Power Generation Stability and Response in DP Applications
An Overview of Modern Diesel Engine Performance

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Topics Discussed in This Paper

1. Frequency control & load sharing
2. Interaction between speed governor and external systems (PMS)
3. Diesel engine performance
4. Potential methods of enhancing loading performance
5. Load sharing; symmetric vs. asymmetric
1.
Frequency Control & Load sharing
Frequency Control - Mission

- Maintaining a desired absolute frequency (isochronous) or frequency range (droop mode), using a speed governor or speed control unit to control the rpm of the diesel engine prime mover.

- Traditionally, mechanical - hydraulic governors

- Today, electronic speed control units with either hydraulic or electric actuators.
Frequency Control - Control Loop

Fuel → Actuator → Engine → Load

Flywheel Pickup → Actual speed

Speed control unit

Speed reference → Speed reference
Frequency Control - Main Elements

- Increase/Decrease Speed
- Engine Load
- Average Engine Load

Control Output
- 0 - 200mA

Actuator
- Position 0 - 10

Engine Speed

Fuel Rack Position
- 0 - 56 mm
Signals, Example of Relationships - Example

- Controller Output %
  - 0, 6, 20, 68, 84, 100
- Controller Output mA
  - 0, 13, 40, 135, 168, 200
- Actuator Indicator Position
  - 0, 1.7, 7.7, 10
- Fuel Pump position mm
  - 0, 12, 42, 56
- Engine Load %
  - Stop, 0, 100, 120
Engines which are connected to a common load must have the same speed reference and the same speed droop % in order to share the load equally.
Load Sharing – Isochronous Mode

- Load sharing lines between speed control units.  
  (-Voltage signal proportional to average load level)

- No speed droop, fixed frequency.

Some issues:

- Short circuit on load sharing lines paralyses load control 
  (but gensets resort to independent droop mode operation. –not fatal).

- Wire break more critical. Will lead to unstable situation.

- Today’s speed control units do not have galvanically isolated load sharing 
  lines. –A voltage induction could (in theory) knock out the speed controllers.

Coming technology:

- Digital load sharing lines.
2. Interaction Between Speed Control and External Systems (PMS, etc.)
Distinguish between *Load Sharing* and *Load Balancing*.

The governors *share* the load, both in speed droop systems and in isochronous systems, while the PMS can *balance* or *offset* the load.

The PMS should ideally adjust the load balance only when a generator is recently connected, or before disconnecting a generator in a speed droop system.

The governors work to eliminate short term frequency fluctuations (seconds).

The PMS should correct only long term frequency changes due to changed network load (minutes).
In Droop Mode:

- PMS does not control load directly, governors load share.
- PMS performs *frequency correction* and *load balancing* by adjusting the load reference signal to the speed control unit (ref. droop curve)

Remember:

- Speeding up the PMS update (control) rate does not increase system response. (It rather makes it unstable).
In Isochronous Mode:

- PMS does not control load directly, governors load share on load sharing lines.
- PMS does not balance the load. The load is normally shared equally.
- PMS cannot affect frequency after synchronizing.
3. Diesel Engine Performance
Diesel Engine Functions/Features Critical for Performance & Response

- Turbocharging System
- Fuel injection system
- Brake Mean Effective Pressure
- Acceleration value (a-value)

Little or no influence:
- Bore & stroke
- Number of cylinders
- RPM
- V-engine vs. in-line
Turbocharger

Modern diesel engines:

The turbocharger stands for 75-80% of the rated power.
Development of charge air pressure ratio

[Graph showing the development of charge air pressure ratio from 1960 to 2000, with key years and models marked.]
Efficiency Development of Wartsila Engines
Pulse charging systems, cylinder numbers with multiple 4 (4L, 8L, 8V, 16V).

2-Pulse

4-Pulse

Pulse Converter (PC)

Combi (2-Pulse / PC)

Multi Pulse Converter (MPC)
Pulse charging systems, cylinder numbers with multiple 3 (6L, 9L, 12V, 18V) and 5 (5L, 10V, 20V).

3-Pulse

"2 - 1 - 2 Pulse"
- Avoid "constant pressure" turbocharging.
Technology advancements - Turbochargers

- Variable Geometry Turbochargers
  - Variable nozzle ring vane angle
  - Today used on gas engines
  - Improves performance envelope, but will not dramatically improve the situation in rapid transients.
  - Mechanically more complex
Conventional injection system

Fuel pressure produced each time by the injection pump

Mechanical/hydraulic control at the injectors

Common Rail Injection

Electronic/hydraulic control of injection

Constant fuel pressure
Injection pressure possibilities by different systems:

- **Common rail**
- **Conventional at constant speed**
- **Conventional on propeller curve**

**Graph:**
- **Y-axis:** Fuel Injection Pressure (bar)
- **X-axis:** Engine Load (%)

Levels:
- Common rail: 0 to 1500 bar
- Conventional at constant speed: 0 to 1000 bar
- Conventional on propeller curve: 0 to 500 bar

**Legend:**
- Green: Common rail
- Yellow: Conventional at constant speed
- Red: Conventional on propeller curve
- By definition, the mean pressure on the piston calculated over the entire cycle.
- Indicates how much power output is produced for a certain bore / stroke / rpm.
- Indicates “development stage” of engine

\[
BMEP[\text{bar}] = \frac{1}{100000} \cdot \frac{\text{Power}[\text{kW}] \cdot 1000 \cdot 4 \cdot \text{Stroke}[\text{mm}]}{\left(\frac{\text{Bore}[\text{mm}]}{1000}\right)^2 \cdot \frac{\text{Stroke}[\text{mm}]}{1000} \cdot \pi \cdot 2 \cdot \frac{\text{RPM}}{60} \cdot \text{NUMCYL}}
\]

Example:
“Vesslefrikk” -1985: 12V32BC, BMEP = 20.1 bar
“Deepwater Horizon” -2000: 18V32LNE, BMEP = 24.0 bar
- Indicates the acceleration properties of a rotating mass (e.g. alternator)

- Detailed genset performance optimization should include optimization of the a-value (flywheel, coupling, generator rotor, etc.)

- Performance simulations reasonably good indicator for correct (driver / flywheel / alternator) configuration selection.
4. Can Loading Performance be Improved Using Special “Gadgets”?
Potential Gadgets

- **Air injection in turbocharger**
  - Large air consumption
  - Controls tends to always lag

- **Mechanical blower**
  - Widely used for 2-stroke engines (a must)
  - Unpractical on 4-stroke engine, too big parasitic loss.

- **Hydraulic (or electric) forced rotation of turbocharger**
  - Was used already in the 1960s on e.g. icebreakers
  - High rotational speed is a technical challenge

Drilling is difficult!
- Load swings are somewhat unpredictable,
Innovative Control Schemes

- **Load feed forward**
  - Electrical load demand (changes) are fed forward to the speed control.

- **Electrical actuators**
  - Reduced lag
  - Technical maturity?
5. Load Sharing
Symmetric vs. Asymmetric
Asymmetric load sharing is a valuable operating mode e.g. after engine overhauls (running in new components) or when power output is limited due to technical reasons (contaminated alternator heat exchanger, thermal overload above certain % load, etc.)

PMS should be able to recognize “maximum power available” for each unit in order for asymmetric load sharing to be practical.

Occasional load drops below the level of the lowest loaded generator must be avoided in a speed droop system to avoid tripping on reverse power.
Thank You!