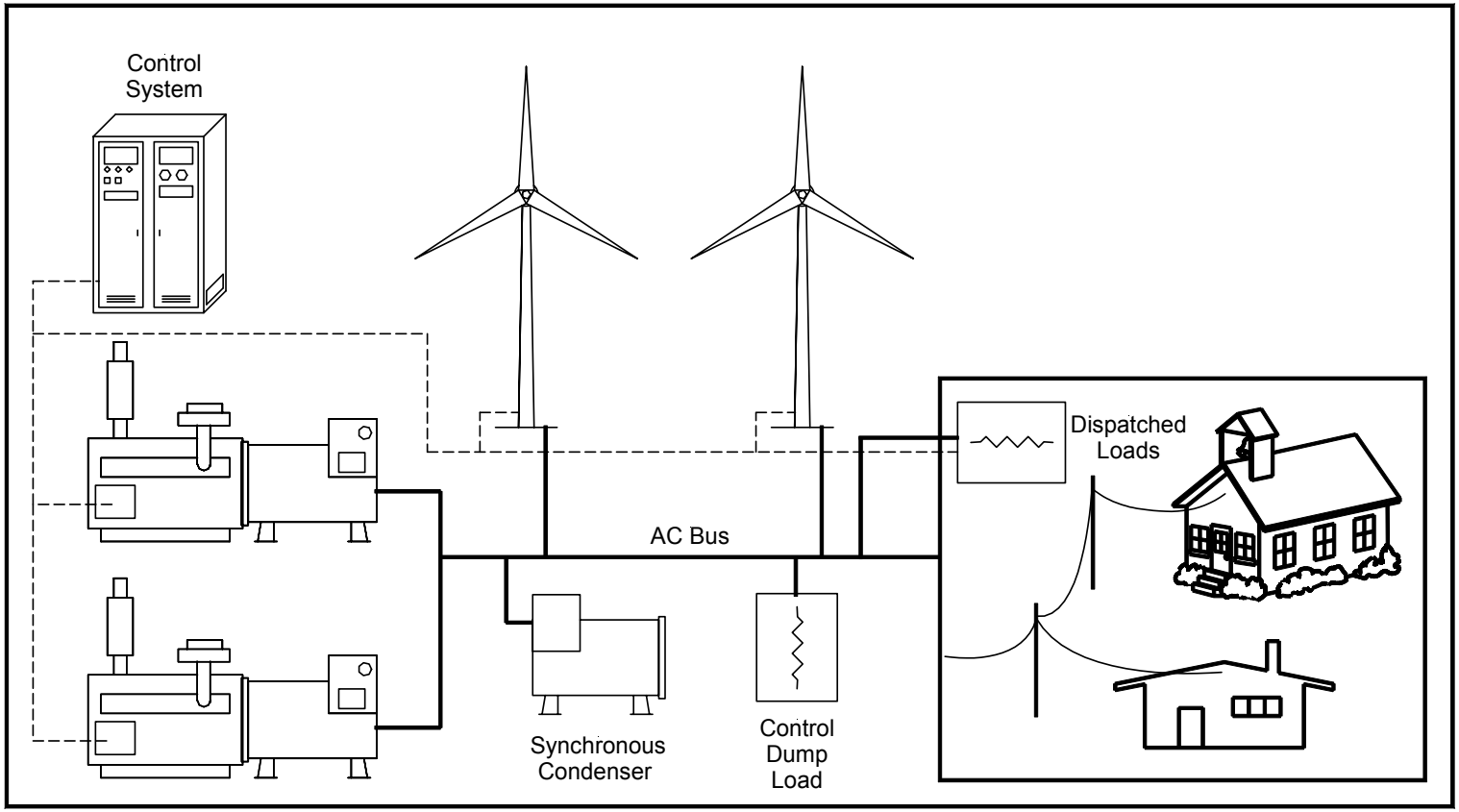
Medium Penetration W/D Schematic



High Pen W/D Specifications

- Choice # 1: No Storage systems
- Equipment
  - Wind turbine or series of turbines
  - Dump load to smooth out power fluctuations
  - Synchronous condenser to allow autonomous operation
  - Dispatchable loads to reduce loading on diesels and help control system frequency - May have capacitor bank
- Control
  - Wind turbine and advanced diesel controls
  - Power control of wind turbines possible but not required
  - Fully integrated system controller
  - Some power forecasting may be implemented

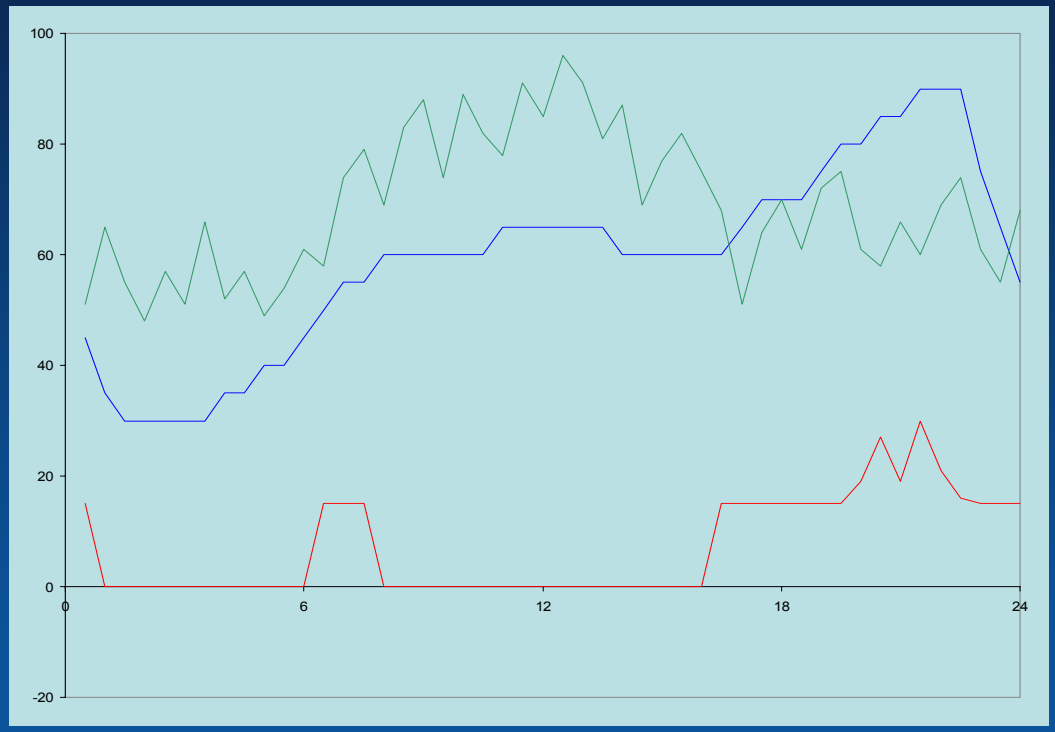
High Penetration W/D Schematic



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

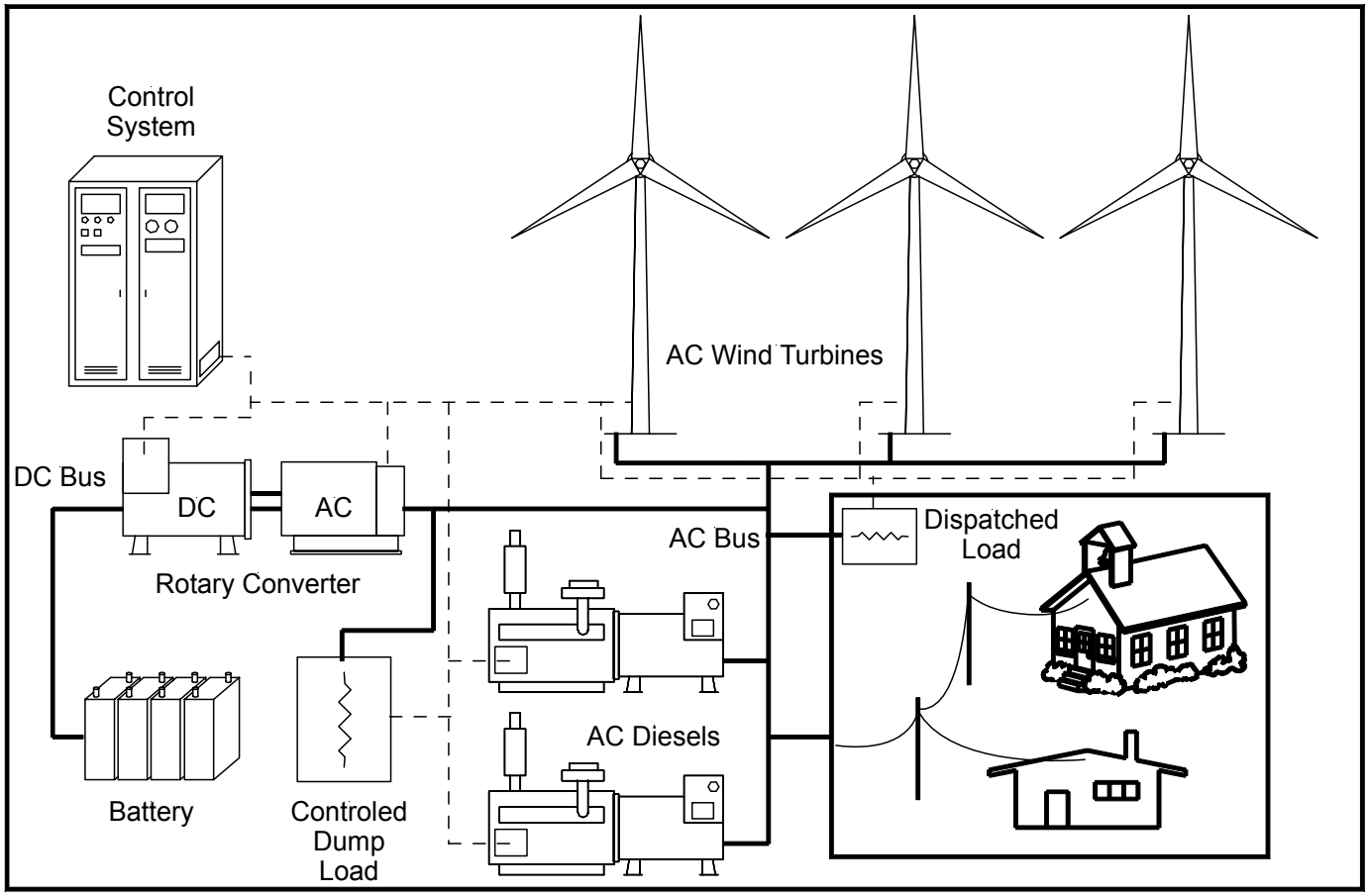


Red = Diesel
Blue = Load
Green = Windpower

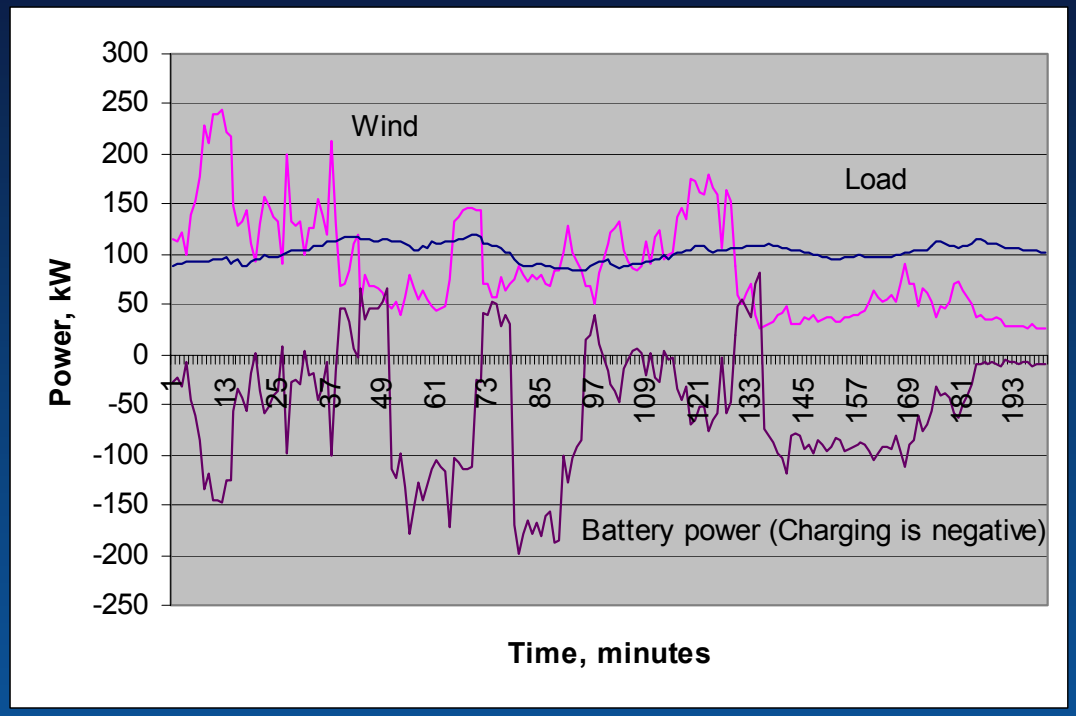
High Pen W/D Specifications

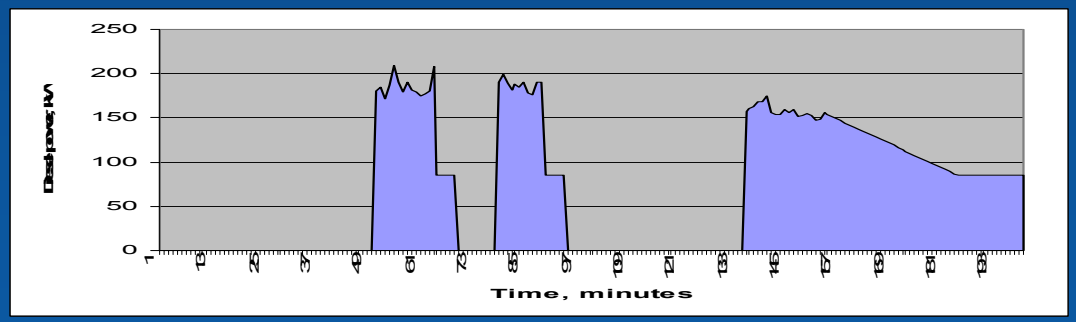
- Choice # 2: Storage systems
- Equipment
  - Wind turbine or series of turbines
  - Dump load to smooth out power fluctuations
  - Power converter and battery with ability to provide power control
  - Dispatchable loads to reduce loading on diesels and help control system frequency - May have capacitor bank
- Control
  - Wind turbine and advanced diesel controls
  - Power control of wind turbines possible but not required
  - Fully integrated system controller
  - Some power forecasting may be implemented

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

AC Based System Recap

- **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

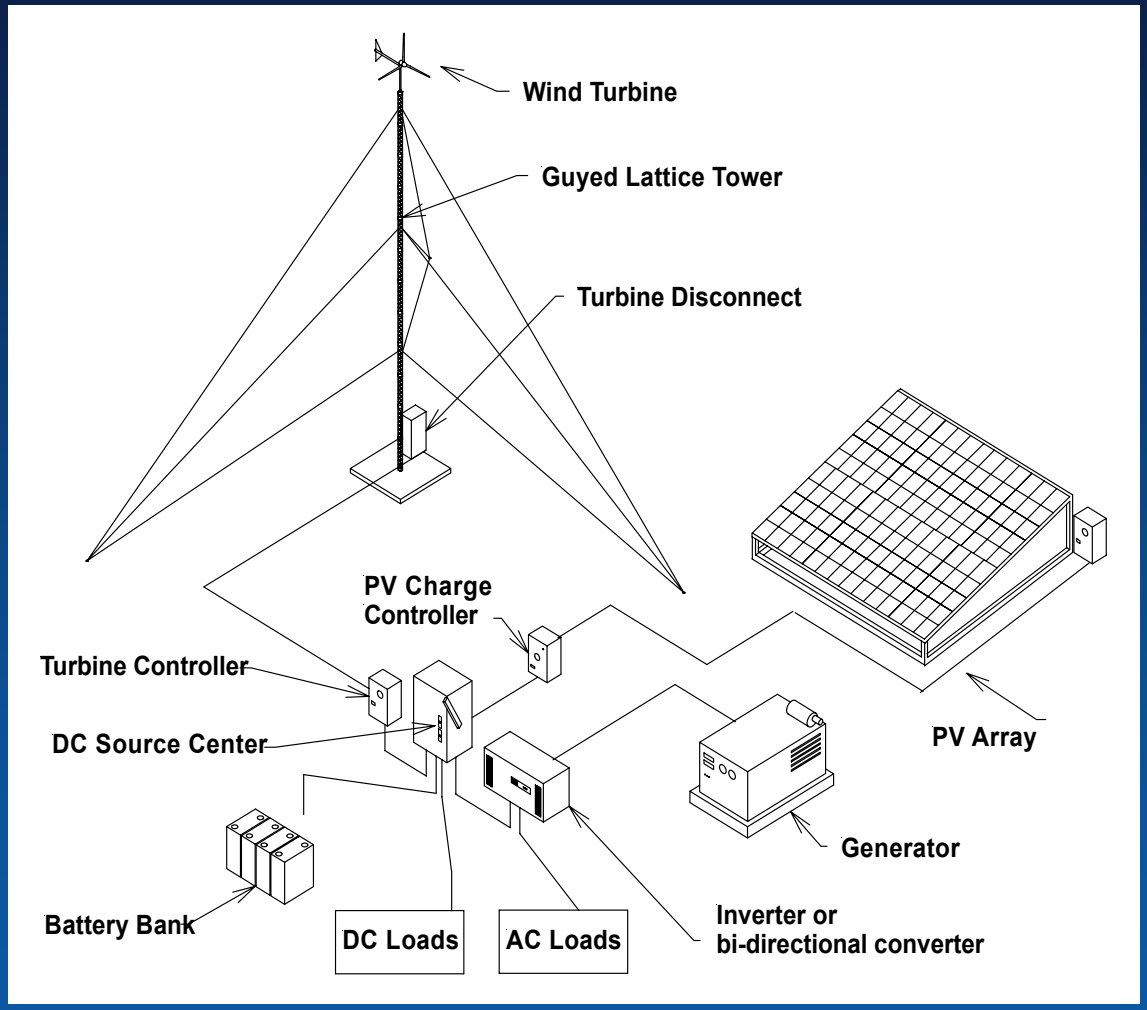
These are really three different systems which all should be considered differently

Note: People play loose with the definitions

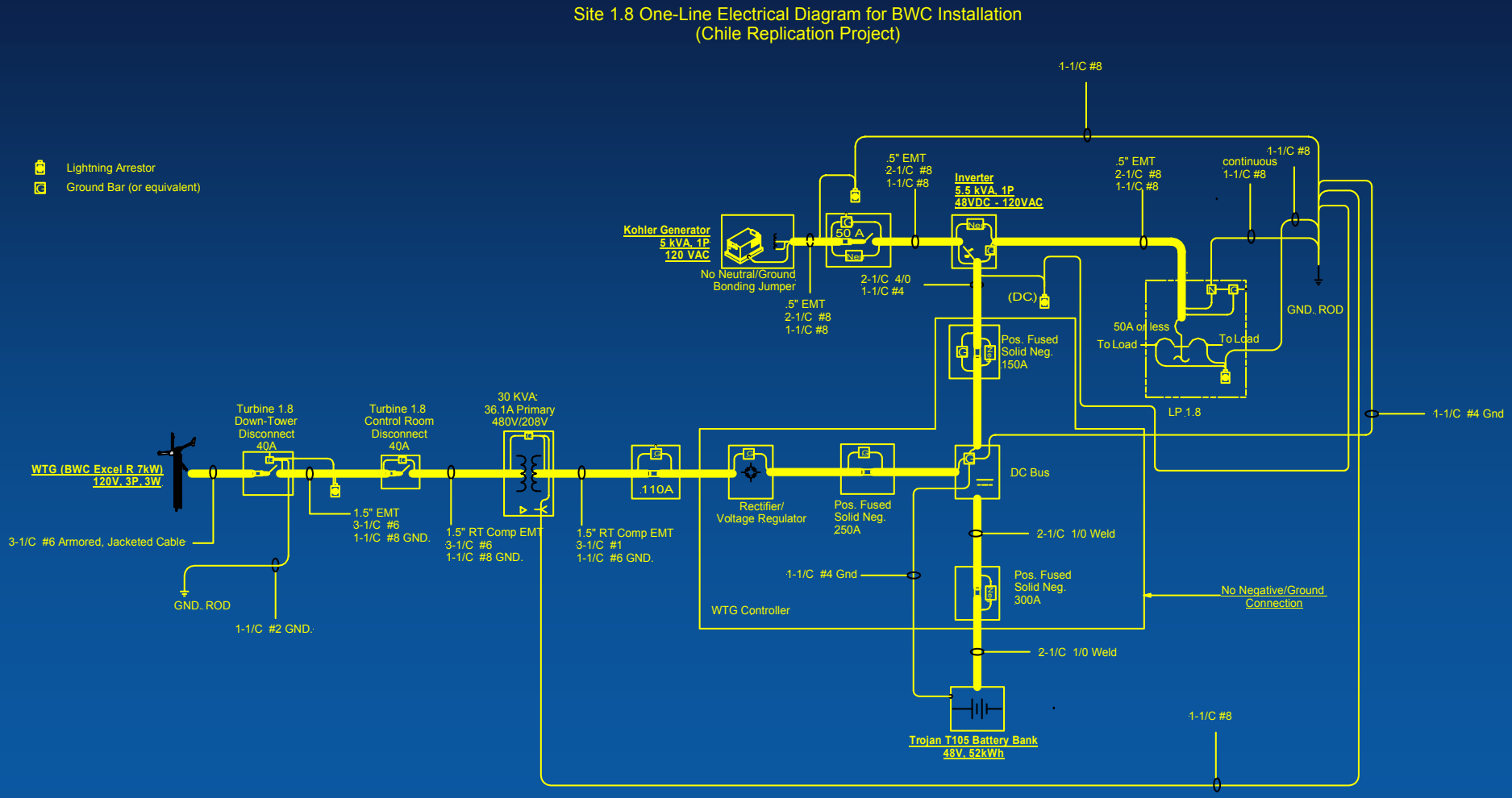
Power systems are inherently complicated

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.

DC Based Small System Architecture



Power system schematic



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

Skip

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

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

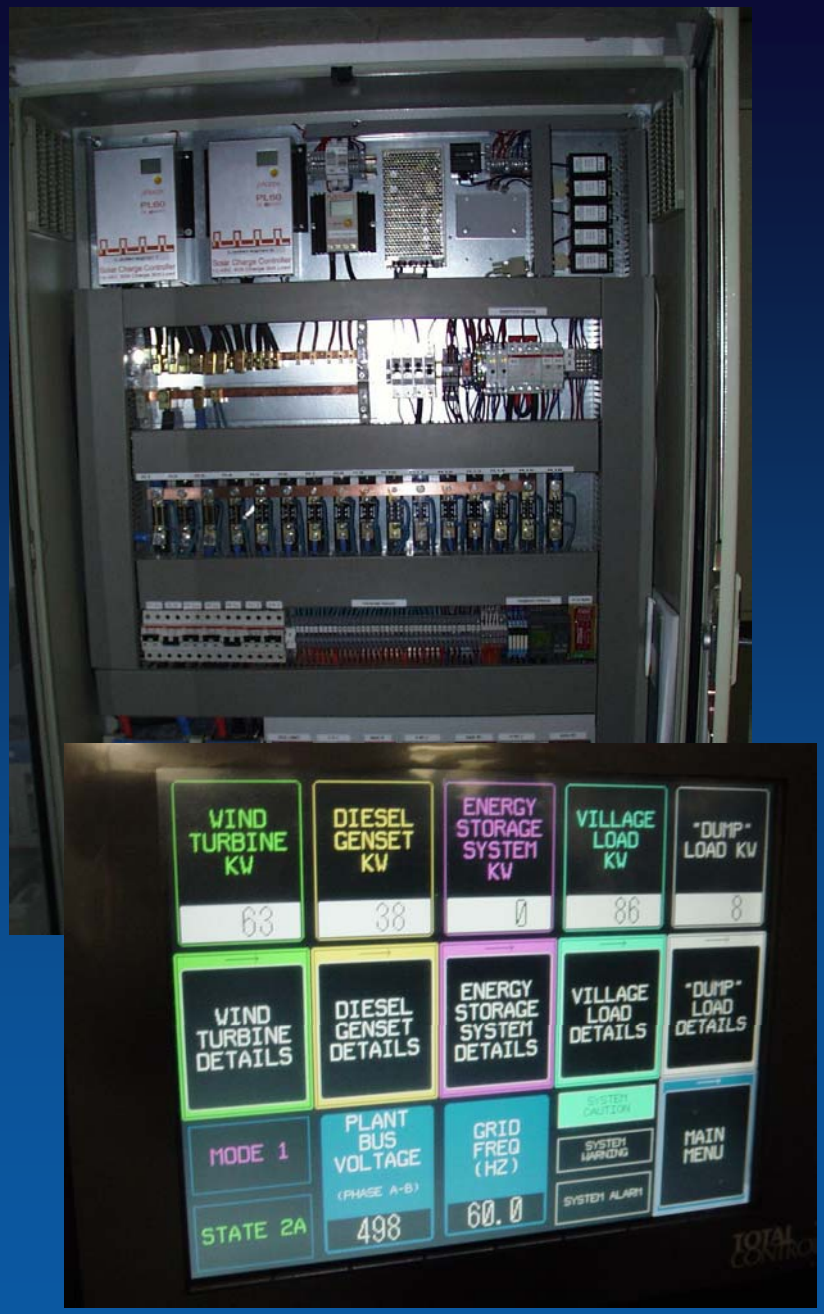
Dump Loads and Community Heating

- 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

- Many design options for hybrid systems
  - Small DC based power systems - relatively easy
  - Low penetration - generally easy and simple
  - Medium penetration - more complex but OK
  - High penetration - very complex and expensive
- There is a lot of off the shelf technology that can be used to implement these systems but some level of skill is required to make them work
- Power quality is a key issue, but not an insurmountable problem at any penetration
- Approach is the same as building a power station, just different technology being implemented
- Many organizations that would be willing to assist in any project development activity