Bruno Gaiddon

TRAINING ON RENEWABLE ENERGY MINI-GRIDS

Session 1 : Grid and mini-grid fundamentals

ISA/Government of Tonga/PCREEE/INES

15 November 2021

Introduction

Training on Renewable Energy Mini-Grids

Day 1

- Session 1: Grid and mini-grid fundamentals
- Session 2: Why Solar PV Mini-grid is a promising alternative for conventional power generation in Tonga
- Session 3: How to select components that suit the Tonga/Pacific Islands context ?

Day 2

- Session 4: PV system and storage predesign
- Session 5: Commissioning on the ground
- Session 6: Optimizing maintenance

Content of session 1

- Introduction
- Island grids and diesel generator sets
- Integration of PV into diesel mini-grids
- Mini-grid architectures
- Voltage drops

Electricity production in small islands

- Most common way to produce electricity : Diesel generator sets (gensets)

Kaledupa
(source: energynautic)

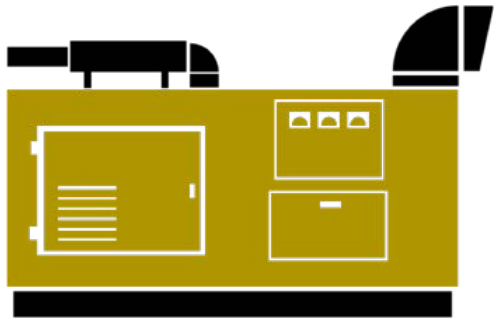
Bequia
(source : P. Blechinger)

Advantages of Diesel gensets

- Low capital cost
- “Grid forming” generators

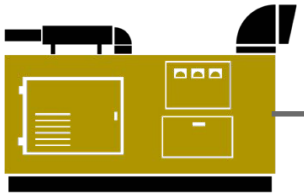
(don’t need any other generator to run)

- Power production automatically matches consumption



Daily power consumption profile

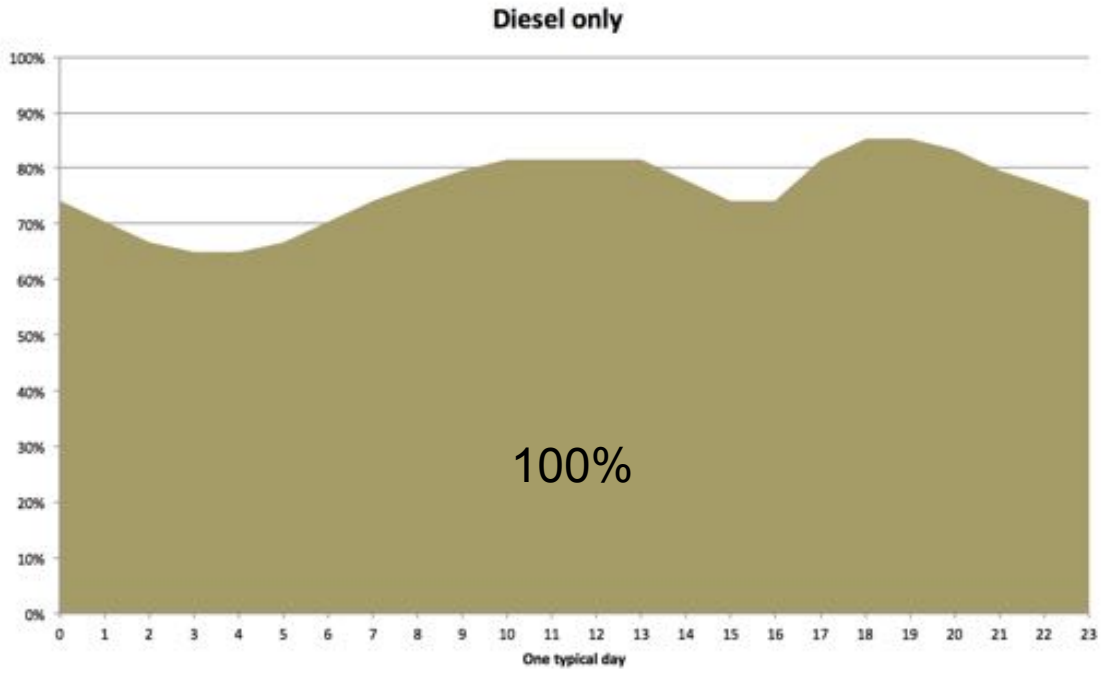
Diesel only



Mini-grid

Genset

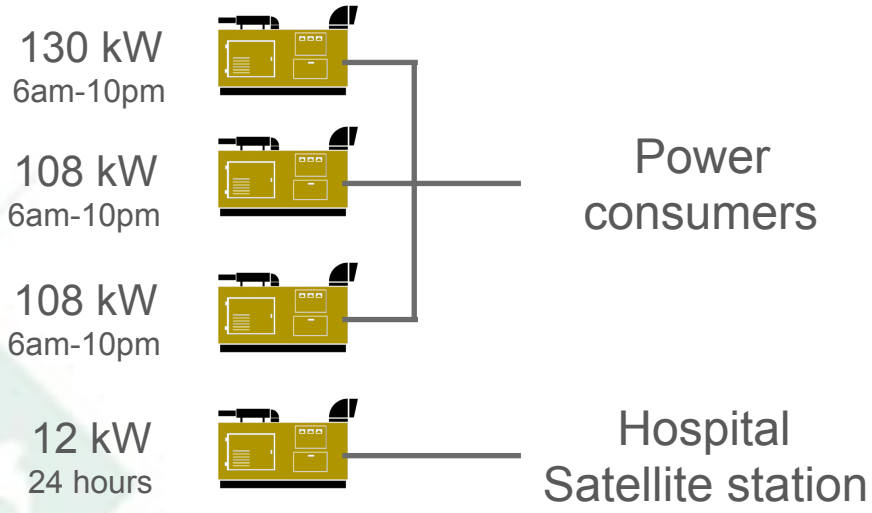
Loads



Electricity production in small islands

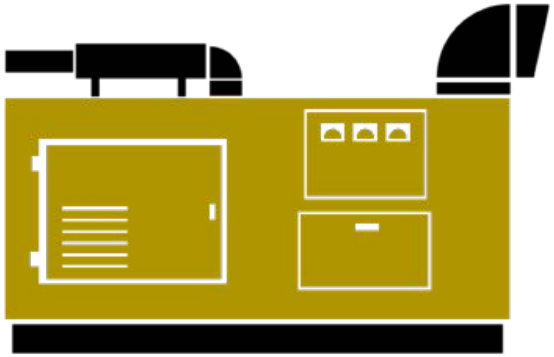
Example : Adamstown (Pitcairn)

- Annual consumption : 150.000 kWh (estimated)
- 4 diesel gensets located in a power station



Disadvantages of Diesel gensets

- High operating cost
- Volatile price of Diesel
- On-site delivery (access, theft)
- High environnemental impacts
- Low power quality



Rationales to switch from diesel to solar

(source : SMA)

(source : Delta)

Environmental / Social / Economical

Rationales to switch from diesel to solar

Reduction of oil spill risk / reduction of CO2 emissions

- Rennell Island (Solomon Islands)
- Shipwreck of MV Solomon Trader in February 2019
- 300 tonnes of heavy fuel oil

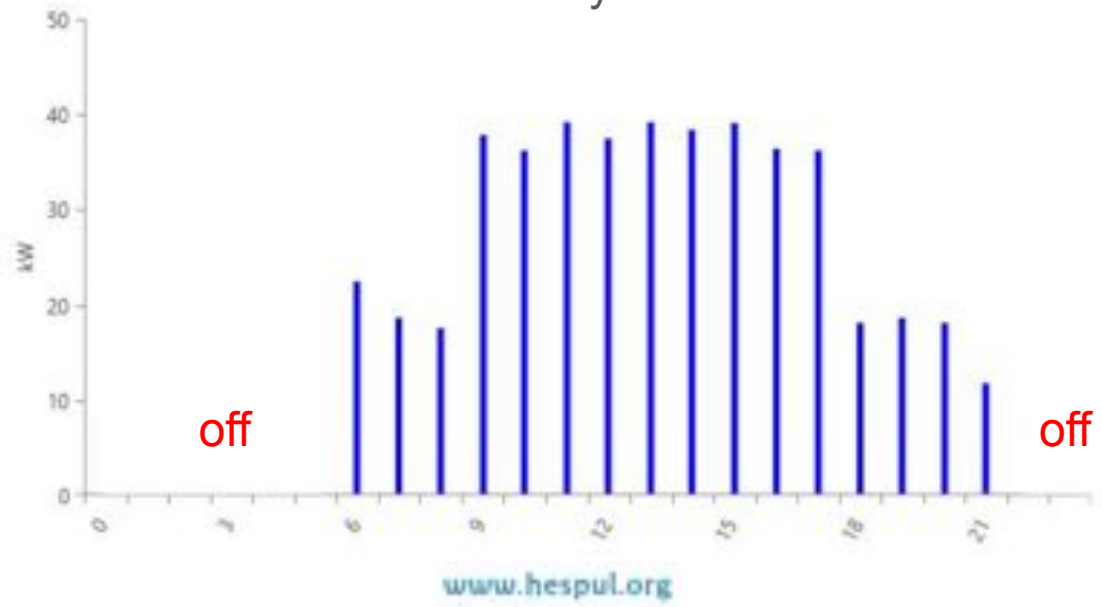
(source : Solomon Star/Carlos Aruafu)

Rationales to switch from diesel to solar

Improvement of the quality of supply with less power outages

- Adamstown (Pitcairn)
- Diesel gensets are off from 10pm to 6am !
- Emergency genset for the Hospital and the Satellite station runs 24 hours

Mean daily load curve

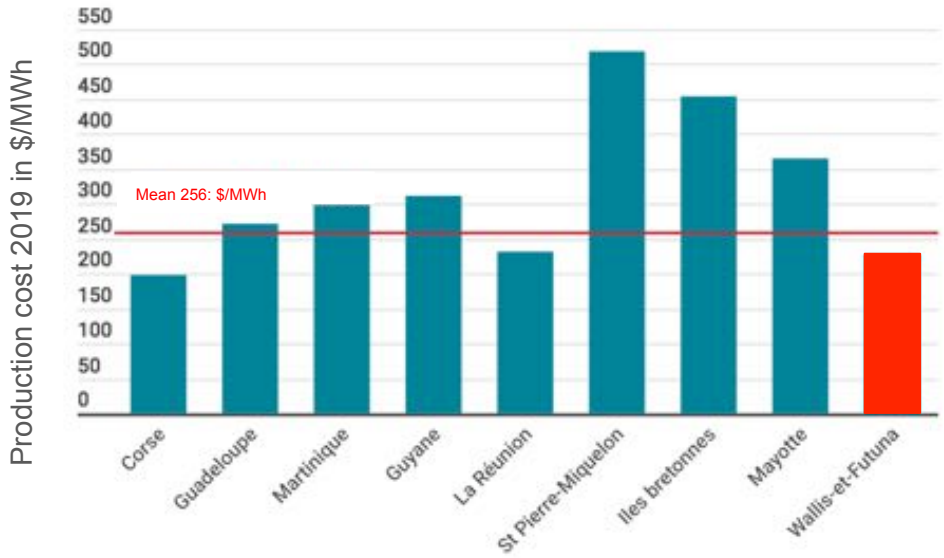


Rationales to switch from diesel to solar

Reduction of the electricity generation cost

- Wallis-et-Futuna (France)
- 7 gensets – 6,8 MW (Wallis) + 4 gensets – 1,7 MW (Futuna)
- Production cost of approx. 230$/MWh
- Price paid by consumers : 153$/MWh !

(source : EEWF)



(source : CRE)

Advantages of photovoltaic systems

- No fuel needed (except the sun !)
- Low environmental impacts
- Low operating cost
- Low production cost compared to Diesel (0,05-0,2 USD/kWh)
- High quality of the power delivered

Disadvantages of photovoltaic systems

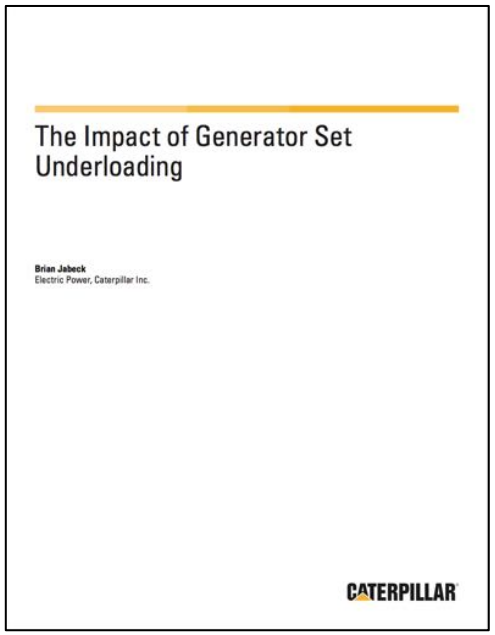
- High capital cost
- Land use
- “Grid following” generators

(need another generator to run)

Operation of gensets with PV

Underloading impacts gensets negatively

Hosting capacity of Diesel Island grids : « *Operating a diesel generator set at load levels less than **30 percent** of rated output for extended time periods impacts the unit negatively.* »

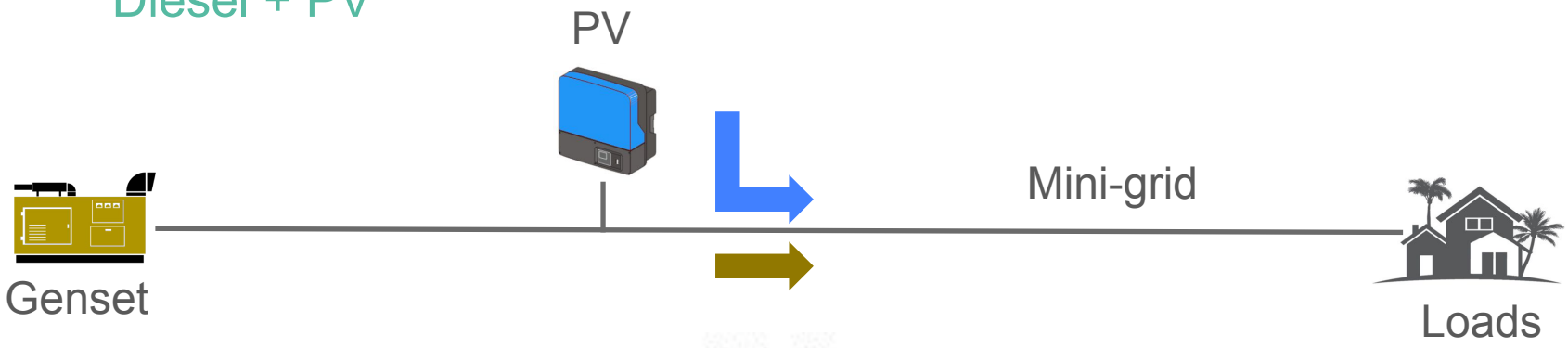

The Impact of Generator Set Underloading

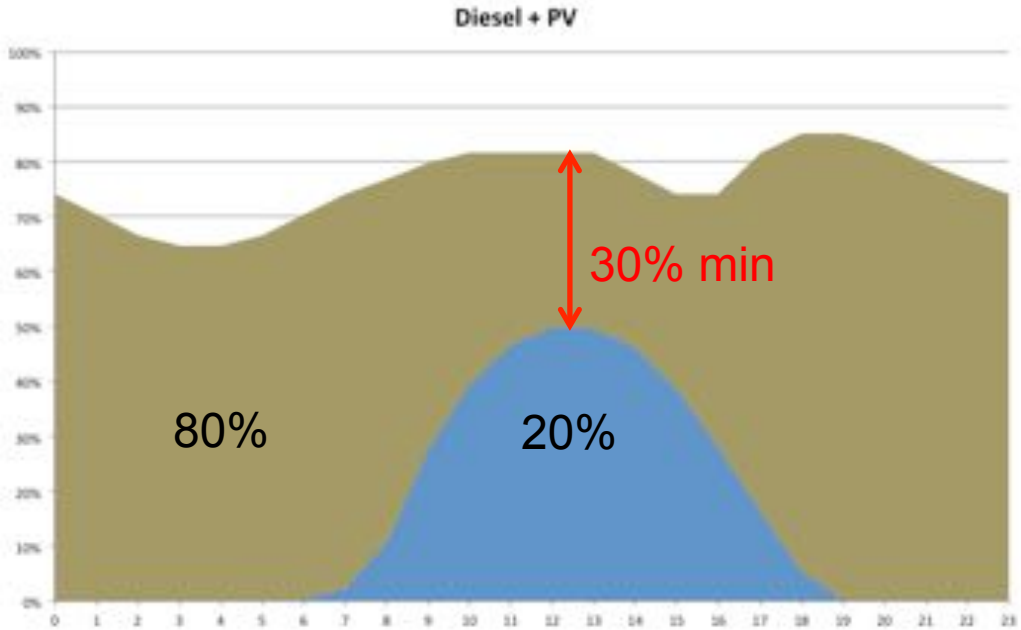
Brian Jabeck
Electric Power, Caterpillar Inc.

CATERPILLAR

Daily power consumption profile

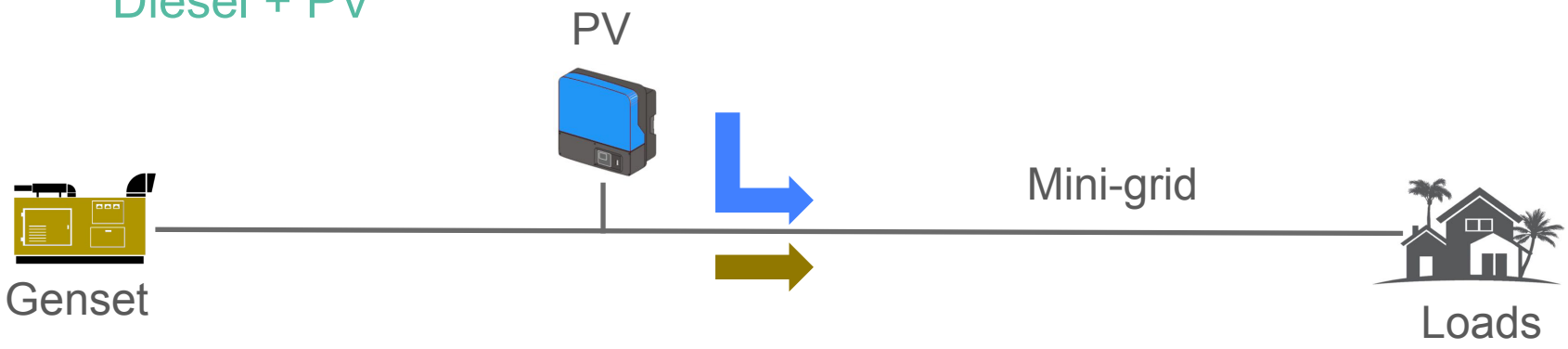
Diesel + PV



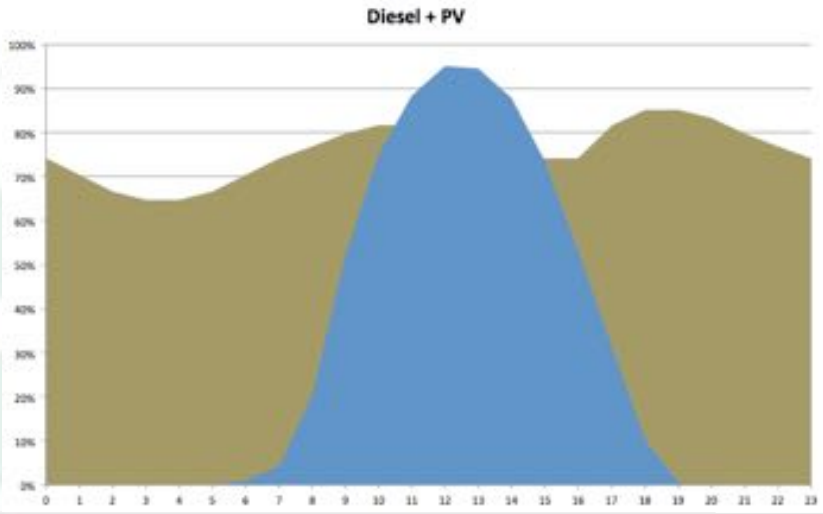


Daily power consumption profile

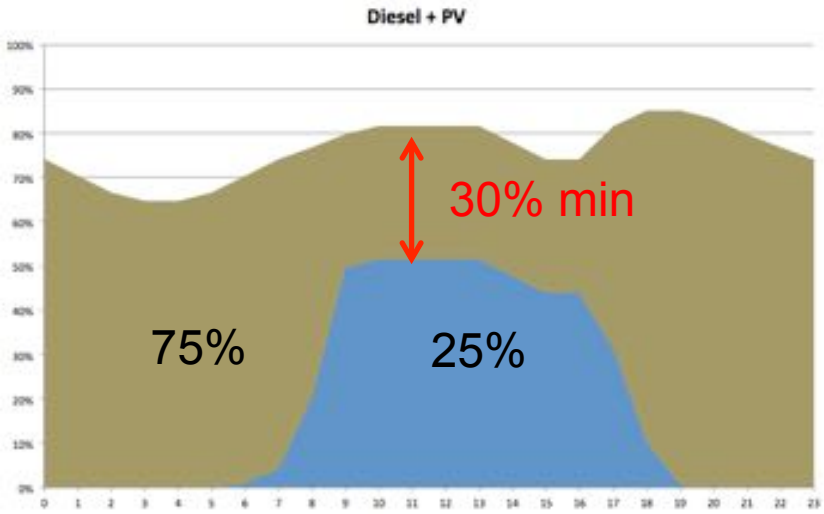
Diesel + PV



Oversizing of PV …



will lead to massive curtailments !

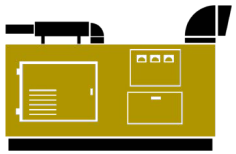


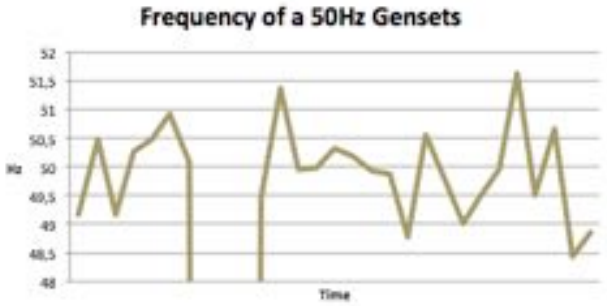
Added value of storage

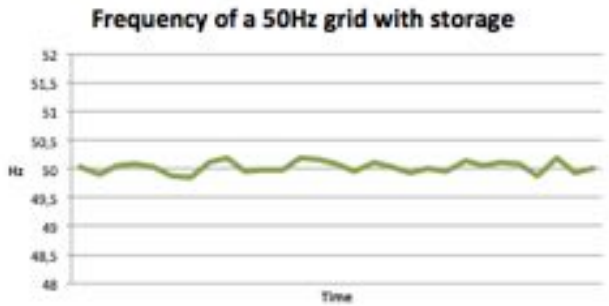
- Improvement of the power quality
- “Grid forming” generators

Added value of storage

Improvement of the power quality





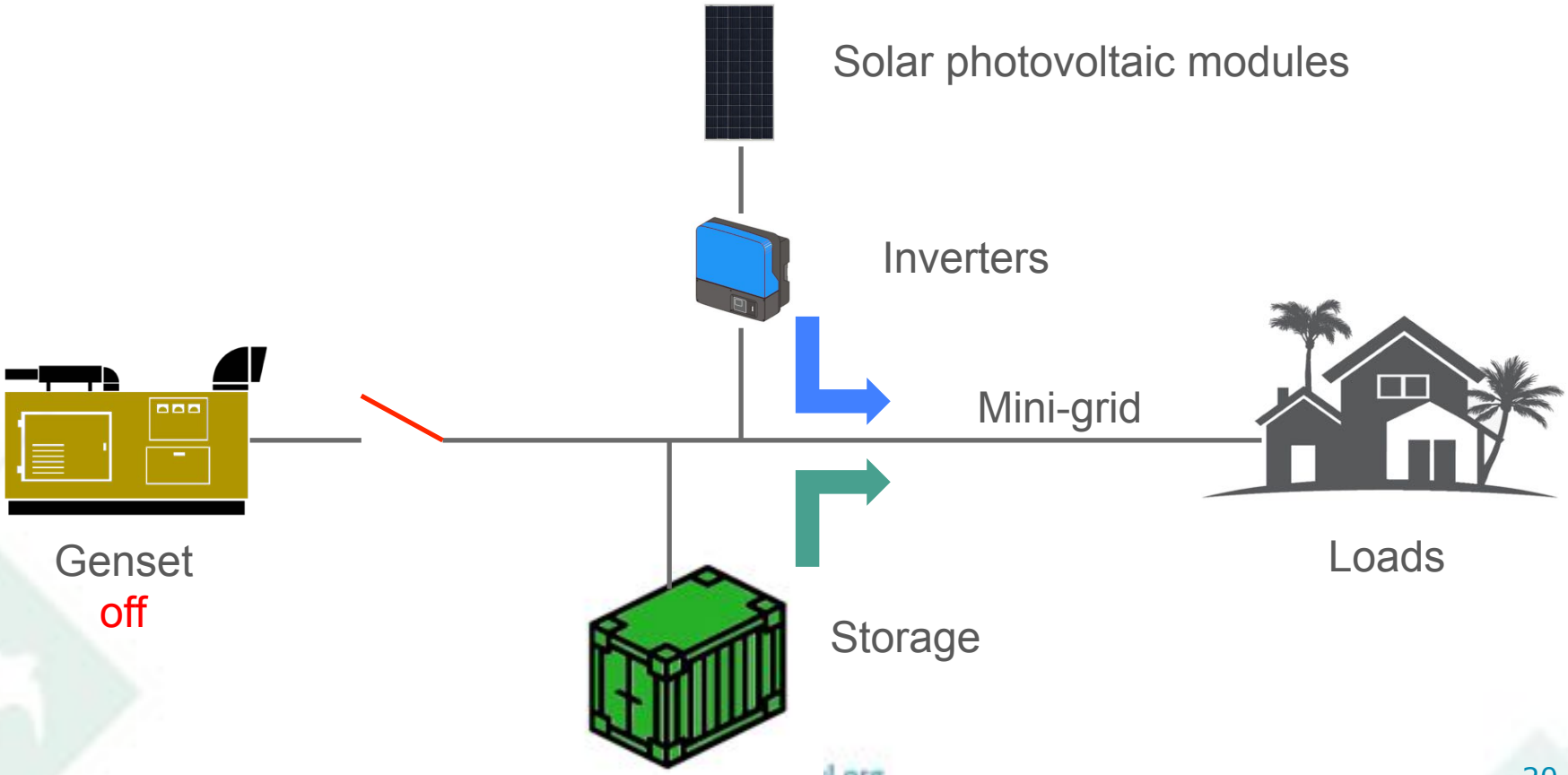


→ Genset back-up in case of power outage

→ Stabilisation of the frequency

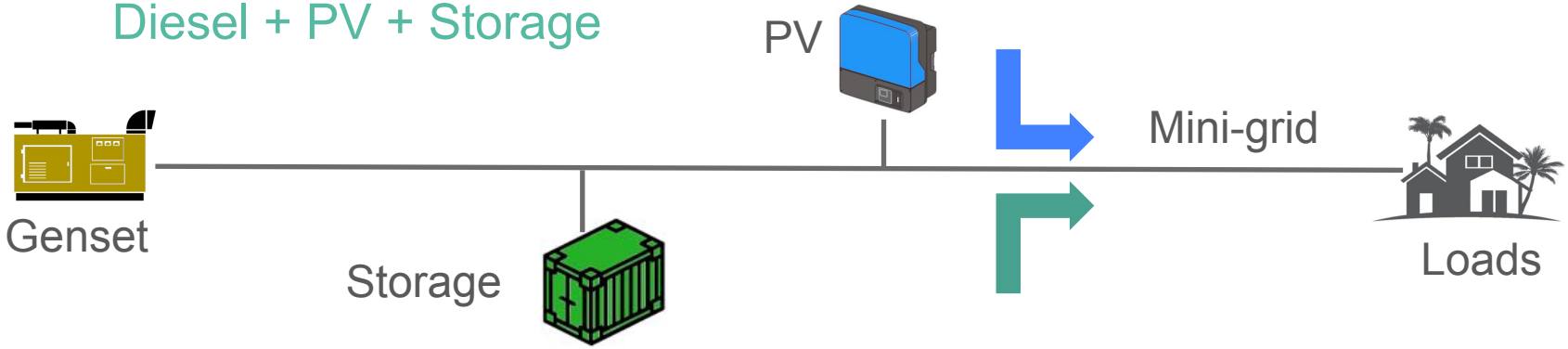
Added value of storage

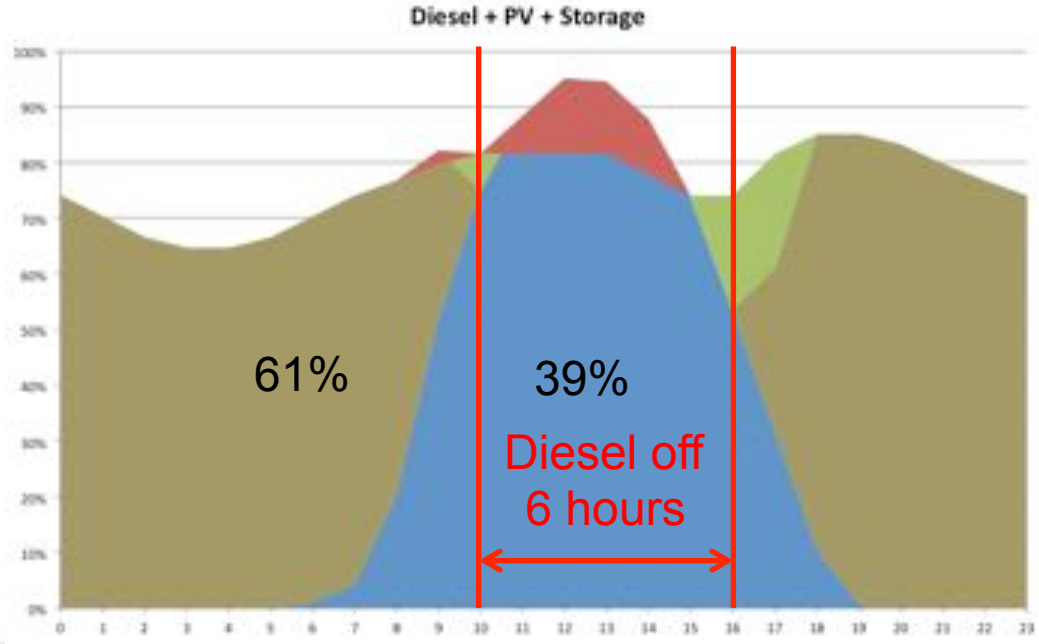
"Grid forming" generators that can replace gensets



Daily power consumption profile

Diesel + PV + Storage

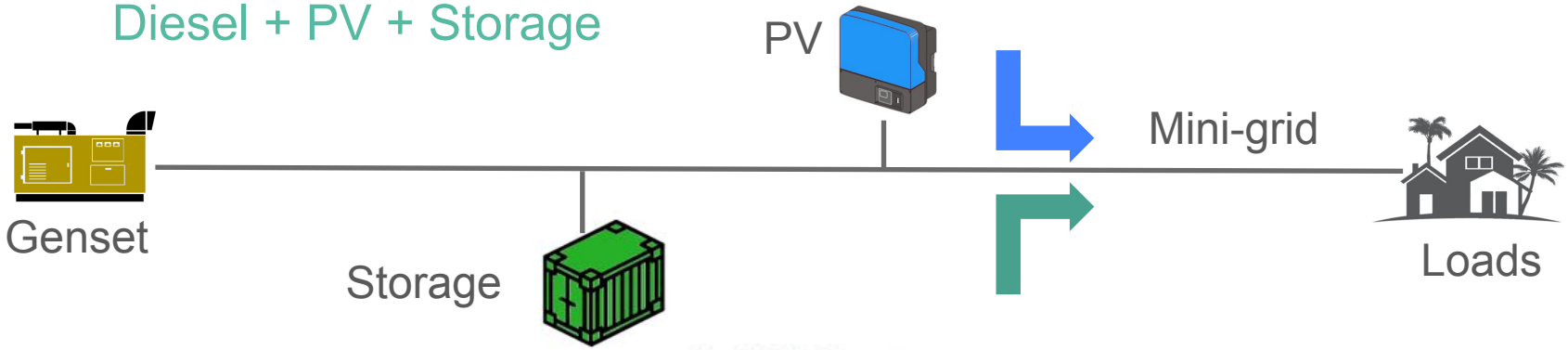


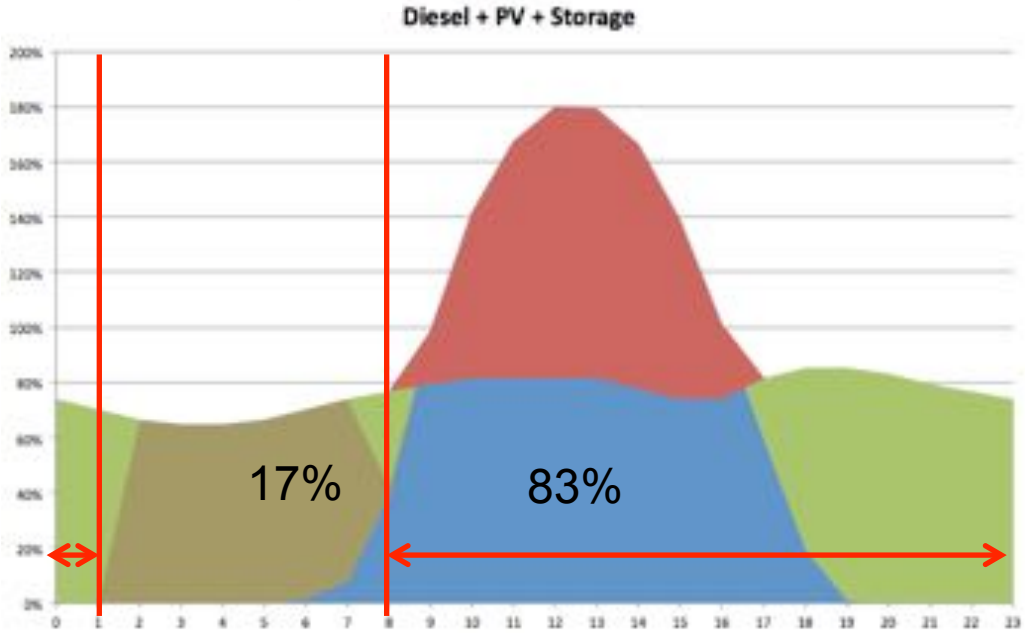


Small storage

Daily power consumption profile

Diesel + PV + Storage



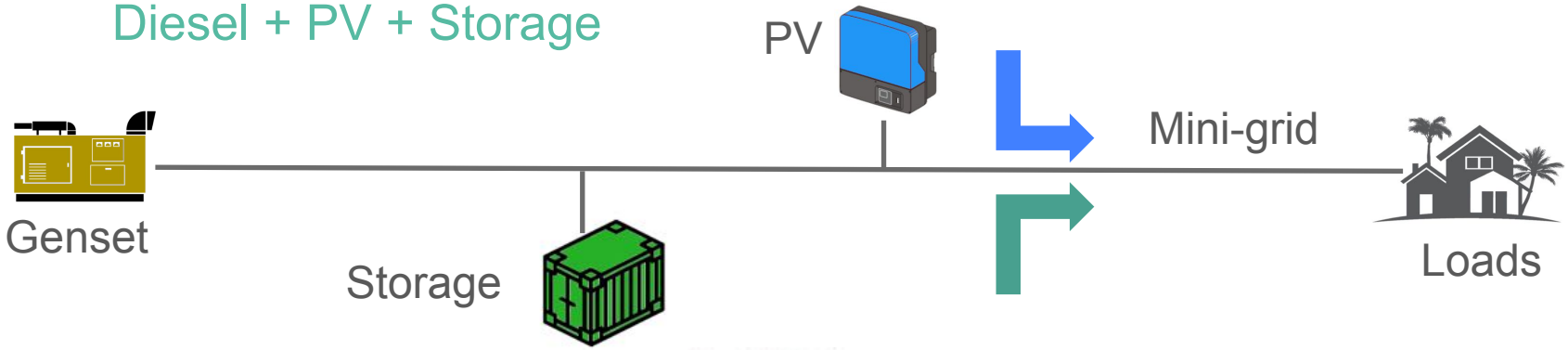


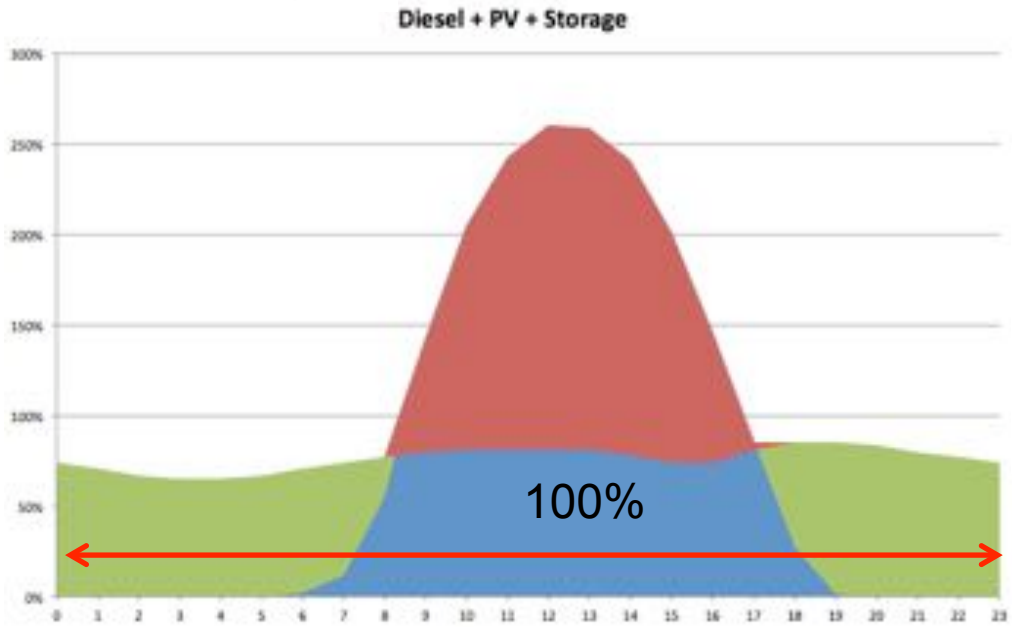
Medium storage

Diesel off
14 hours

Daily power consumption profile

Diesel + PV + Storage



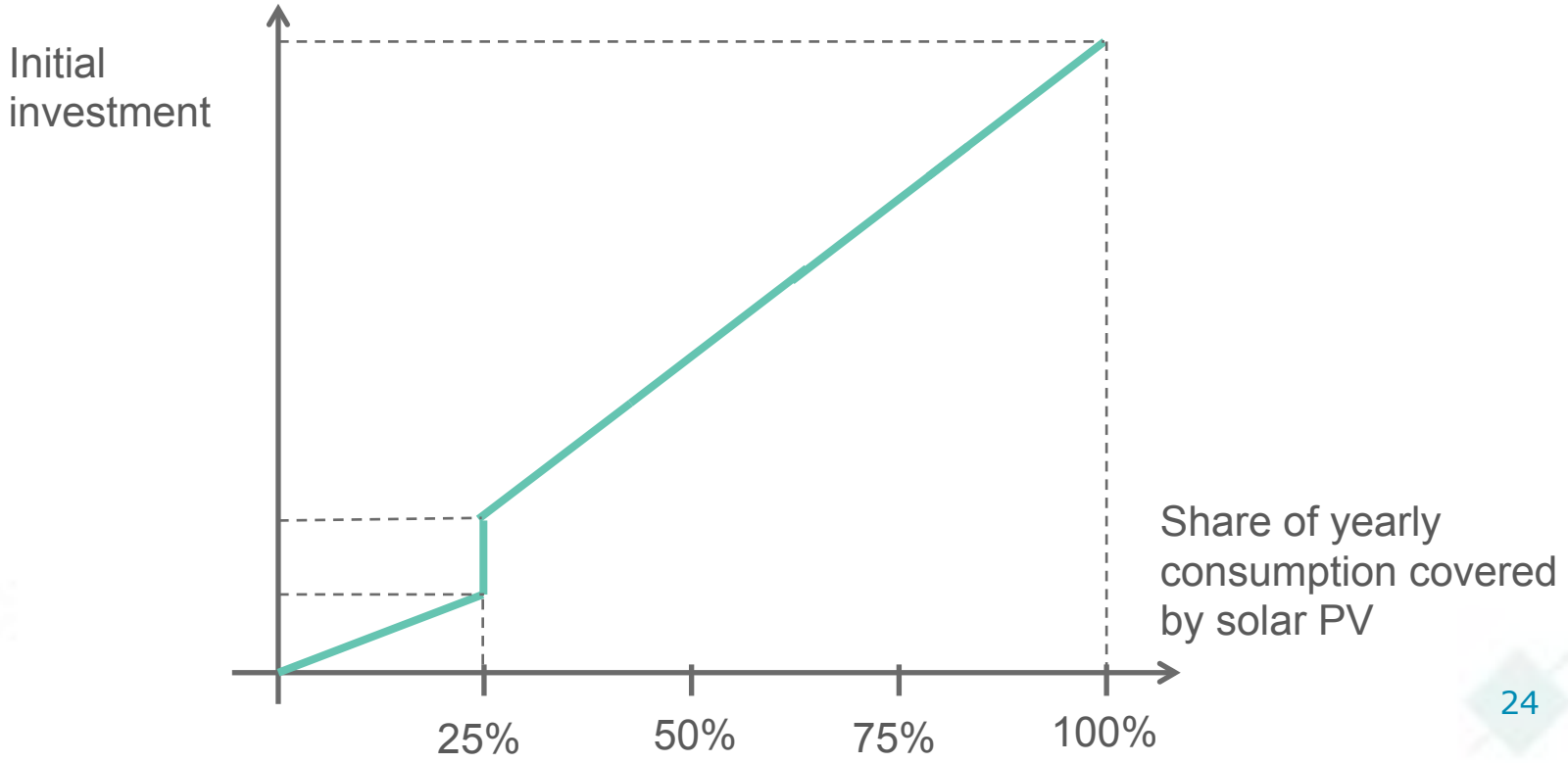


Large storage

Diesel always off !

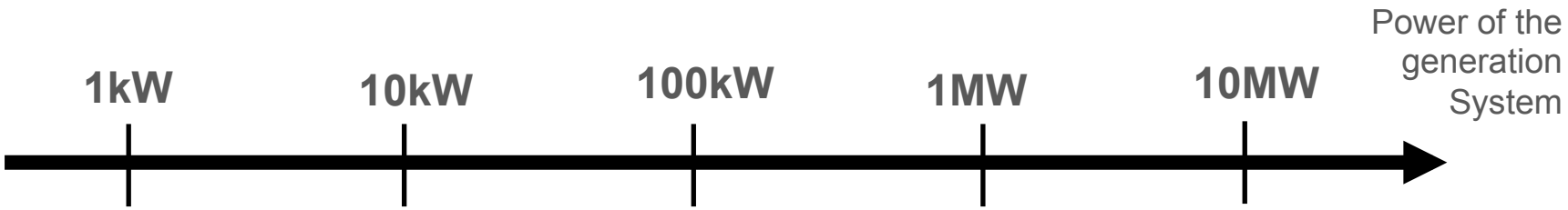
Energy supply of Islands with solar PV

- 0-25% of yearly consumption covered by solar PV easily achievable
- 25-100% of yearly consumption covered by PV requires additional investments



Mini-grids ?

Various approaches

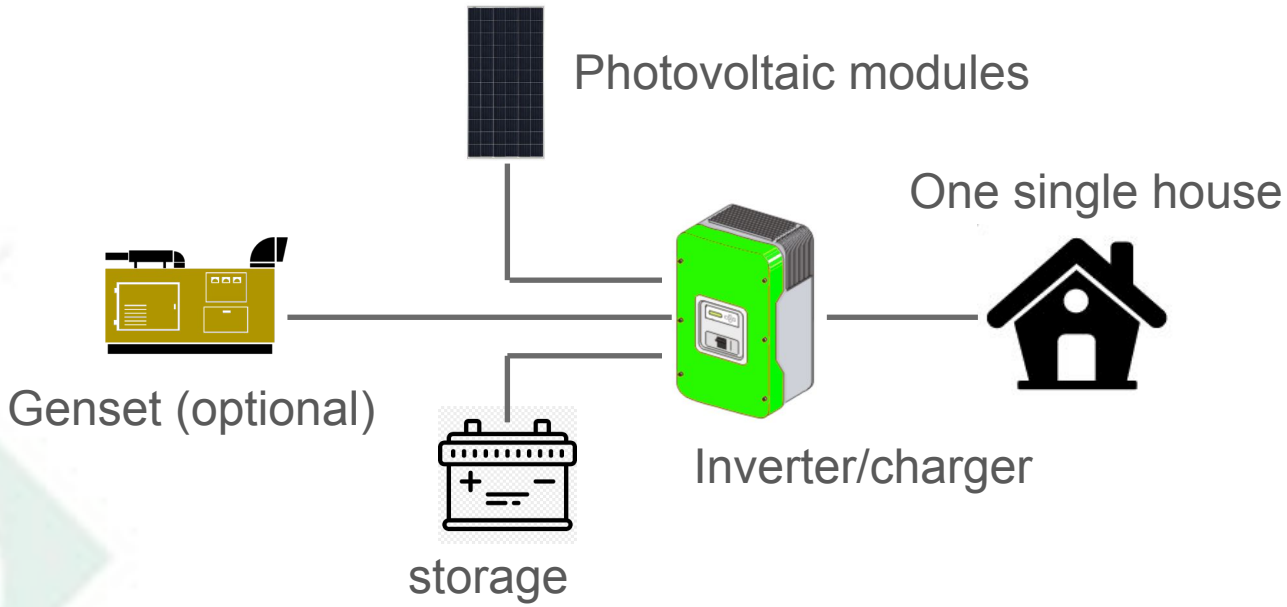


Stand-alone PV systems

Mini-grids ?

Stand-alone based architecture

- One inverter/charger connected to the PV modules, the storage (lead-acid) and a back-up genset (optional)



Mini-grids ?

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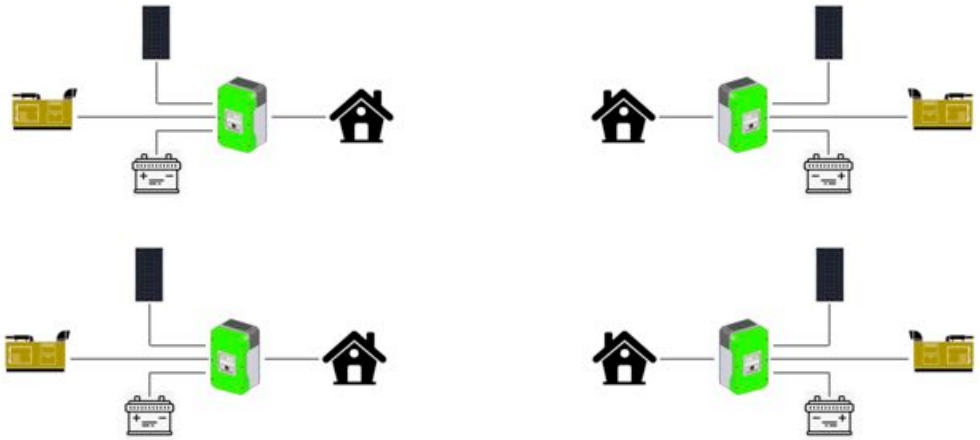

Mini-grids ?

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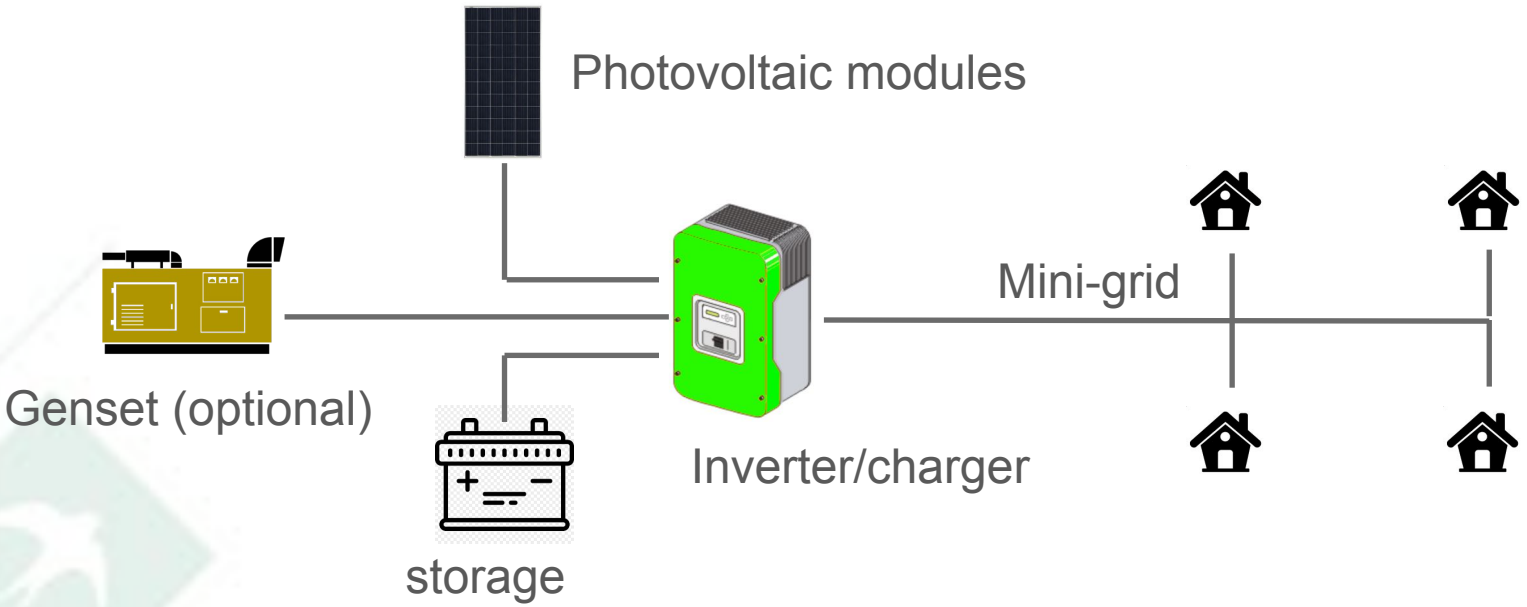
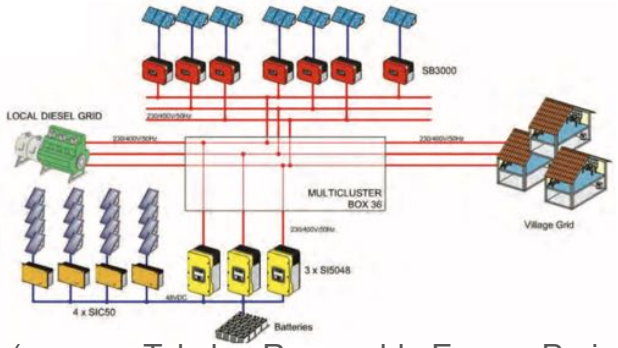


Mini-grids ?

Stand-alone based architecture

- One inverter/charger connected to the PV modules, the storage (lead-acid) and a back-up genset (optional)
- Example : Nukunonu (Tokelau)
  - 265 kWp PV system
  - 2,3 MWh storage (lead-acid)
  - 91% of annual consumption covered by solar

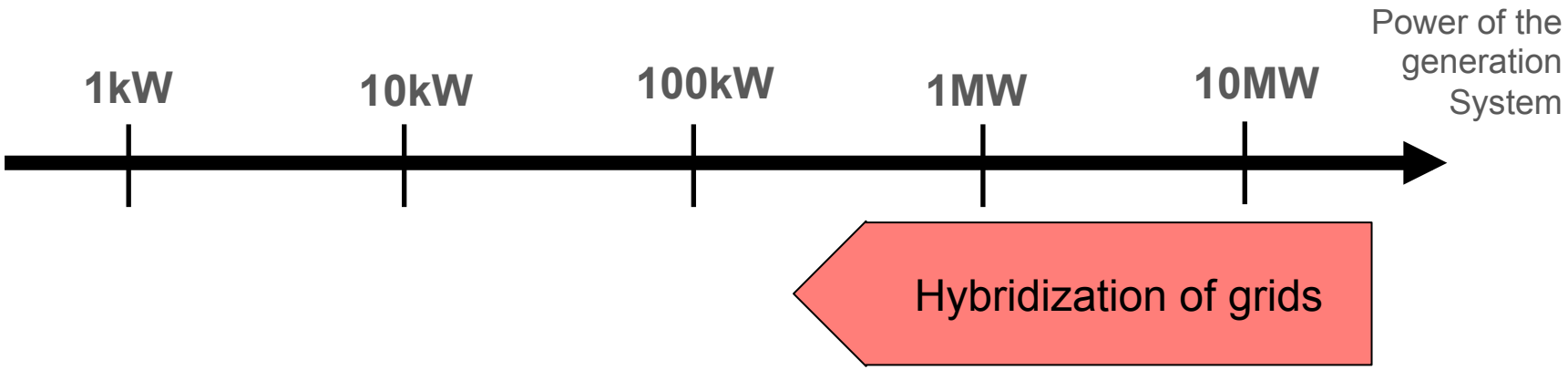
(source : U. Weissbach)



(source : Tokelau Renewable Energy Project)

Mini-grids ?

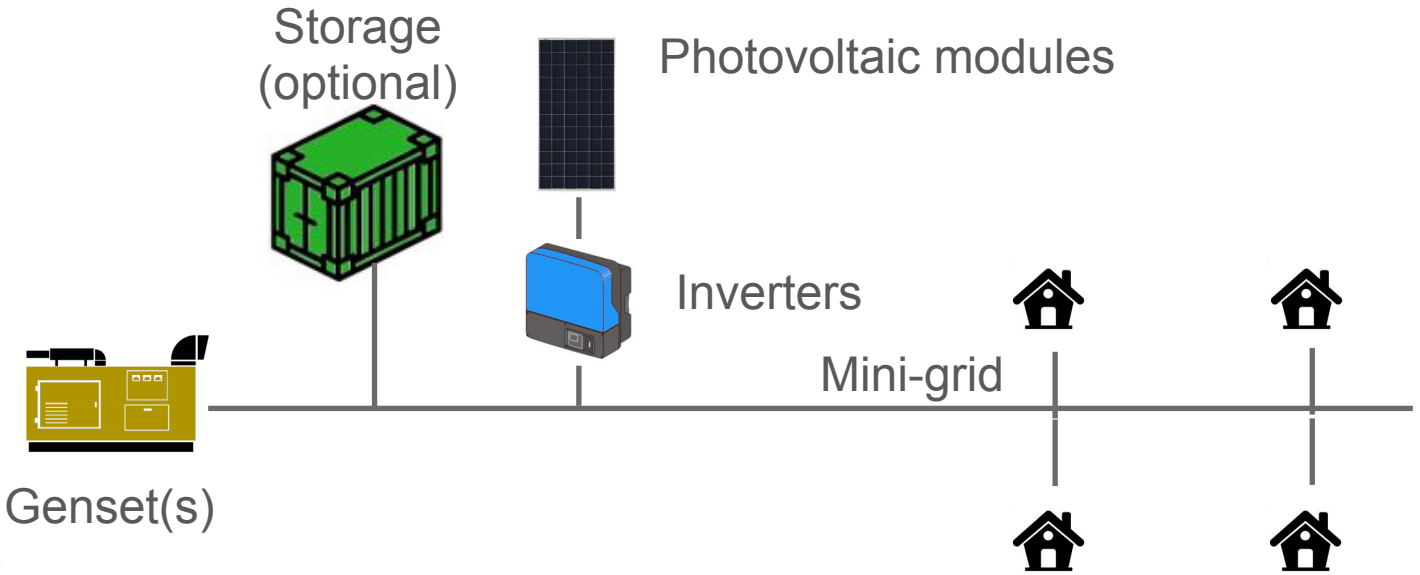
Various approaches



Mini-grids ?

Hybridization of grids

- PV system connected to a diesel genset powered micro-grid with an inverter/charger dedicated to Li-ion storage (optional)



Mini-grids ?

Hybridization of grids

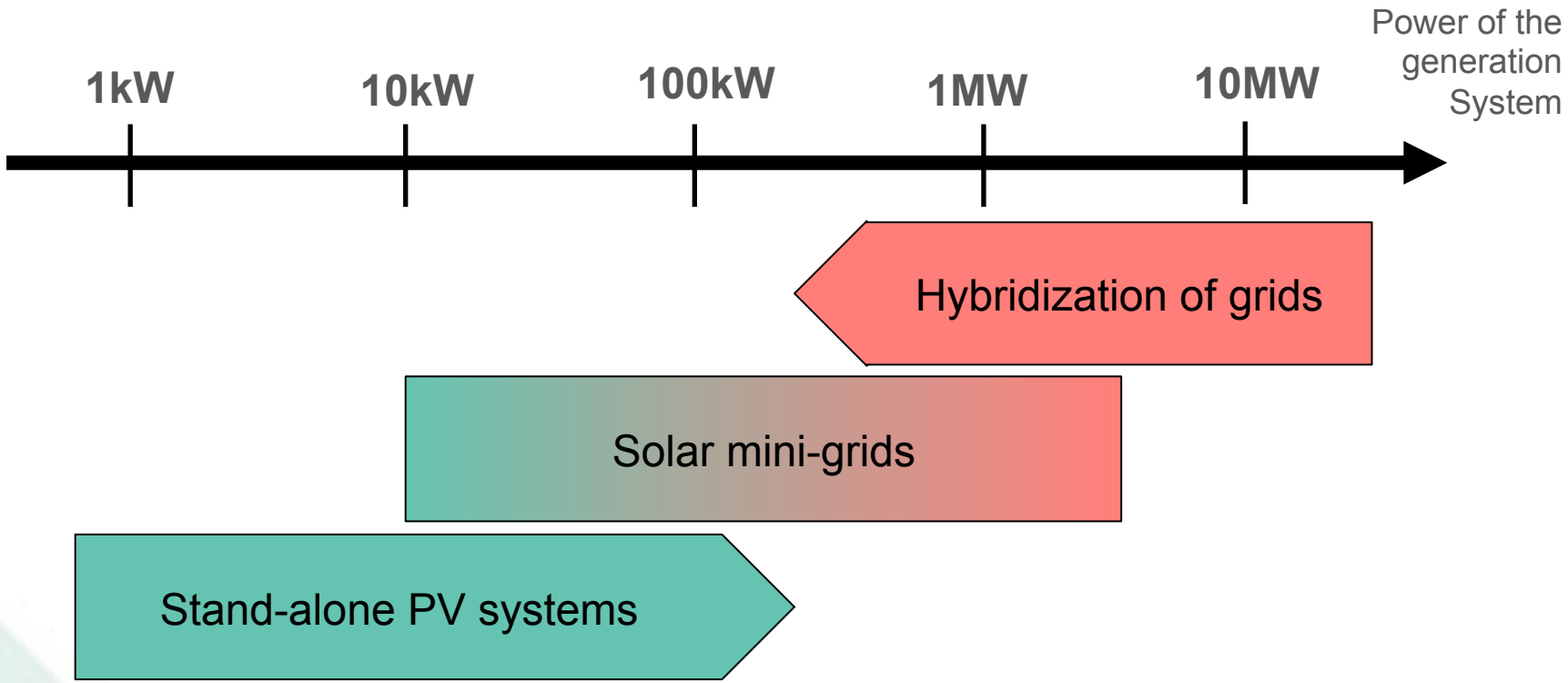
- PV system connected to a diesel genset powered micro-grid with an inverter/charger dedicated to Li-ion storage (optional)
- Example : Tongatapu (Tonga)
  - Island grid powered by 14,3 MW of diesel gensets
  - 3 PV systems for a total of 4,32 MWp
  - 2 storage systems for a total of 13,2 MW/29,3 MWh storage (Li-ion)

(source : Tonga Power LTD)

(source : Tonga Power LTD)

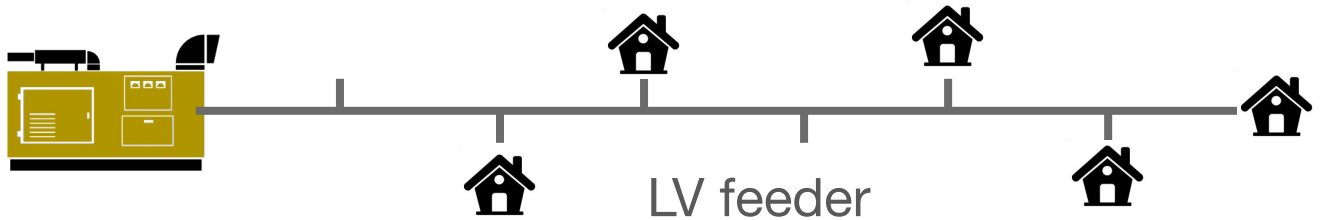
Mini-grids

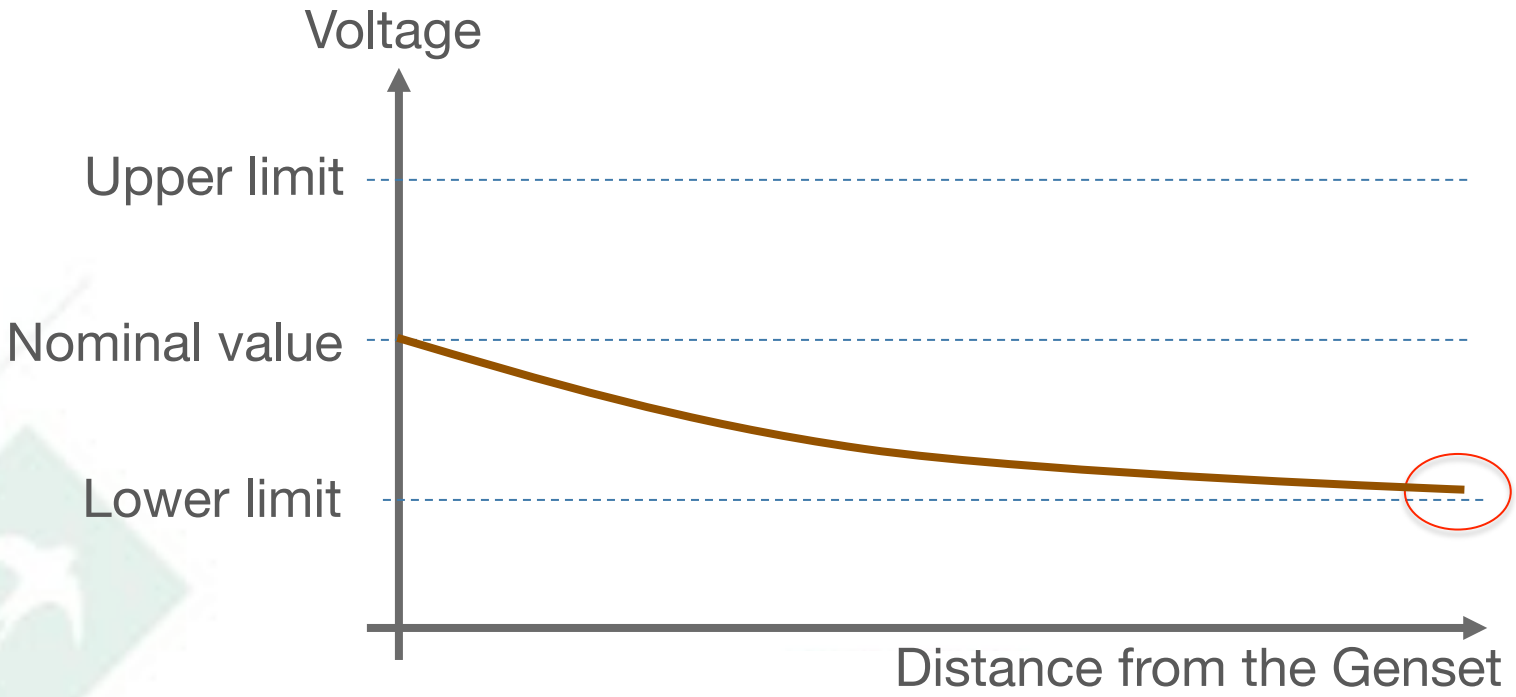
Various approaches



Voltage drops

Basics





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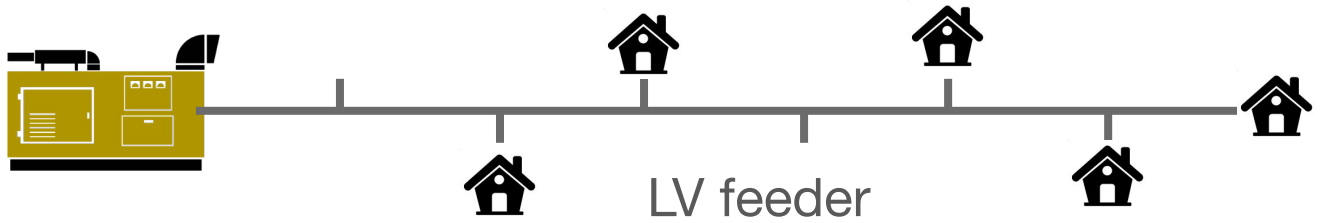


$$\Delta U(\%) = 100.\frac{R_L}{U^2}.P.L$$

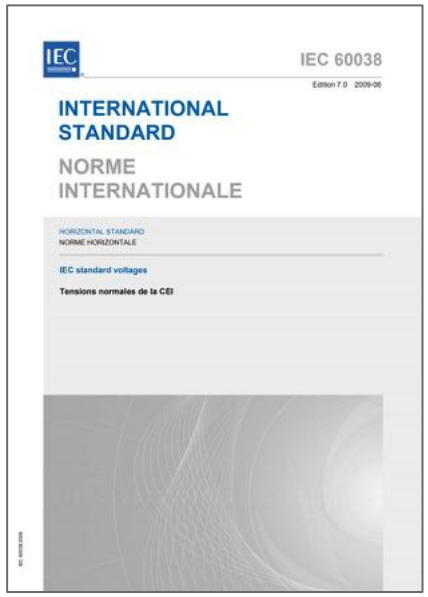
Voltage drop increases with :

- the linear resistance of the cable (R_L)
- the power consumed (P)
- the length of the cable (L)

Voltage drops

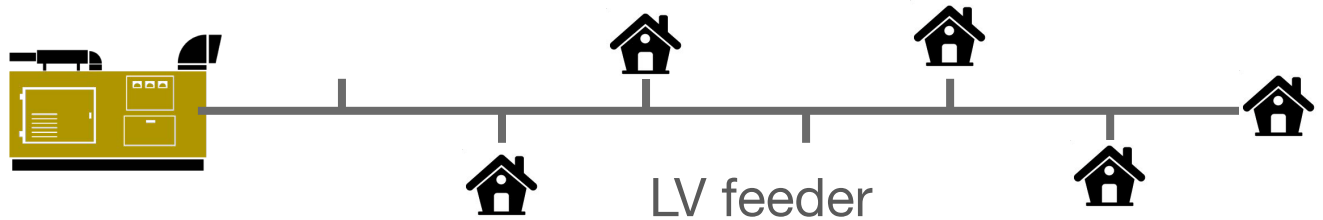
International standard

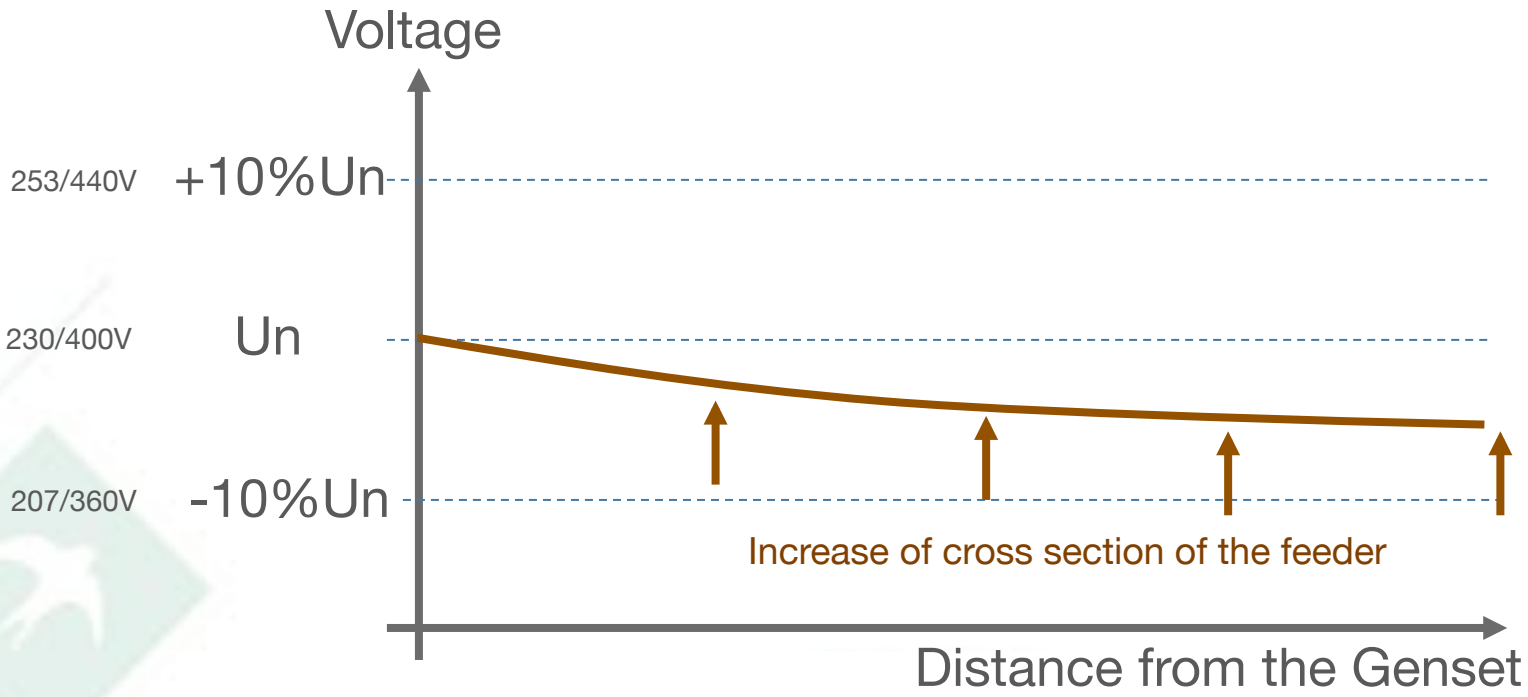
- **IEC 60038 - IEC standard voltages**
  - Low voltage : 230/400 V
  - "*the supply voltage should not differ from the nominal voltage of the system by more than ±10 %*"



Voltage drops

Increase cross section of the feeder

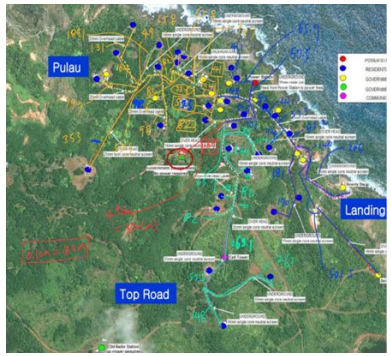


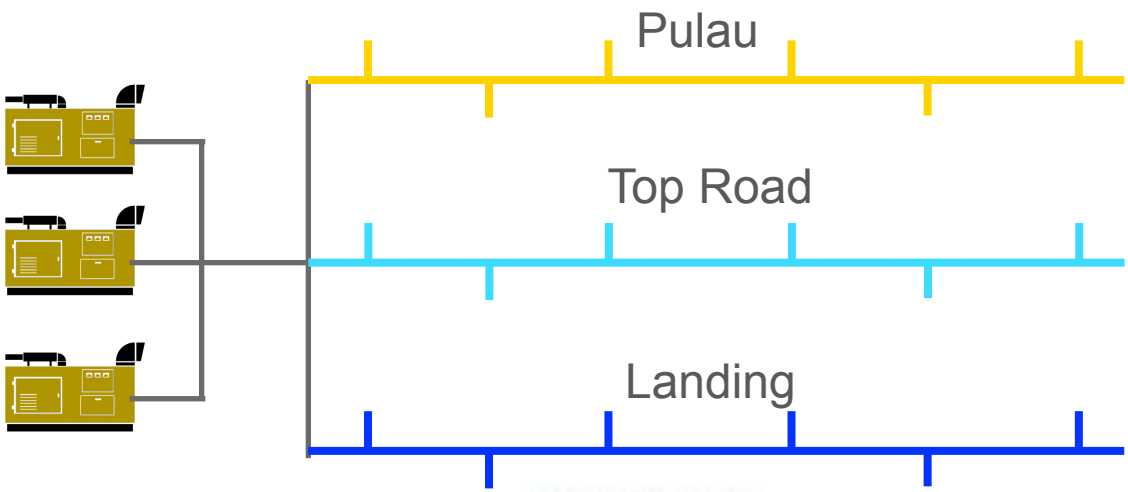


Voltage drops

Example : Adamstown (Pitcairn)

- 3 feeders
  - Pulau (North West)
  - Top Road (South West)
  - Landing (South East)





Voltage drops

Example : Adamstown (Pitcairn)

The cables are too old, and although they are not accurately measured, serious voltage drops were observed at the end point of each feeder.

Recommended cable U1000R2V or equivalent grade section are indicated as per below:

- 35mm2 underground cable for a distance of 2,200m
  - Maximum power to limit voltage drop to 10% ?
    - Resistance of copper : 23,6 Ω.mm2/km
    - Resistance of cable : 23,6 x 2,2 / 35 = 1,48 Ω
    - Voltage drop = 10%Un = 40 V
    - Imax = ΔU / R / √3 = 40 / 1,48 / √3 = 15,6A
    - Pmax= U x I x √3= 400 x 15,6 x √3 = **10.800 Watts**

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