PV Diesel 101

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EDS/ACEP

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Abstract

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

Overview

This talk covers:

- Electricity, 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 the 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.*

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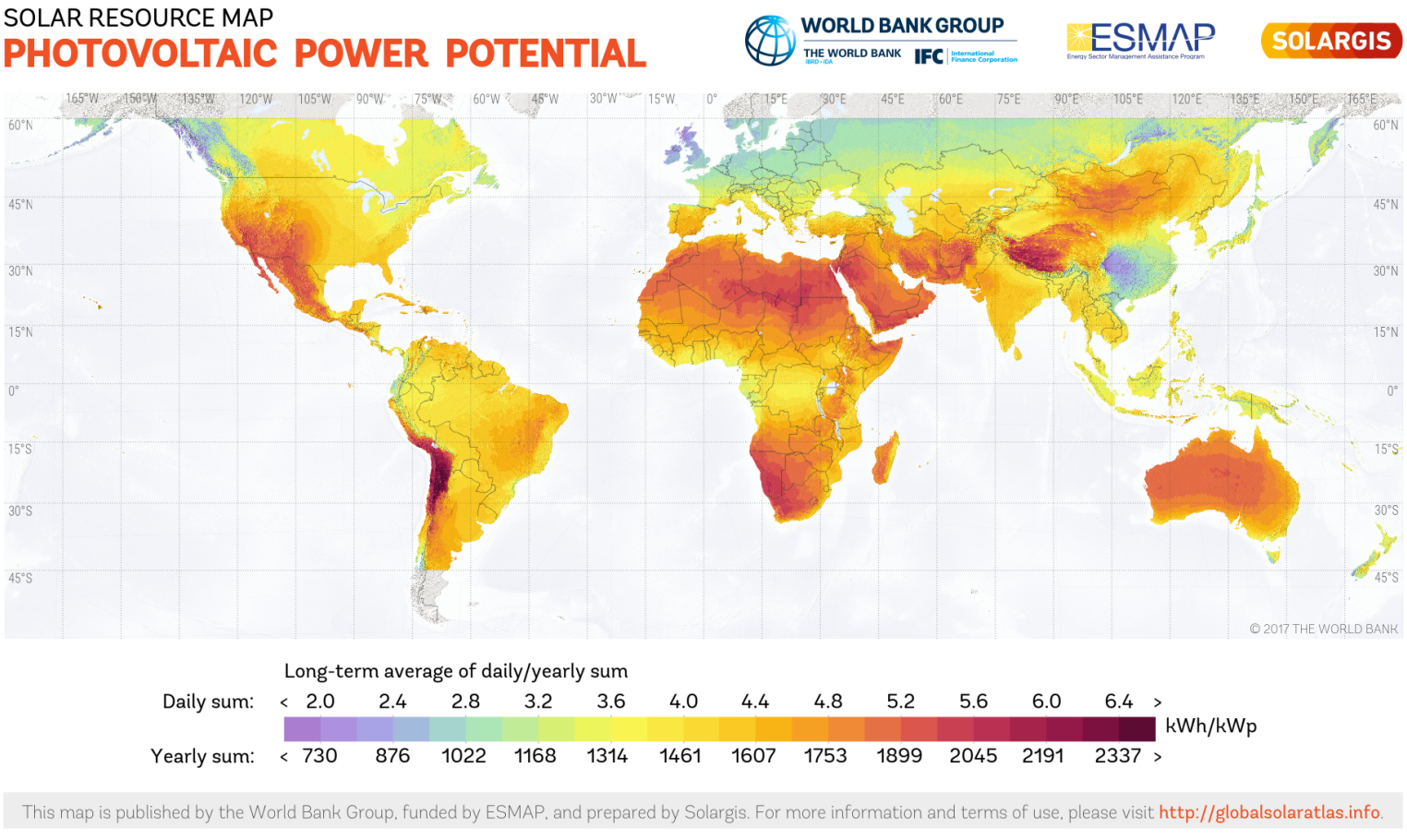
Conventions and References

- SETuP
- Solar Diesel Handbook - a handbook about this topic.
- ASIM - a simulator for PV Hybrid Systems (also see HOMER).
- 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.

Potential and Land Use



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 result in an **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.
- **Reactive Power (vars)**, regulates the voltage, similar to kW it must balance:
  `GenQ = LoadQ`

Note that:

- If `(GenP or PvP > LoadP` then `F` increases.
- And vice versa
- Similarly for `Q` and `V`.

PV good days and bad days

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Capacity factor, Spinning Reserve, Step Load

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

- 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.

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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 possible but:
  - Always run a set for perhaps 30 minutes after starting it.
  - Switch down only after the load has gone down a bit further (hysterisis).
  - Many other things...
- Generator 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

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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. Typical generator start times are around 1 minute.
  Dill Alert: PV varies once every minute for data sampled once every minute
- A bad cloud event typically takes 10s, e.g.
  1. Wind speed at 1000m = 5m/s
  2. Field is 50m across.
  3. Result is obvious, i.e. PV variability depends on wind speed.
- Low Penetration is limited to 10..20% (spinning reserve).

Dill Alert: Design a power system where we keep 30kW of Spinning Reserve and try to install 60kW of PV.

Medium Penetration PV

Medium penetration systems typically do not use storage and reach a peak penetration of perhaps 60% for a 40% minimum 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.

Medium Penetration Example

- Keep enough spinning reserve online:
  `GenMaxP >= GenP + max(PvP,GenSpinPPa)`
- So loss of 100% of the Pv over 10s will be covered by the diesel.
- We must limit PV output in order to the diesels loaded:
  `PvSetP = LoadP - GenMinP`
- The system must keep a diesel online all the time, the PV cannot create the grid (vars, ...)
- Finally: if min loading is 40% the maximum penetration is 60% sif the loads match the generators.

Spill

- `PvAvailP > PvSetP` so we are wasting PV. **Dill Alert: Is this a bad thing, splling?**
- Inevitable in Medium Penetration Systems.
- We need to minimize spill by:
  - Appropriate Generator sizing.
  - Controlling load profiles.
- Note that most of the cost of the PV in is in the mobilisation, i.e. its X+Y*K not Y*K.

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 in order to run Diesel Off.
This is not the normal PV inverter. Remember we need to balance P and Q. (Faults are left for the 102 course).

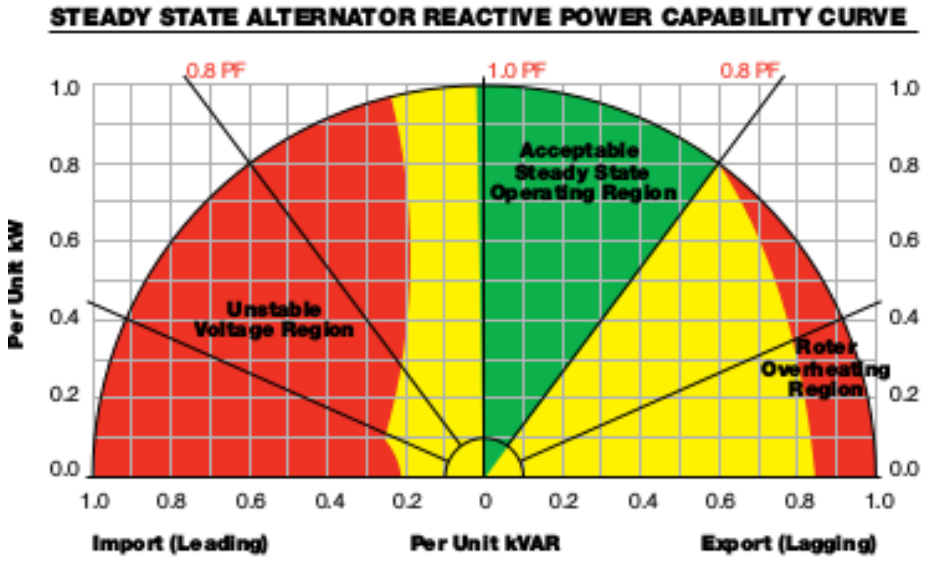
Examples are available from WA, AQ, AK, MY, ID, etc.

But its not off the shelf for larger systems.

Powerfactor

Powerfactor is the ratio between P and S where S=P+Q.

- P is the kW loading,S is the kVA loading, i.e. the current x volts, Q is the kvar loading.
- Typically 0.8 to 0.9, 1.0 means its just a resistor.



Dill Alert: At low loads my powerfactor is bad, panic

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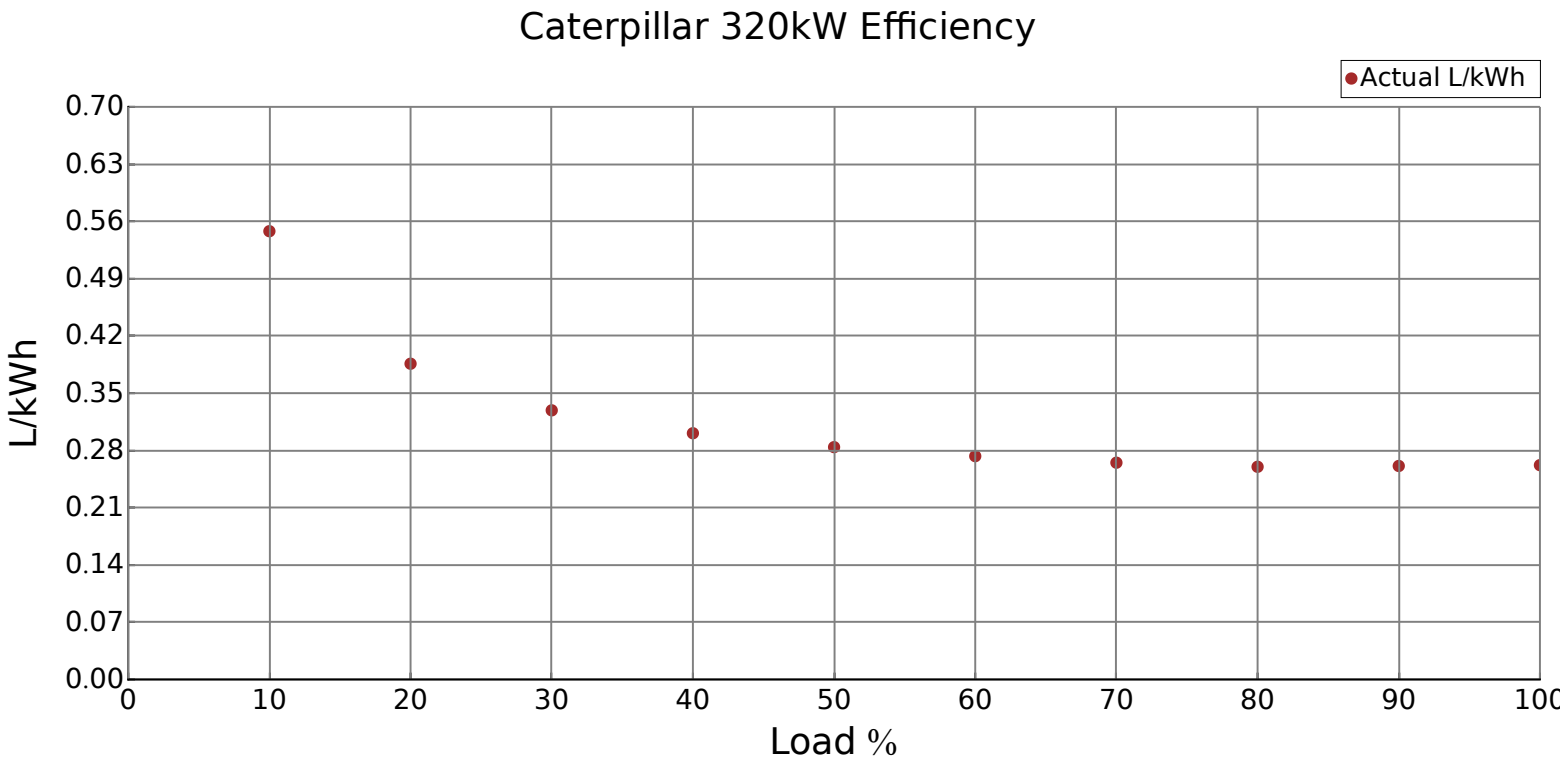
Fuel Efficiency



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

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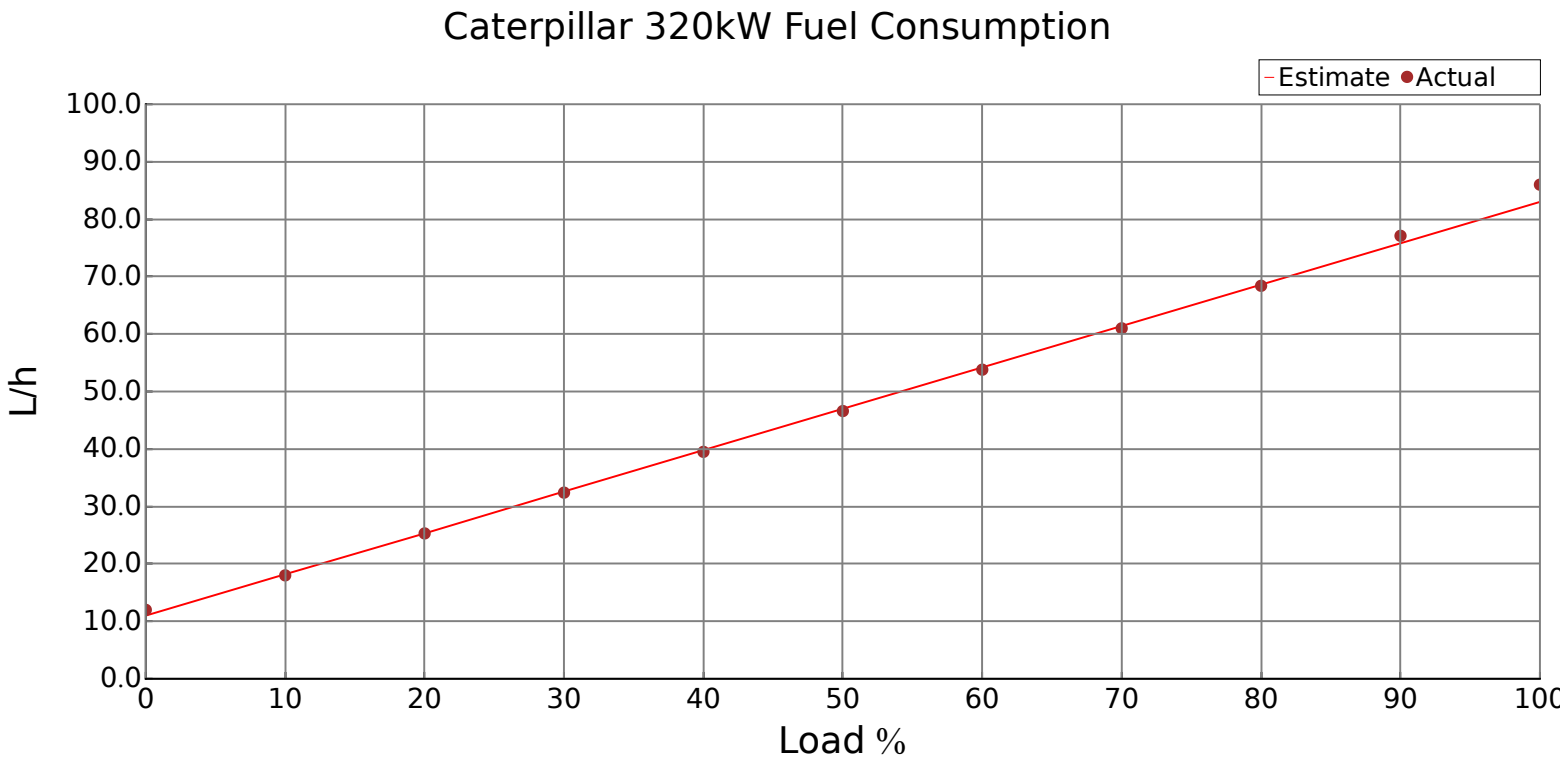
Fuel Consumption



- This makes sense since diesels run at fixed speed.
- So there is a cost for spinning and a cost for generating.
- So every bit of PV saves fuel, running a smaller generator saves fuel.

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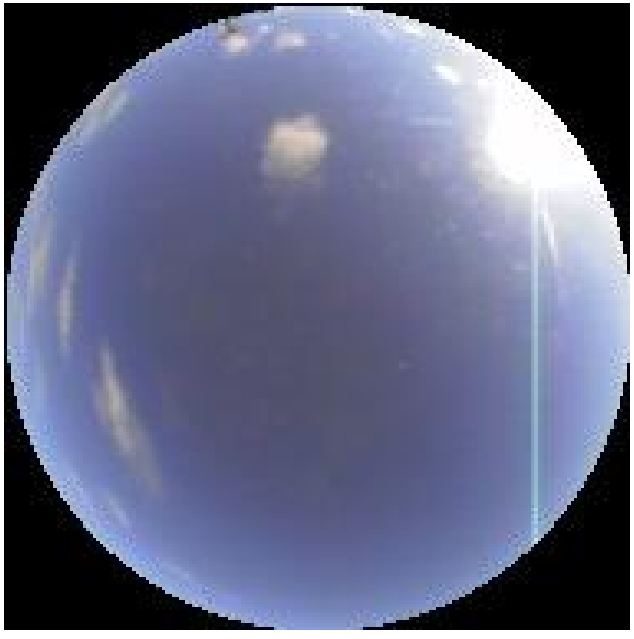
Sky Camera Forecasting

Use a SkyCamera to predict cloud over the next 2 minutes:



So you can run a smaller diesel: 2x320kW vs 1x320kW is around 30k$/y.

Then start the next diesel when the cloud comes.

Demand Management

Control `LoadP` so we can turn off some 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

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

Finally:

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