Primmer on Dispactchable Energy Technology and Plant Control

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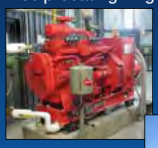
May 31st 2009

Power Generation Options

Dispatchable means you can start them when you want them

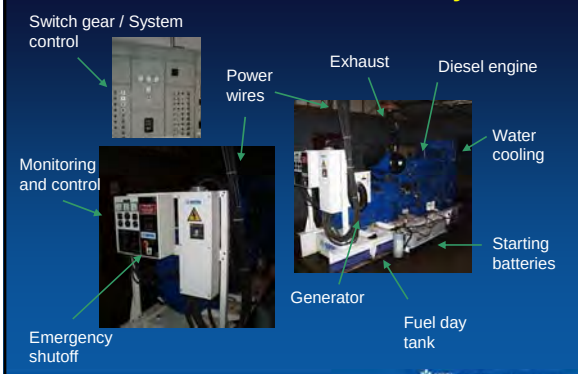
Reciprocating Engines



Microturbines

Fuel Cells

Diesel Generator - The Basic System



Diesel Generators

Diesel engines make grate prime movers – that's why we use them

- Reliable
- Efficient
- Well understood technology
- Developed maintenance infrastructure
- Fuel is easily transported, stored, and has high energy density

But they are not perfect

- Fuel must be transported and stored
- Environmental damage from the plant and fuel transport
- Expensive and variable cost of diesel fuel (tagged to price of oil and demand)
- Produces emissions – CO2, NOx, and particulate matter
- Noise

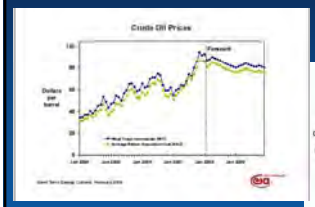
Photo credit: Josh Landis – National Science Foundation

Photo credit: Mia Devine

Photo credit: Ian Baring-Gould

EIA (U.S. DOE) Short term Projections of Crude Oil Price

No offense to EIA – but the one thing I know is that they will be wrong. The other thing I know is that their community is not dependent on them being right.



February 2008

May 2009

New Emissions Requirements

Emissions Tier 2
- NOx g/hp-hr – 5.74 g/hp-hr
- CO g/hp-hr - .4 g/hp-hr
- HC g/hp-hr - .01 g/hp-hr
- PM g/hp-hr - .019 g/hp-hr

CAT 500 ekW 625 kVA

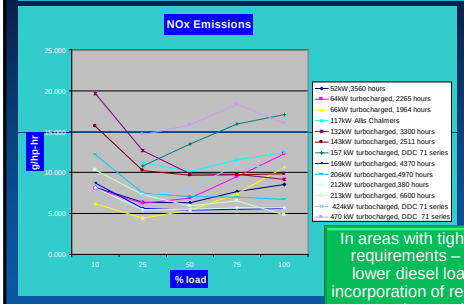
Emissions Tier 3
- NOx g/hp-hr – 3.7 g/hp-hr
- CO g/hp-hr - .26 g/hp-hr
- HC g/hp-hr - .03 g/hp-hr
- PM g/hp-hr - .025 g/hp-hr

CAT 450 ekW 563 kVA

Tier 3 (and most decreased emissions requierments) come with a slight increases in fuel use and cost

Diesel Emission Vary with Power

Diesel Emissions also vary with diesel power (temperature and burn efficiency) which should be accounted for



In areas with tight air emissions requirements – the impact of lower diesel loading with the incorporation of renewable should be considered

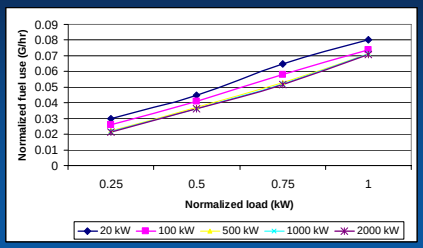
Diesel Ratings

There are internationally agreed definitions of the rating levels for diesel engines:
- Standby - Output available with varying load for the duration of the normal source of electrical supply. In essence it is the "prime overload" condition with no time limit for an engine which is normally not operated.
- Prime - Output available with varying load between 25% and 100% of the rating for an unlimited time. The unit can be overloaded to 110% of the rating for one hour in twelve.
- Continuous - Output available without varying the load for an unlimited time.

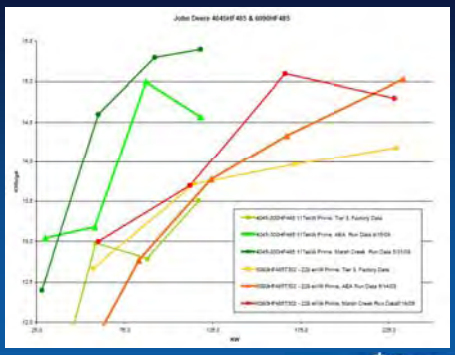
If the standby rating were 1000 kW, then a Prime Power rating might be 850 kW, and the continuous rating 800kW.

Variation in Fuel Use

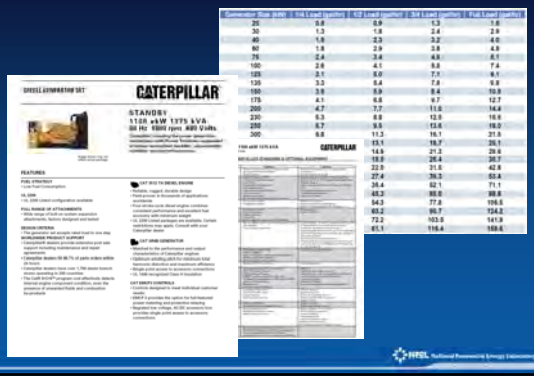
Fuel use with most generators is quite linear, with values typically given at several specific loading levels – New diesels have better lower load efficiency



But Field Results can Vary



Diesel Engines – Fuel & Other Information



Diesel Only Power System

Elements of Power Quality

- Power reliability: Having power when you should have it.
- Power Quality: Is the power supplied appropriate for the needs or to meet some set requirement.
  - **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

Power Reliability

Is the power reliable?

- Driven by system maintenance, designed component redundancy, proper plant control and having enough capacity on line to meet the load
- All of these are factors that impact diesel plant reliability now - plant design, equipment age, and experience of station staff play a large part in ensuring operation
- Adding wind technology adds more components and makes the task more complicated
  - Clearly depends on the penetration of the system
  - More/new equipment to maintain
  - New processes and operational considerations
  - More complicated plant management and seasonal dispatch

Power Quality

If the power quality is poor, some loads will be negatively impacted and eventually the power plant or generators will trip off line – meaning that the lights will go out.

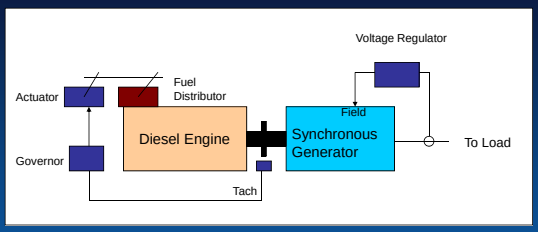
The prime elements of concern are

- **Voltage:** Amplitude of the power wave form. Generally maintained by the manipulating the electric field of rotating equipment (like generators or synchronous condensers) but can also controlled using solid state devices such as power control units.
- **Frequency:** Maintaining a balance of power supply and demand; to much power the frequency goes up, not enough and the frequency goes down. Generally controlled by the throttle of the diesel but can be implemented through combination of thermal loads, dispatchable loads, and power storage.

Power Quality – Continued

- **Power Factor maintenance & Reactive Power supply (VAR Support):** All impedance devices (motors, florescent lighting, electronics) require both active and reactive power. The power system must be able to provide reactive power and balance power factor. Normally done by the diesel but can be assisted or replaced by capacitor banks, synchronous condensers or advanced solid state power converters
- **Harmonics Distortion:** The quality of the power that comes down the line and can impact electronic devices. Most rotating machinery provide high quality power harmonics (the power is very smooth) but the addition of more low quality loads and low quality electronics can increase distortion. This is generally addressed in the selection of power electronic equipment employed in the design of the power systems and continued assessment/tuning.

Generator Control



Frequency Control

Voltage Control

Diesel Engine Operating Criteria

Maintain minimum load levels on your diesels (typically ~40% of rated power)

- Need to keep a generator above a set operating temperature and want to make sure of proper lubrication
- Low loads mean low operating temperatures – which if prolonged lead to:
  - Increased corrosion (corrosives gas and high moisture) - wet stacking
  - Coking on cylinder's and exhaust due to incomplete fuel burn – cylinder glazing
  - Oil contamination (fuel, acid)
  - Higher maintenance requirements
- Voltage and frequency control break down at very low loads

Good maintenance is key to high efficiency

Alaska Energy Authority

Modern Diesel Control

Improved Diesel Engine Controls can allow large increases in diesel efficiency

- Automatic engine startup and shutdown
- Automatic synchronization
- Automatic load (kW) sharing with other diesels
- Soft loading and unloading
- Automatic reactive power (VAR) sharing

Improved Switch gear incorporating remote Supervisory Control And Data Acquisition (SCADA) systems allow better plant interface and maintenance tracking

When looking at controls and switchgear upgrades – make sure that the equipment can be expanded if other technology options are being considered. Just because they say it can – does not mean it is.

Diesel Plant Efficiency

In rough numbers – of the heat content of the fuel, a modern diesel engine in excellent condition, will produce:

- 30 % - Electricity
- 33 % - Heat out of the stack exhaust
- 33 % - Heat out of the water jacket
- 4 % - Mechanical losses

However – not all of this can be used while maintaining plant performance and emissions requirements

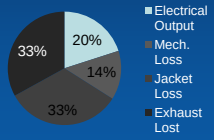
At peak efficiency -

- 54.5% (23,400 BTU) from water jacket
- 45.5% -(19,500 BTU) from stack exhaust

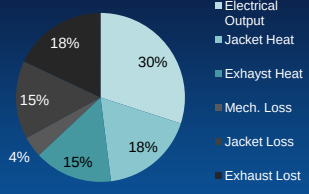
Can be recovered – leading to a total 63% utilization

Diesel Plant Efficiency

In-efficient Diesel Plant



Efficient Diesel Plant



Diesel plant efficiency for high and low efficiency diesel plants point to maximizing diesel performance and energy capture as a key first step in improving fuel efficiency

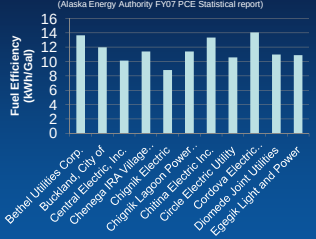
(Alaska Energy Authority – Alaska Energy Report)

Diesel Plant Efficiency Can Vary Wildly

- Fuel consumption of above 14 kWh/gal (3.7 kWh/l) can be achieved with an addition of ~43,000 BTU/gal (3.33 kW/l) of thermal energy
- An old and poorly maintained plant however can be as low as 7.6 kWh/gal (2.0 kW/l) with no heat recovery

Diesel plant efficiency for a sample of communities in Alaska show large differences in generation efficiency

(Alaska Energy Authority FY07 PCE Statistical report)



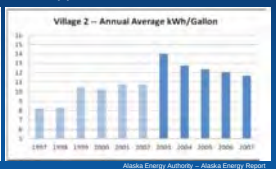
Changes in Efficiency

A good amount of information can be learned by looking at the long term efficiency ratings of existing diesel plants

Irregular efficiency is an indication of sporadic and/or poor maintenance

Declining efficiency is an indication of low maintenance – general engine decline, reduced support or resource limitations

Alaska Energy Authority – Alaska Energy Report



Alaska Energy Authority – Alaska Energy Report

Use of Diesel Thermal Energy

Not taking advantage of the diesel's thermal energy is like burning money

In northern climates you can use the extra thermal energy to heat buildings and water.

- Jacket water (~$220k)
- Exhaust Stack (~625k)

But everybody should look at ways to use this energy.

- Water purification / desalination
- Ice Making
- Process heat (Drying Crops, etc)

Photo credit: Ian Baring-Gould

Temperature controlled snow melting and space heater heat recovery system for diesel plant at Summit Station in Greenland

If some sort of diesel replacement is being considered – aka wind – any analysis must consider the impact of reductions in thermal energy available for other uses

Modern Diesel Plants

Seeing many more modular diesel plants

- Pre-engineered / fabricated containerized systems
- High level of control and monitoring
- Easy diesel replacement
- Integrated fuel storage and safety equipment

Photo credit: Mia Devine

Photo credit: Mia Devine

Alaska Village Electric Cooperative modular diesel plant

Modular plants may make them harder to retrofit for renewables – this addition should be considered at the start of new plant development

Conclusions

- Diesel is a trusted generation technology that is here to stay
- However it is dependent on imported fuels
- Several other options – NG, Propane
- Although it has been around for a while – technology is still improving through advanced control and new units should be considered as part of any analysis
- Advanced controls can greatly improve performance
- New integration approaches being worked on – AEA and AVEC

NREL National Renewable Energy Laboratory
Innovation for Our Energy Future

Questions?

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