PV Diesel 101

Phil Maker <philip.maker@gmail.com>

Powerwater Remote Operations/ACEP

March 2014

Abstract

An introduction to PV Diesel Systems including principles of operation for medium and high penetration systems.

Overview

This talk covers:

- Electricty, PV, Diesel, Control.
- How PV/Diesel Systems can be applied in isolated grids.

Overview

This talk covers:

- Electricty, PV, Diesel, Control.
- How PV/Diesel Systems can be applied in isolated grids.

It is *not* about::

- Procurement, Kit, ...
- Operations,...

Overview

This talk covers:

- Electricty, PV, Diesel, Control.
- How PV/Diesel Systems can be applied in isolated grids.

It is *not* about::

- Procurement, Kit, ...
- Operations,...

There will be another chat about that, this is why and how not what..

> *"There had been certain difficulties during the expedition and afterwards, There was no use denying it, I had simply told the story from my own point of view, as honestly as I could" - Tenzing Norgay.*

Conventions and References

- Solar Diesel Handbook - a handbook about this.topic.

Conventions and References

- Solar Diesel Handbook - a handbook about this.topic.
- ASIM - a simulator for PV Hybrid Systems

Conventions and References

- Solar Diesel Handbook - a handbook about this.topic.
- ASIM - a simulator for PV Hybrid Systems
- Naming conventions are as for ASIM:
  - Pv = Photo Voltaic, Gen = Generator, Load = Load, ...
  - P = power, Q = reactive power, I = current

  So what is:
  - `Gen3P`. `GenP`, ...
  - `PvSetP`. `Gen2I3`

Conventions and References

- Solar Diesel Handbook - a handbook about this.topic.
- ASIM - a simulator for PV Hybrid Systems
- Naming conventions are as for ASIM:
  - Pv = Photo Voltaic, Gen = Generator, Load = Load, ...
  - P = power, Q = reactive power, I = current

  So what is:
  - `Gen3P. GenP`, ...
  - `PvSetP. Gen2I3`
- See also Ackermann for Wind Diesel Hybrid Systems.

Penetration and Contribution

- **Power (kW)**, i.e. what is being used/generated now.

Penetration and Contribution

- **Power (kW)**, i.e. what is being used/generated now.
  1. Generation and Loads must balance: `GenP + PvP = LoadP`
  2. **Instantaneous Penetration** is the. % of renewable power (kW) at this time: `100 * PvP/LoadP`

Penetration and Contribution

- **Power (kW)**, i.e. what is being used/generated now.
  1. Generation and Loads must balance: `GenP + PvP = LoadP`
  2. **Instantaneous Penetration** is the. % of renewable power (kW) at this time: `100 * PvP/LoadP`
- **Energy (kWh)**, i.e. what power has been used over a period.

Penetration and Contribution

- **Power (kW)**, i.e. what is being used/generated now.
  1. Generation and Loads must balance: `GenP + PvP = LoadP`
  2. **Instantaneous Penetration** is the. % of renewable power (kW) at this time: `100 * PvP/LoadP`
- **Energy (kWh)**, i.e. what power has been used over a period.
  1. Over any period kWh must balance.
  2. **Average Penetration** is the % of renewable energy (kWh) over a period (typically year): `100 * PvE/LoadE`

Penetration and Contribution

- **Power (kW)**, i.e. what is being used/generated now.
  1. Generation and Loads must balance: `GenP + PvP = LoadP`
  2. **Instantaneous Penetration** is the. % of renewable power (kW) at this time: `100 * PvP/LoadP`
- **Energy (kWh)**, i.e. what power has been used over a period.
  1. Over any period kWh must balance.
  2. **Average Penetration** is the % of renewable energy (kWh) over a period (typically year): `100 * PvE/LoadE`
- So a system with a **Peak Instantaneous Penetration** of 60% might have a **Average Penetration** of 15%.
- **Penetration** is also known as **Contribution**

Penetration and Contribution

- **Power (kW)**, i.e. what is being used/generated now.
  1. Generation and Loads must balance: `GenP + PvP = LoadP`
  2. **Instantaneous Penetration** is the. % of renewable power (kW) at this time: `100 * PvP/LoadP`
- **Energy (kWh)**, i.e. what power has been used over a period.
  1. Over any period kWh must balance.
  2. **Average Penetration** is the % of renewable energy (kWh) over a period (typically year): `100 * PvE/LoadE`
- So a system with a **Peak Instantaneous Penetration** of 60% might have a **Average Penetration** of 15%.
- **Penetration** is also known as **Contribution**

Dill Alert: never confuse peak with average or kW and kWh!

It is not all just about kW

- **Frequency (Hz)**, typically ranging from 49 to 51Hz. (cycles per second for the boffins).
- **Voltage (V)**, typically 430V, for the hydro analogy this is height.
- **Current (I)**, for the hydro analogy this is flow rate.

It is not all just about kW

- **Frequency (Hz)**, typically ranging from 49 to 51Hz. (cycles per second for the boffins).
- **Voltage (V)**, typically 430V, for the hydro analogy this is height.
- **Current (I)**, for the hydro analogy this is flow rate.
- **Reactive Power (vars)**, regulates the voltage, similar to kW it must balance:
  `GenQ = LoadQ`

Note that:

- Increasing `P` results in an increase `F`.
- And a decrease in `P` results in a decreate in `F`
- Similarly for `Q` and `V`.

Capacity factor, Spinning Reserve

- **Capacity Factor**: is the energy generated divided by the energy it would have generated at full power over a period (year).

Capacity factor, Spinning Reserve

- **Capacity Factor**: is the energy generated divided by the energy it would have generated at full power over a period (year).
  1. PV: 20% since the sun doesn't shine all the time.
  2. Wind: typically 25% up to 57%
  3. US Coal is 63%, U.S. Nuclear is 93%.
  4. Three Gorges dam is around 50%.

Capacity factor, Spinning Reserve

- **Capacity Factor**: is the energy generated divided by the energy it would have generated at full power over a period (year).
  1. PV: 20% since the sun doesn't shine all the time.
  2. Wind: typically 25% up to 57%
  3. US Coal is 63%, U.S. Nuclear is 93%.
  4. Three Gorges dam is around 50%.
- **Spinning Reserve**: the available spare power in the system:

```
SpinP = GenMaxP - GenP
```

Capacity factor, Spinning Reserve

- **Capacity Factor**: is the energy generated divided by the energy it would have generated at full power over a period (year).
  1. PV: 20% since the sun doesn't shine all the time.
  2. Wind: typically 25% up to 57%
  3. US Coal is 63%, U.S. Nuclear is 93%.
  4. Three Gorges dam is around 50%.
- **Spinning Reserve**: the available spare power in the system:
  `SpinP = GenMaxP - GenP`
- **Step Load**: the capability to take a single immediate increase in load. Typically:
  `StepP` $<$ `SpinP`

Sharing: Droop, Isochronous and Setpoints

Consider a two generator example:

Sharing: Droop, Isochronous and Setpoints

Consider a two generator example:

- Everything has to balance: `Gen1P + Gen2P = LoadP`

Sharing: Droop, Isochronous and Setpoints

Consider a two generator example:

- Everything has to balance: `Gen1P + Gen2P = LoadP`
- Load must be shared between generators: `Gen1P/Gen1MaxP near Gen2P/Gen2MaxP`

This can be achieved by:

- **Droop:** uses frequency to communicate load, e.g. 49.5Hz generator runs at 100% capacity, at 50.5Hz it runs at 0%.

Sharing: Droop, Isochronous and Setpoints

Consider a two generator example:

- Everything has to balance: `Gen1P + Gen2P = LoadP`
- Load must be shared between generators: `Gen1P/Gen1MaxP near Gen2P/Gen2MaxP`

This can be achieved by:

- **Droop:** uses frequency to communicate load, e.g. 49.5Hz generator runs at 100% capacity, at 50.5Hz it runs at 0%.
- **Isochronous**: uses a separate load sharing line so that each generator can share whilst keeping frequency around 50Hz.

Sharing: Droop, Isochronous and Setpoints

Consider a two generator example:

- Everything has to balance: `Gen1P + Gen2P = LoadP`
- Load must be shared between generators: `Gen1P/Gen1MaxP near Gen2P/Gen2MaxP`

This can be achieved by:

- **Droop:** uses frequency to communicate load, e.g. 49.5Hz generator runs at 100% capacity, at 50.5Hz it runs at 0%.
- **Isochronous**: uses a separate load sharing line so that each generator can share whilst keeping frequency around 50Hz.
- **Setpoint control**: can be used to control output of devices but we need a mixture of Droop and Isochronous in order to balance the system.

No Penetration PV

- Start and stop diesel in order to keep:
  `SpinP > SpinMinPPa`
- For a 500kW system `SpinMinPPa` might be 30kW. It is typically the largest load in town.

No Penetration PV

- Start and stop diesel in order to keep:
  `SpinP > SpinMinPPa`
- For a 500kW system `SpinMinPPa` might be 30kW. It is typically the largest load in town.
- Always try to run the smallest set possibe but:
  - Always run a set for perhaps 30 minutes after starting it.
  - Switch down only after the load has gone dow, n a bit further (hysterisis).
  - Many other things...

No Penetration PV

- Start and stop diesel in order to keep:
  `SpinP > SpinMinPPa`
- For a 500kW system `SpinMinPPa` might be 30kW. It is typically the largest load in town.
- Always try to run the smallest set possibe but:
  - Always run a set for perhaps 30 minutes after starting it.
  - Switch down only after the load has gone dow, n a bit further (hysterisis).
  - Many other things...
- Sets sizes need to selected based on load.
  - Either all the same and run them together.
  - All different, e.g. small, medium and large.

No Penetration PV

- Start and stop diesel in order to keep:
  `SpinP > SpinMinPPa`
- For a 500kW system `SpinMinPPa` might be 30kW. It is typically the largest load in town.
- Always try to run the smallest set possibe but:
  - Always run a set for perhaps 30 minutes after starting it.
  - Switch down only after the load has gone dow, n a bit further (hysterisis).
  - Many other things...
- Sets sizes need to selected based on load.
  - Either all the same and run them together.
  - All different, e.g. small, medium and large.
- Generators have to be loaded properly (both low and high).

No Penetration PV

- Start and stop diesel in order to keep:
  `SpinP > SpinMinPPa`
- For a 500kW system `SpinMinPPa` might be 30kW. It is typically the largest load in town.
- Always try to run the smallest set possibe but:
  - Always run a set for perhaps 30 minutes after starting it.
  - Switch down only after the load has gone dow, n a bit further (hysterisis).
  - Many other things...
- Sets sizes need to selected based on load.
  - Either all the same and run them together.
  - All different, e.g. small, medium and large.
- Generators have to be loaded properly (both low and high).

Dill Alert: Lets replace Station X with 2 x 1MW containerised sets where load varies from 500..1400 kW

Low Penetration PV

- No control of PV, just let it run at full power all the time.

Low Penetration PV

- No control of PV, just let it run at full power all the time.
- Depend on the normal spinning reserve to handle cloud events.

Low Penetration PV

- No control of PV, just let it run at full power all the time.
- Depend on the normal spinning reserve to handle cloud events.
- A bad cloud event on a 20m wide PV field might take 10s, e.g.
  1. Wind speed at 1000m = 10m/s
  2. Field is 50m across.
  3. Result is obvious, i.e. PV variability depends on wind speed.
- Limited to around 10-20% penetration (which one?)

Dill Alert: Do you want to manage a power system where we keep 30kW of Spinning Reserve and try to put 60kW of PV.

Medium Penetration PV

Medium penetration systems typically do not use storage and reach a peak penetration of round 60% for a 40% minmum generator loading.

Medium Penetration PV

Medium penetration systems typically do not use storage and reach a peak penetration of round 60% for a 40% minmum generator loading.

1. Active control of generation and PV in order to maintain:
   `PvP <= SpinP`
   So if all the PV disappears before we can start a diesel we will be alright.

Medium Penetration PV

Medium penetration systems typically do not use storage and reach a peak penetration of round 60% for a 40% minmum generator loading.

1. Active control of generation and PV in order to maintain:
   `PvP <= SpinP`
   So if all the PV disappears before we can start a diesel we will be alright.
2. We also need to maintain diesel loading above a threshold:
   `GenP >= GenMinP`
   In order to avoid damage to diesel generation.

Medium Penetration PV

Medium penetration systems typically do not use storage and reach a peak penetration of round 60% for a 40% minmum generator loading.

1. Active control of generation and PV in order to maintain:
   `PvP <= SpinP`
   So if all the PV disappears before we can start a diesel we will be alright.
2. We also need to maintain diesel loading above a threshold:
   `GenP >= GenMinP`
   In order to avoid damage to diesel generation.
3. So control:`GenMaxP` and `PvSetP` in order to meet 1 and 2.

High Penetration PV

A high penetration system requires some sort of:

- Load dump
- Energy storage: flywheels, batteries, synchronous condensers.
- Advanced control

In order to achieve above 90% peak penetration.

High Penetration PV

A high penetration system requires some sort of:

- Load dump
- Energy storage: flywheels, batteries, synchronous condensers.
- Advanced control

In order to achieve above 90% peak penetration.
Note: you need either a generator, synchronous condenser or Grid Forming Inverter run Diesel Off. This is not the normal PV inverter. Remeber we need to balance things!

High Penetration PV

A high penetration system requires some sort of:

- Load dump
- Energy storage: flywheels, batteries, synchronous condensers.
- Advanced control

In order to achieve above 90% peak penetration.
Note: you need either a generator, synchronous condenser or Grid Forming Inverter run Diesel Off. This is not the normal PV inverter. Remeber we need to balance things!

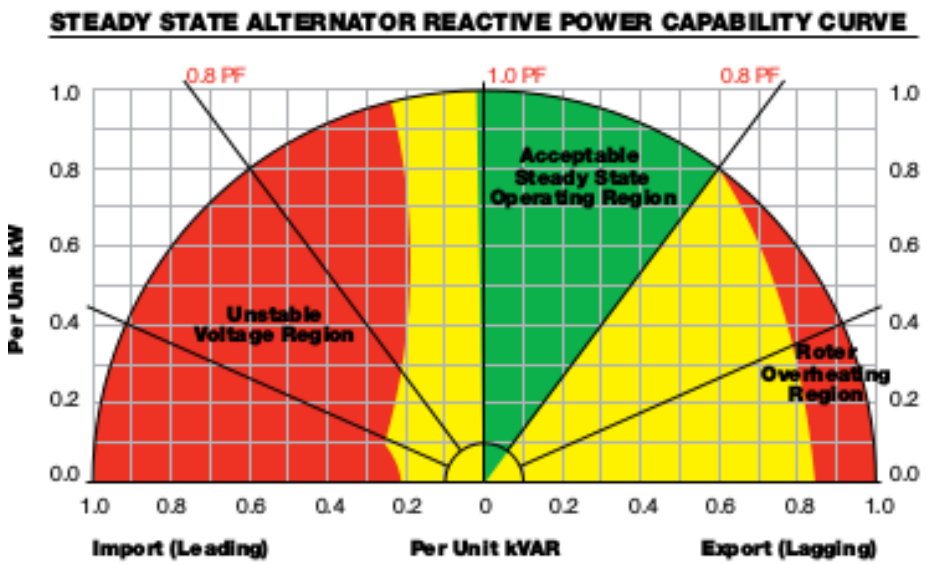
Examples are available from WA, AQ, AK, MY, ID, etc.

But its not off the shelf for larger systems.

Powerfactor

Powerfactor is the ratio between P and S where

- P is the kW loading,S is the kVA loading, i.e. the current x volts, Q is the kvar loading
- P+Q = S

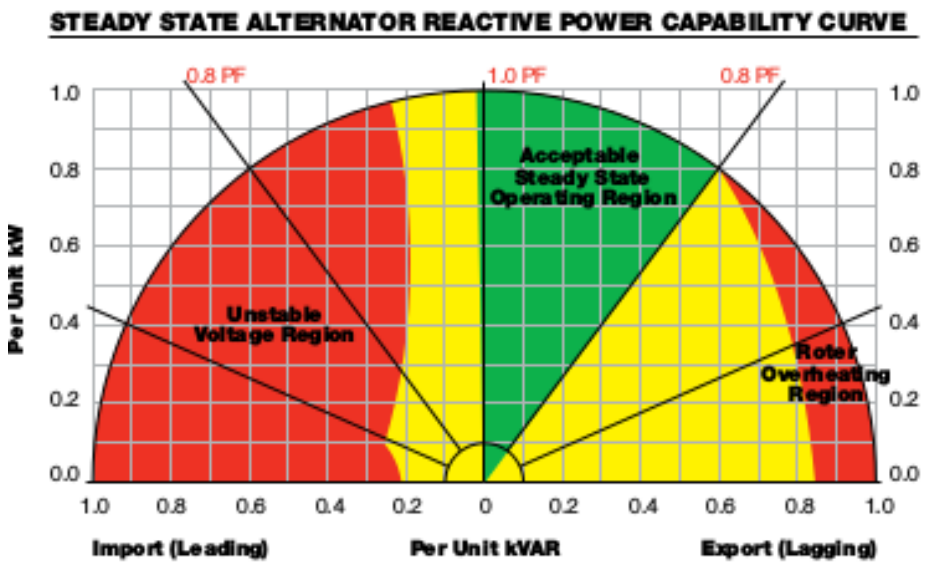


Dill Alert: At low loads my powerfactor is bad

Powerfactor

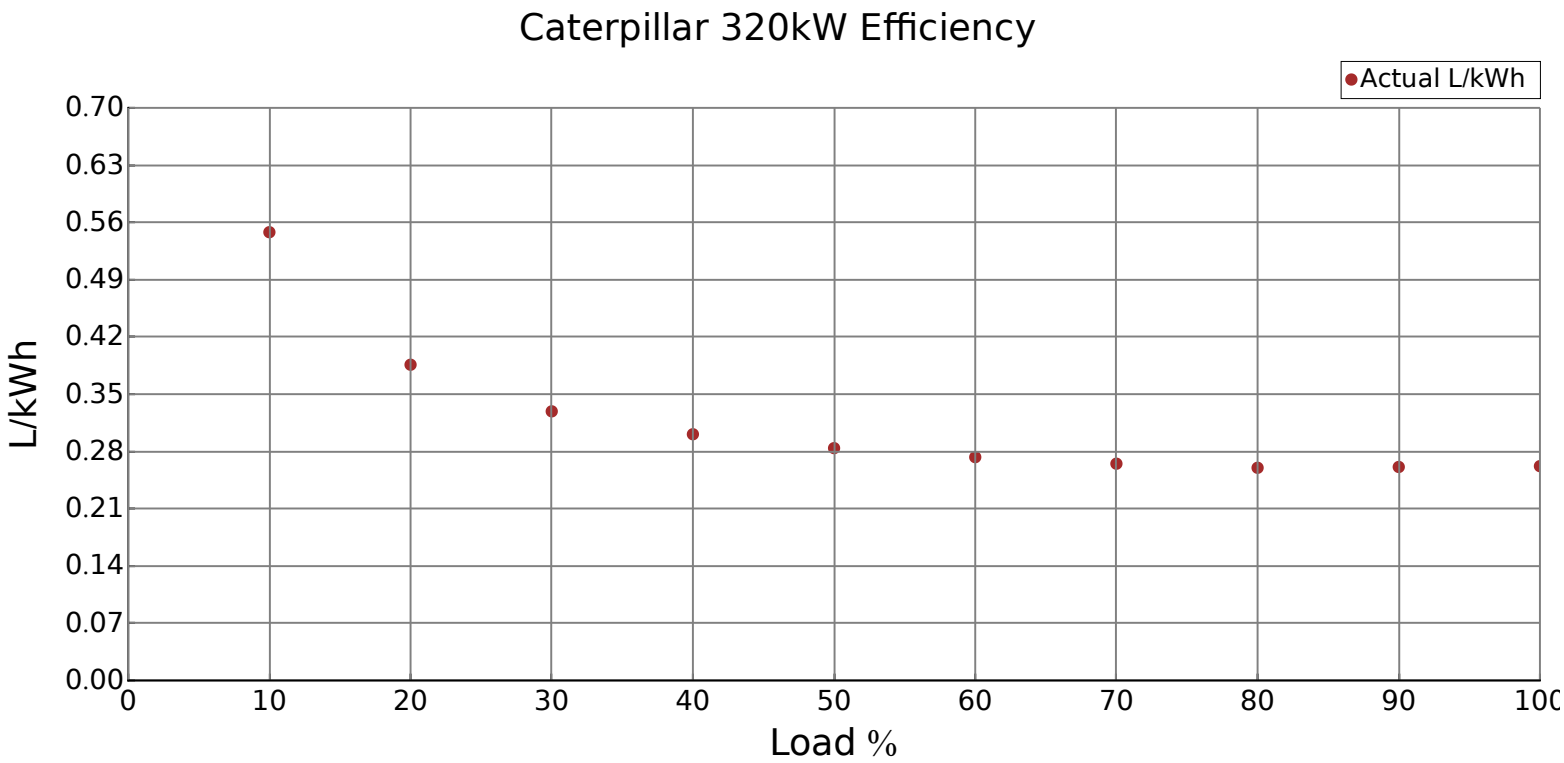
Powerfactor is the ratio between P and S where

- P is the kW loading,S is the kVA loading, i.e. the current x volts, Q is the kvar loading
- P+Q = S



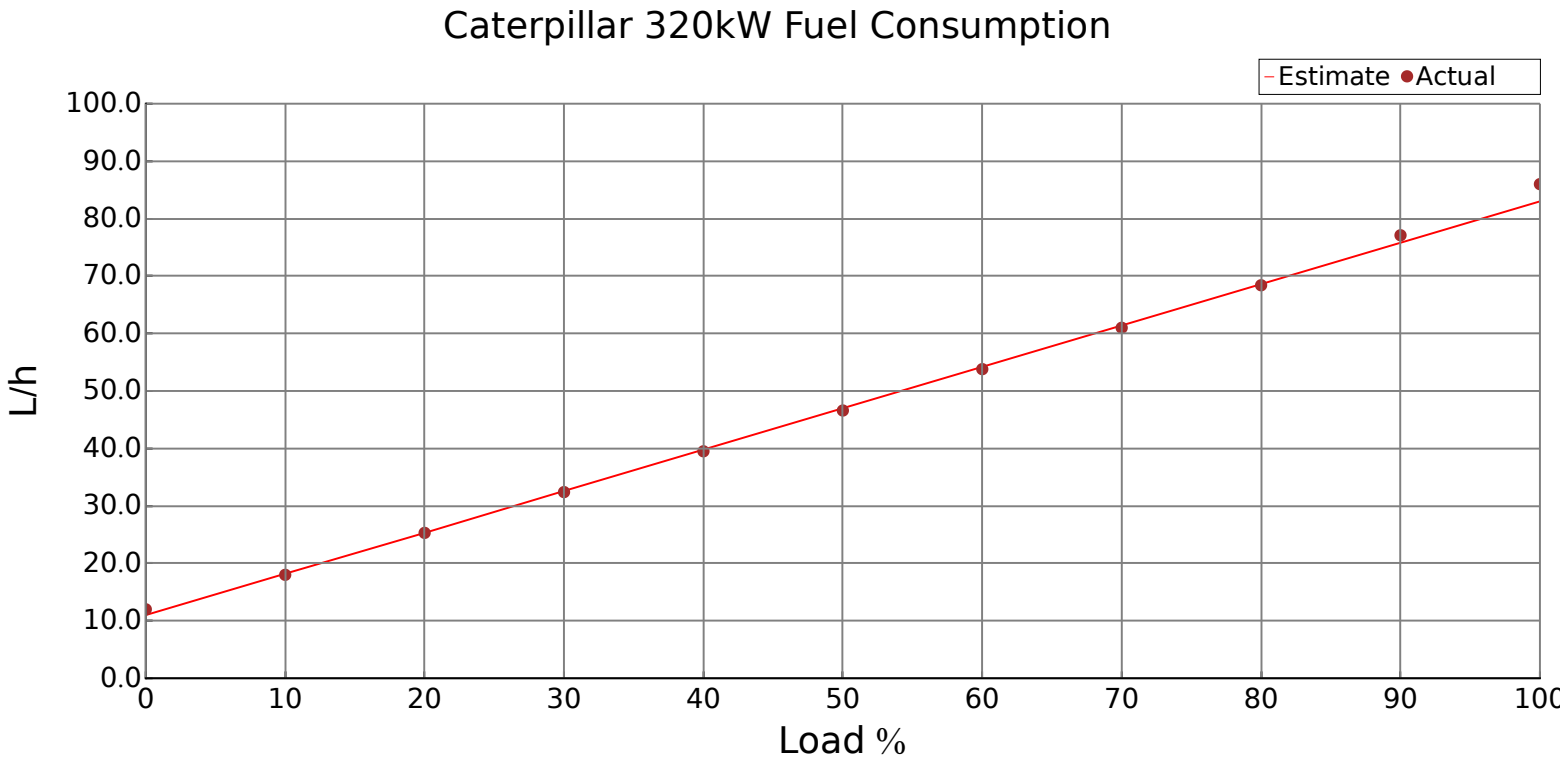
Dill Alert: At low loads my powerfactor is bad Tell someone who cares, its current that matters.

Efficiency



Dill Alert: So clearly we need to run diesels at around 80% load so they are efficient

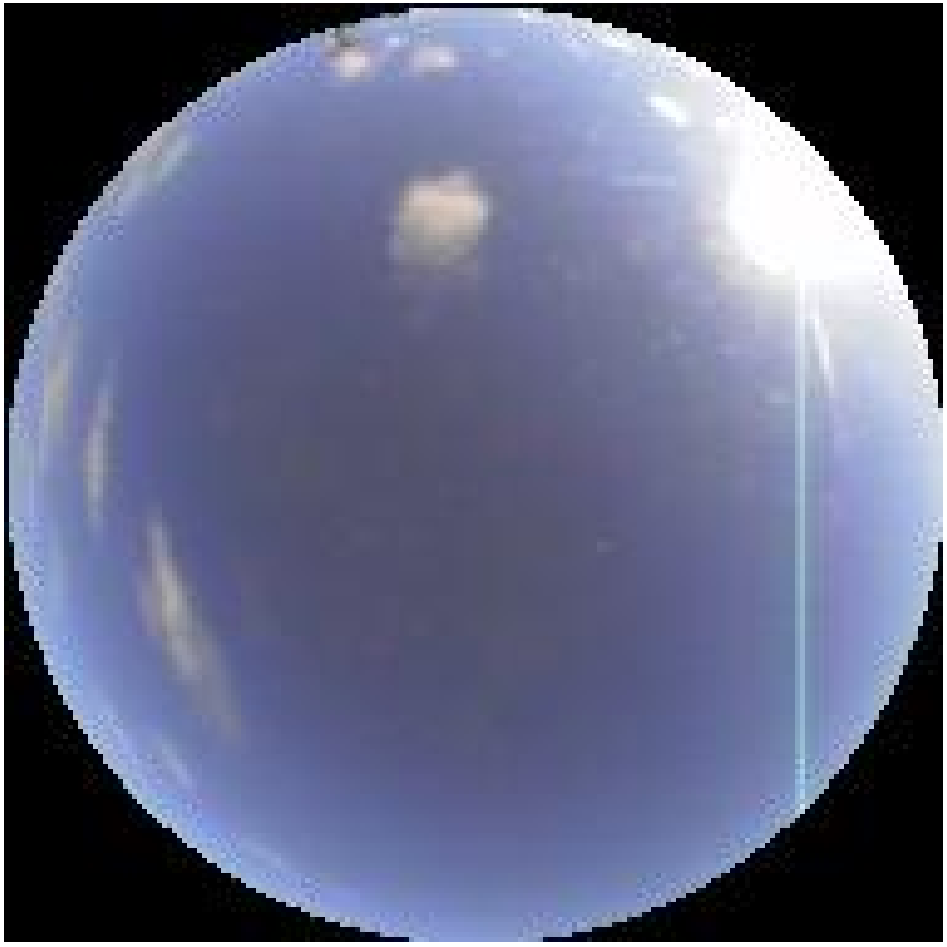
Consumption



Dill Alert: Uhm: so its two parts, X for spinning reserve and Y for each kW produced. We better use the smallest set then.

Sky Camera Forecasting

Use the sky:camera to predict over 2 minutes:



So you can run a smaller diese: 2 x 320 vs 1 x 320 is around 30k$/y.

Demand Management

Control `LoadP` so we can turn off load, perhaps using:

Green Power Point power iff there is excess green power.

Brown Power Point we assure power but there might be an outage for 2 minutes whilst we start a diesel.

Red Power Point always on.

The key thing is we need two way control and measurement. See Saturn South

So what

Finally, we've covered about 20 years research and development in the last wee while.

So what

Finally, we've covered about 20 years research and development in the last wee while.
Feel free to finger poken the author but also try to avoid the dill tests.

So what

Finally, we've covered about 20 years research and development in the last wee while.
Feel free to finger poken the author but also try to avoid the dill tests.

Finally:

Learning is not compulsory...

So what

Finally, we've covered about 20 years research and development in the last wee while.
Feel free to finger poken the author but also try to avoid the dill tests.

Finally:

> *Learning is not compulsory...*
> *neither is survival W. Edwards Deming*