Optimum Combination of Photovoltaics and Batteries to Substitute Diesel Generators

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Isn´t it paradox: where there is a lot of sunshine there is a lot of soot and exhausts from diesel generators

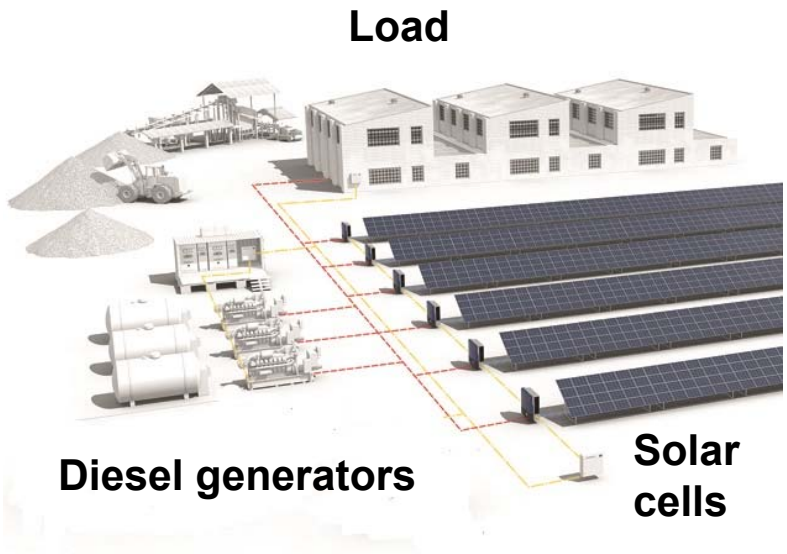
More than 1 million diesel generator systems from a few kilowatts to several megawatts provide power for islands, off-grid locations and in case of (frequent) blackouts, especially in developing countries.

[Source: GENO]

So why not use the sunshine to reduce soot emissions and lower the fuel bills?

The tremendous decrease of the costs for solar power makes photovoltaics an attractive substitute for diesel generation in diesel generator supply systems, lowering power costs and environmental impact.

How do photovoltaics-diesel-battery systems work?



The aim: use as much solar power as possible instead of diesel power.

Offgrid hybrid systems

- Diesel generator supplies an off-grid system with power and provides local grid frequency
- Photovoltaics is added to substitute diesel generation – diesel gen reacts to negative load with reduced output

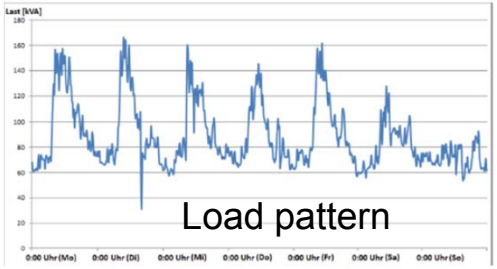
Grid-connected hybrid systems

- Diesel generator supplies power in case of (frequent) blackout
- Photovoltaics is added to substitute grid electricity and diesel generation

Batteries increase level of usable solar power and diesel savings

[Source: SMA]

What are challenges and limits to hybrid systems?



Load pattern

Load patterns - Major differences between daily hours, weekdays and weekends, day and night

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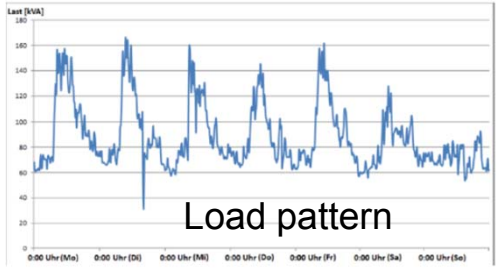

Load patterns - Major differences between daily hours, weekdays and weekends, day and night

Fluctuating photovoltaics (PV)

- Cloud-Passing → Sudden decrease of photovoltaics (PV) feed-in
- Rainy or misty weather leads to longer period of low solar feed-in
- No sunshine at night (e.g. 12 hours a day)

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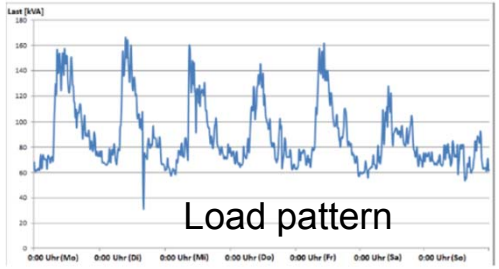

Load pattern

Diesel generator load classes

0 – 25 %	Extreme low load
25 – 40 %	Low load
40 – 80 %	Regular generator operation load
80 – 90 %	High load
90 – 100 %	Extreme high load

Load patterns - Major differences between daily hours, weekdays and weekends, day and night

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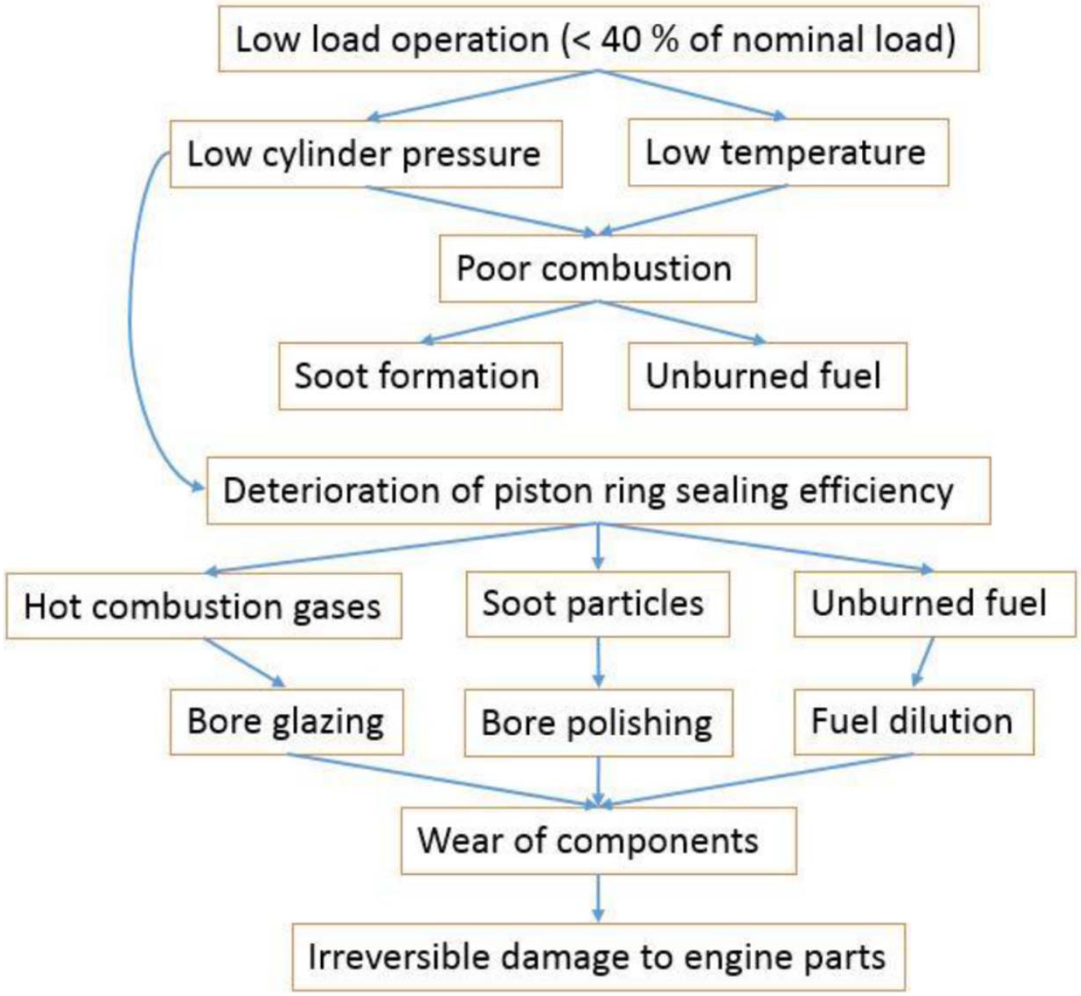
Diesel generators (diesel gens)

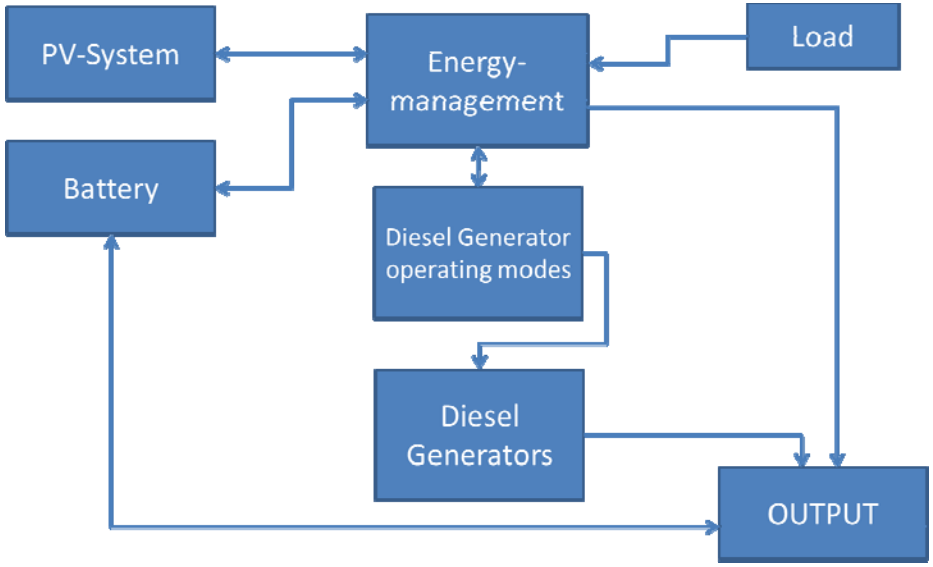
- Diesel generators must provide frequency
- Diesel gens must react quickly to sudden changes of PV – quick ramp-up required
- What is the minimum load and how long can diesel gens survive at these low load levels?

Low load problems of diesel generators



- Low and extremely low load levels lead to higher fuel consumption and bad internal combustion
- Longer time operation at those conditions includes risk of soot clogging and damage of piston seals = total engine damage
- As a result, fixing the lowest possible load level of the diesel gen is key to the design of the hybrid system, but manufacturers hesitate to provide data

Modelling PV-hybrid systems

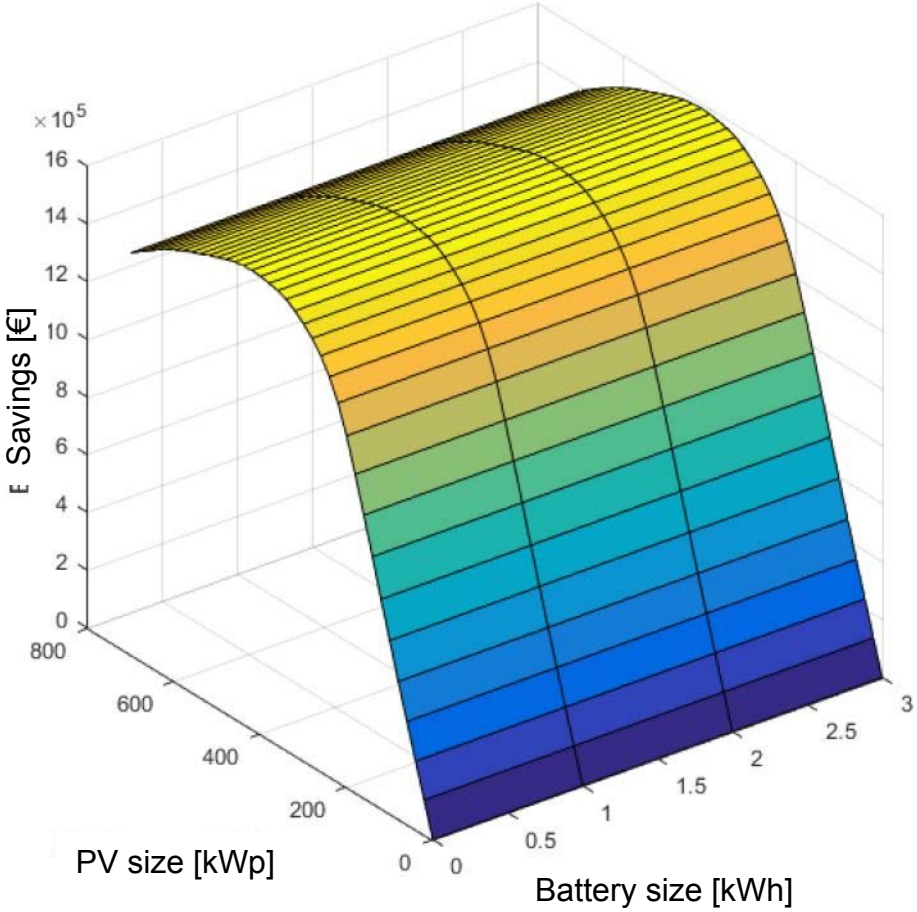


Setup of MatLab modelling tool

- A MatLab based modelling tool was developed to examine the possibilities and limits of integrating photovoltaics into existing diesel generator systems
- It considers the setup and operating modes of the diesel generators and contains modules for the use of different types of batteries (lead-acid, lithium ion)
- As a result, optimum setup of the re-designed hybrid PV-diesel-battery system can be calculated

Modelling output proves PV benefits

Input	Output
Load profile Standardized photovoltaics profile (or insolation values) Generator data (size / fuel consumption /minimum load) Battery data (type / technical properties) Operating modes Costs and lifetime (manufacturer data) Variation of input parameters for the model	Diesel fuel consumption Costs and savings of all combinations **Selection of optimum combination** Aging of components Lost photovoltaics generation due to feed-in restrictions



Results show: due to minimum diesel generator load required, it is better to split large diesel gens into smaller units (e.g. 3x 70 kW instead of 1x 210 kW), while optimum battery size depends on PV size

Reality check: installing PV in Akwatia/Ghana

At the St. Dominic´s Hospital in Akwatia/Ghana, 550 energy-saving LED lights and a 90 kW photovoltaics plant were installed

Reality check: installing a hybrid system in Ghana

Starting point	Lessons learnt	Final results
Due to **frequent blackouts** (up to 20% of time), St. Dominic´s Hospital in Akwatia in Ghana requires diesel gen backup	**Load profiles** had to be measured by hand – strong deviations between working daily hours, nights and weekends (50-160 kW)	First installation of 25 kWp in combination with LED lighting **reduced load** by 16% leading to tangible cost savings
Fuel costs have a strong impact on tight Hospital budget	Though close to equator, **solar yield differs** significantly depending on roof angle (up to 30%)	**More than 550 new energy-saving LED lights** help to reduce load, especially at night times
Sufficient **roof areas** for major installation available, promising **solar potential** and **stable internal grid** infrastructure	Some **Roofs** turned out to be too fragile for PV installations	**Another 60 kWp PV** installation followed, but it requires control to curtail PV generation at low load times because of minimum load level of diesel gen
2x 250 kVA diesel gens are being used to supply the Hospital with blackout power	**Diesel gen "survived"** 18 years of intermittent low load operation	**No batteries** have been installed yet due to limited budget and complexity of system

Multiple projects benefits

Besides the fuel and costs savings, the PV Ghana project was a first step for implementing PV in Ghana, training local craftsmen and preparing future projects

Conclusions

- **Cheap photovoltaics can substitute expensive diesel and soot**
  - Hybrid systems can easily be built up to a certain PV limit
  - Batteries increase savings by solar power
- In hybrid systems, **diesel generators** have to provide frequency and backup to fluctuating solar feed-in
  - Poor information about minimum load of diesel gens – but this is the key parameter for plant layout
- **Modelling tool of PV-diesel-battery systems** was developed
  - Results show dependencies on diesel gen setup and load
  - Overall, a positive balance is achievable
- **Experience from project in Akwatia/Ghana** shows
  - Getting precise data and information at the beginning of the planning is the toughest job
  - Robust design of energy supply is regarded to be more important than sophisticated technology to optimize solar yield

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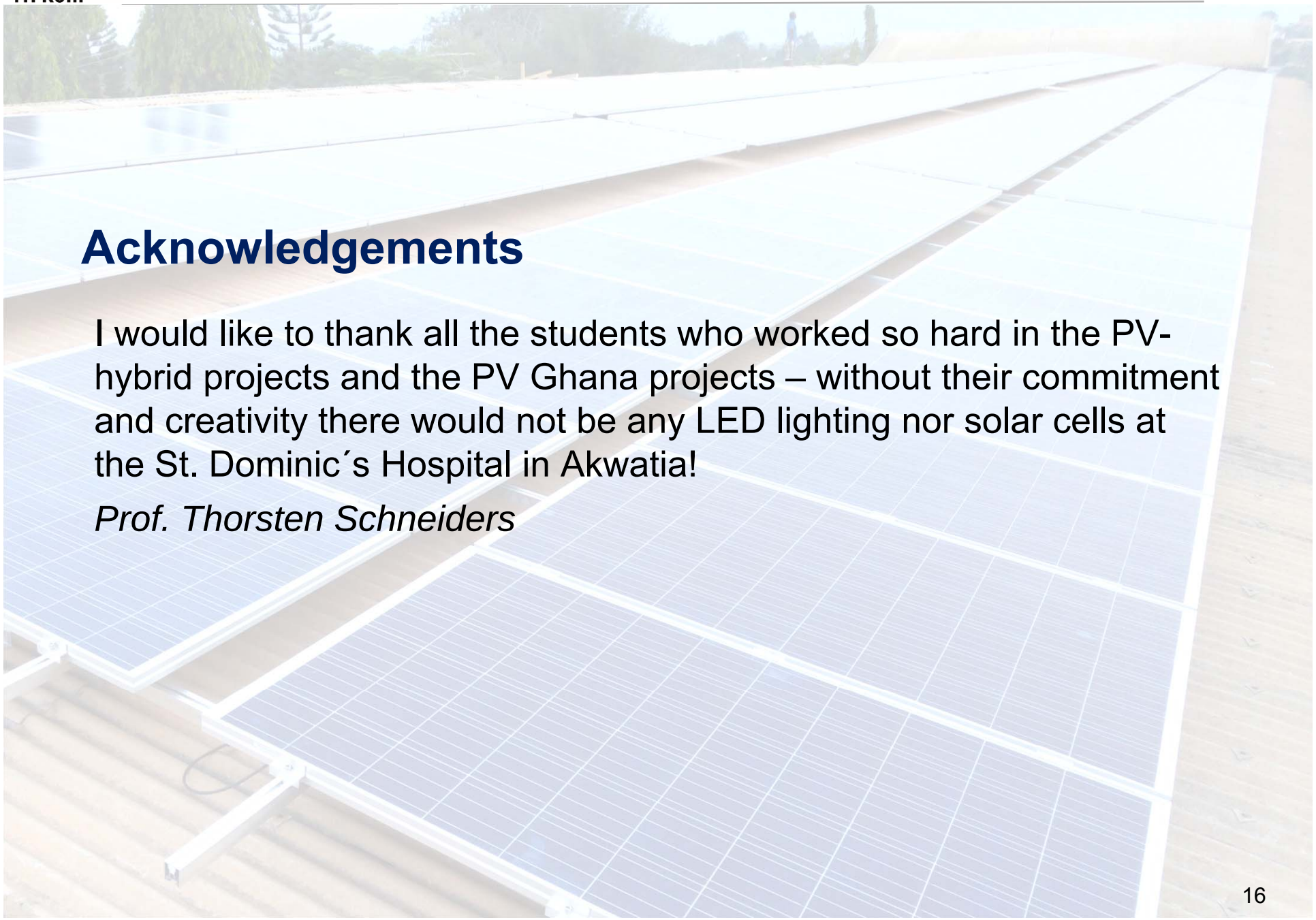

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