PV Integration Studies for Tropical Island Power Systems

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Experience from different consultancy assignments

Peter-Philipp Schierhorn, M.Sc.

3rd International Hybrid Power Systems Workshop

Tenerife, May 8th 2018

1.BACKGROUND

ISLAND POWER SYSTEMS WORLDWIDE

Hot spots: Caribbean and South East Asia

- Several 100,000 inhabited islands world wide
- Most permanently inhabited islands are located in the tropic seas
- Most are high sea islands that are too far out to be connected to main grid
- Almost all are powered with 100 % fossil fuel

TYPICAL ISLAND SYSTEM SETUP

Power generation from diesel engines

- Often old and inefficient
- Slow ramp rates and long startup times
- High minimum stable output
- High pollutant emissions

Medium voltage distribution grid

- Usually 10 – 30 kV
- Overhead lines
- Relatively long feeders, one central power plant
- Customers often connect directly to MV/LV transformers

ENERGYNAUTICS EXPERIENCE

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Energynautics have been commissioned to conduct PV integration studies on various tropical islands since 2013 – these are a few examples.

Studies were commissioned by development banks in cooperation with local utilities.

	Mahe*	Island B**	Island C**	Barbados
Size	28 x 19 km	24 x 11 km	84 x 80 km	35 x 25 km
Population	77,000	15,000	300,000	278.000
Peak demand	Ca. 45 MW	Ca. 1 MW	Ca. 40 MW	Ca. 200 MW
Generators	Diesel	Diesel	Diesel, coal, gas turbines, biogas, biomass	Diesel, gas turbines, steam turbines
Grid	33 kV, 11 kV	20 kV	70 kV, 20 kV	24 kV
Objective	Find max. penetration rate	Develop techno-economic strategy for 25 % renewable energy in 10 years		Review and improve grid code

* Seychelles – other Seychelles islands were included in the study

** Confidential, ongoing project

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2. INTEGRATION STUDY ISSUES

ISLAND RENEWABLES STUDY

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A clean, all-encompassing study requires time, effort and lots of data

- Models: Investment model, dispatch model, steady state and dynamic grid models
- Scenarios: Forecasting the future is hard, so extensive sensitivity analysis is a good idea
- Technology: Assessment of existing system, review of future technologies etc.

Collect all the data, develop all the models, evaluate all possibilities…

… unfortunately, especially in developing countries it often does not work that way!

- Time constraints (results ASAP, often politically driven!)
- Budget constraints – study often only possible with development aid
- Capacity building is often a prime objective – local operators have no experience with VRE

ISSUE 1: OPERATOR'S PERSPECTIVE

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Renewables can save fuel and reduce generation cost

Great, let's go!

We have heard 100 % renewables is already possible in island grids – can we please build something like that by next year?

Nice, but...

If 50 kW of PV will be installed on my 10 MW island – will we get dynamic stability problems? Do we need batteries?

No thanks...

This may work somewhere else, but here it is obviously infeasible. (Also, we earn money with diesel generation.)

Take it easy – give it a chance – allow for some development – and learn as you go along!
(Nobody starts at 100 % right away.)

Please find a technical reason why we can't do it.

ISSUE 2: DATA COLLECTION

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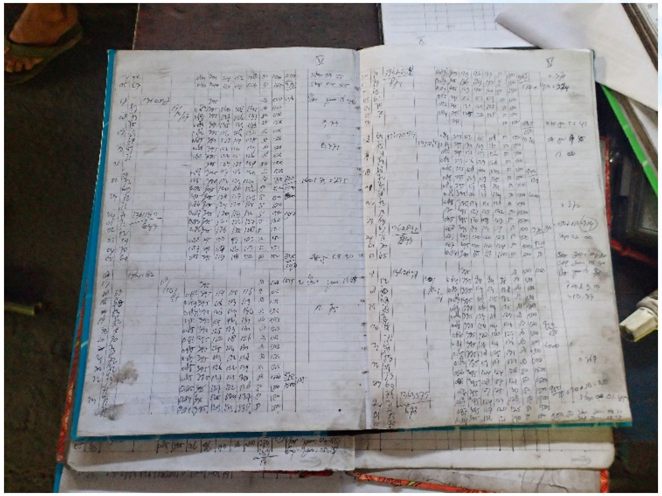
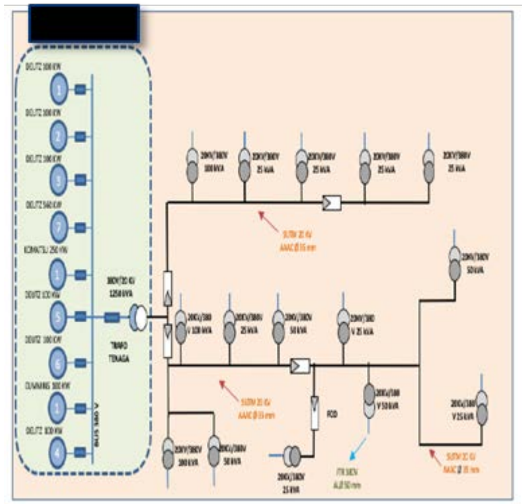
Especially in remote locations in developing countries, data on power system characteristics is often not even available to the operator.



- System is operated based on experience
- Operators can handle their typical situations, but have little background knowledge
- Monitoring and transparency are often not considered important



- ➢ Academic approach of a grid study based on good data and validated models requires extensive site visits and measurement campaigns.
- ➢ Often, a simplified approach needs to be applied.

ISSUE 3: GENERATOR OPERATION

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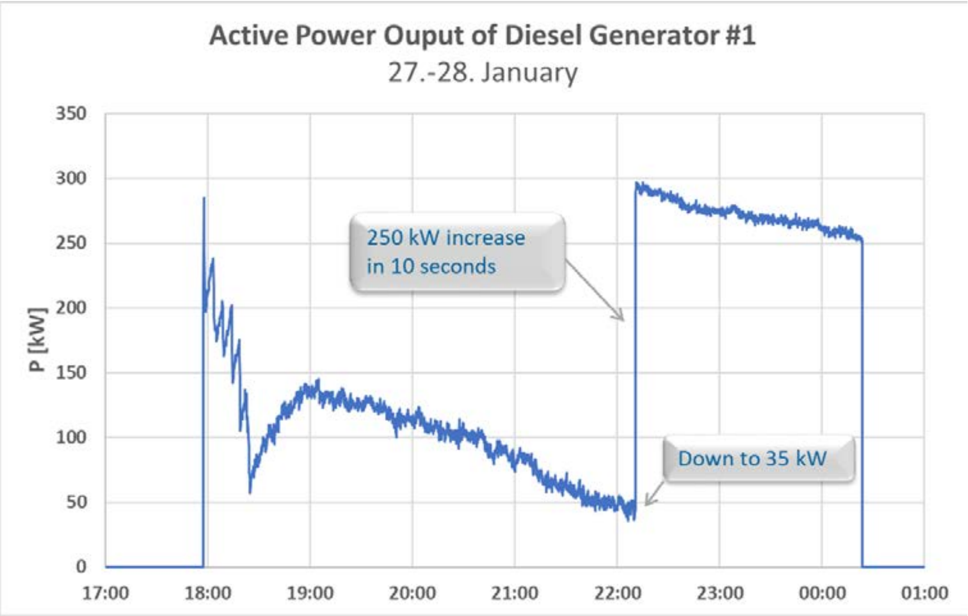
Operators, power plant crews and manufacturers may each have a different perspective on the capabilities of their generators.



Measured data from a 650 kW high speed diesel in East Asia.

Operator: Fast ramping is not possible!

Crew: Of course we can ramp fast, watch this!

Manufacturer: Of course you can ramp… but…at your own risk.

Economist: Ramping is expensive, please avoid!

ISSUE 4: DYNAMIC MODELS

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Dynamic stability may become an issue at high levels of non-synchronous generation, and everyone has heard about it.

Most island grid operators want the dynamic stability of their system assessed.

Validated dynamic models of generators are often only available to the manufacturer – if at all!

(One could make estimates from event data – but that‘s not available in high resolution either.)

If no validated models can be obtained for these generators…

… good luck finding anything for this one!

BUT WE STILL WANT GOOD RESULTS

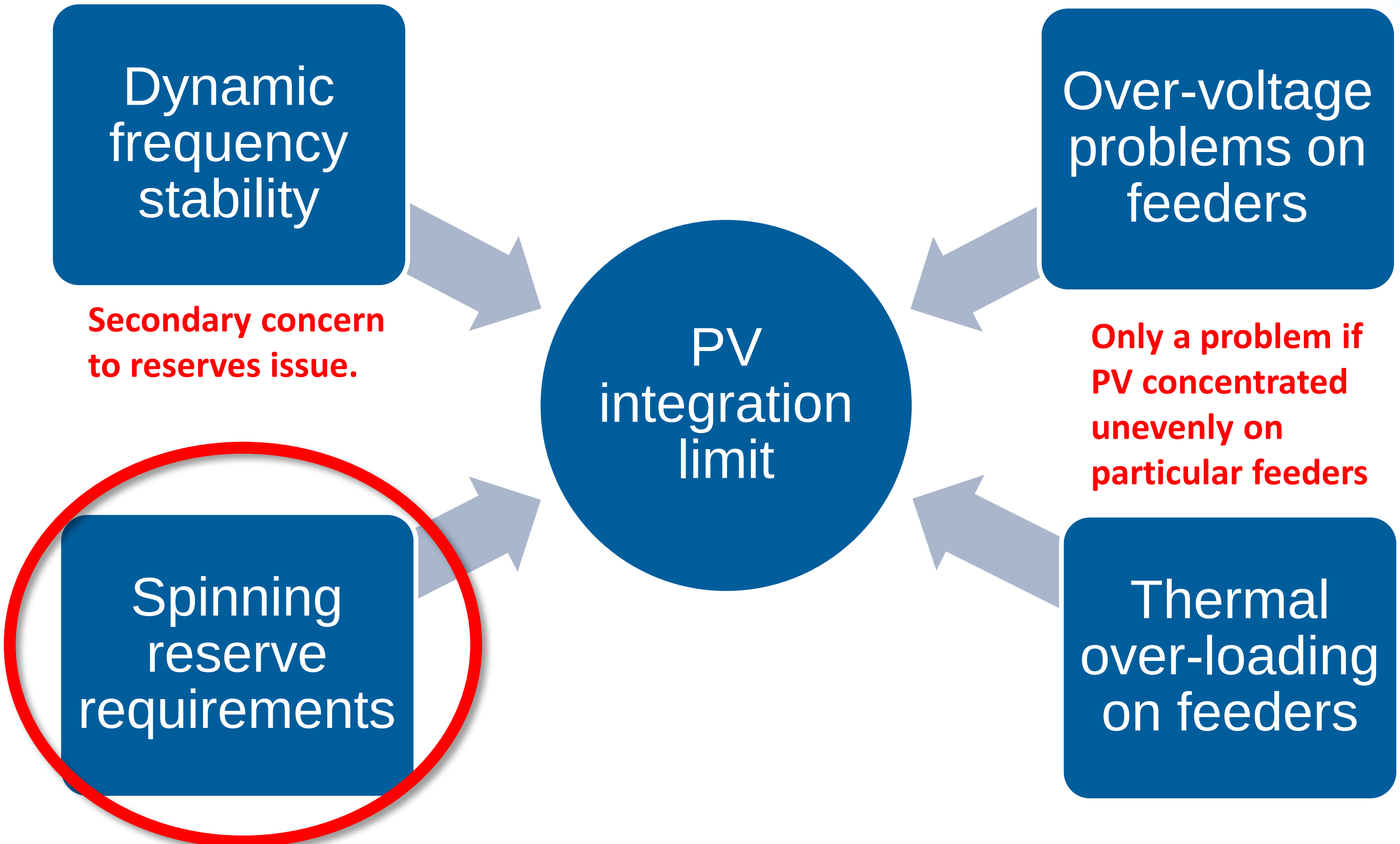
„Garbage in garbage out“ should be avoided as far as possible!

- Identify the shortcomings
- Prioritize the ojectives (often, teaching the local operator the basics is #1!)
- Start with the simplest questions and answer these well – half baked answers to overly complex questions help nobody in the long run
- Develop simple and efficient approaches
- Encourage small VRE installations along with better data collection and monitoring systems. **Start small, grow large! Learning by doing!**
- **Many systems are still a step behind – but we can start the conversation!**

3. SIMPLE METHODOLOGY

WHICH ISSUES DOMINATE?

The various issues are **not** equally problematic. Based on simulations:



RENEWABLE INTEGRATION STUDY

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Assessment of renewable energy potential and selection of technologies

Question 1: How much RE can be installed without any change to the system?

- How far can conventional generation be reduced?
- How much spinning reserve can be provided?
- How fast can frequency control (reserves) react?
- Assessment of expected RE fluctuation
- Are there any grid constraints? Where can RE be installed?

Question 2: What enabling measures can be taken to raise the RE share?

- Optimization of generator controls and/or overhaul of existing generators
- Are there alternative ways of obtaining spinning reserve?
- Is there any pontential for demand side management?
- What degree of controllability must RE generators provide?
- Is energy storage an economically feasible option?
- Is there any need for grid reinforcements?

RESULTS MAHE (SEYCHELLES)

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Combine technology options into groups:

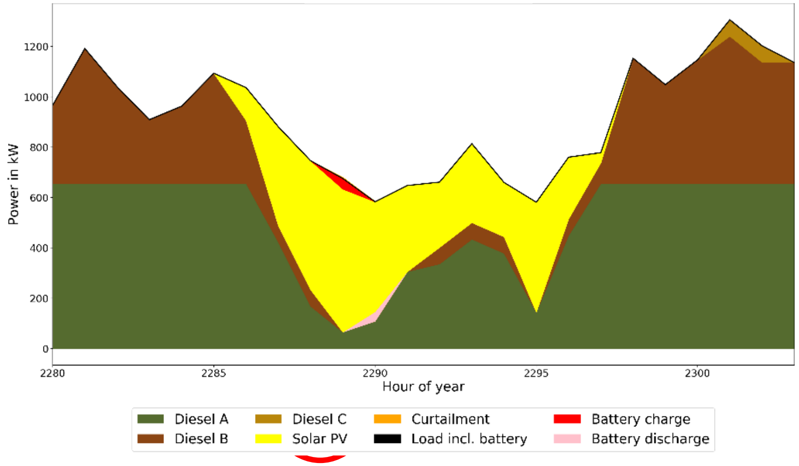
Maximum PV by Technology Scenario [MW Panel Size] (load coverage by PV in %)	2015	2020	2030
Conservative - No changes to current operational practices - 75% minimum diesel loading level	7.4 (3.0%)	12.0 (3.5%)	21.5 (3.4%)
Moderate - 65% minimum diesel loading level - Limit inverter size to 80% of panels - Curtailment during bottlenecks of plants > 500 kW - Demand-Side Management of 2 MW by 2020, 7 MW by 2030	n/a	28.8 (8.4%)	57.2 (9.1%)
Ambitious - 50% minimum diesel loading level - Limit inverter size to 80% of panels - Curtailment during bottlenecks of plants > 500 kW - Demand-Side Management of 2 MW by 2020, 7 MW by 2030 - 15 MW Generator on standby to start at short notice	n/a	46.7 (13.6%)	85.8 (13.7%)

5. DYNAMIC STABILITY

DYNAMIC SIMULATION – WHERE IT MAKES SENSE

New diesel power plant on small island:

- New 2x 656 kW Cummins generators
- Minimum stable output: 20 kW per genset
- Normal ramp rate: 25 kW/s
- Demonstrated ramp rate: 150 kW/s (!)
- Automatic isochronous load sharing
- Modern and capable generators should have no problem balancing out PV fluctuations

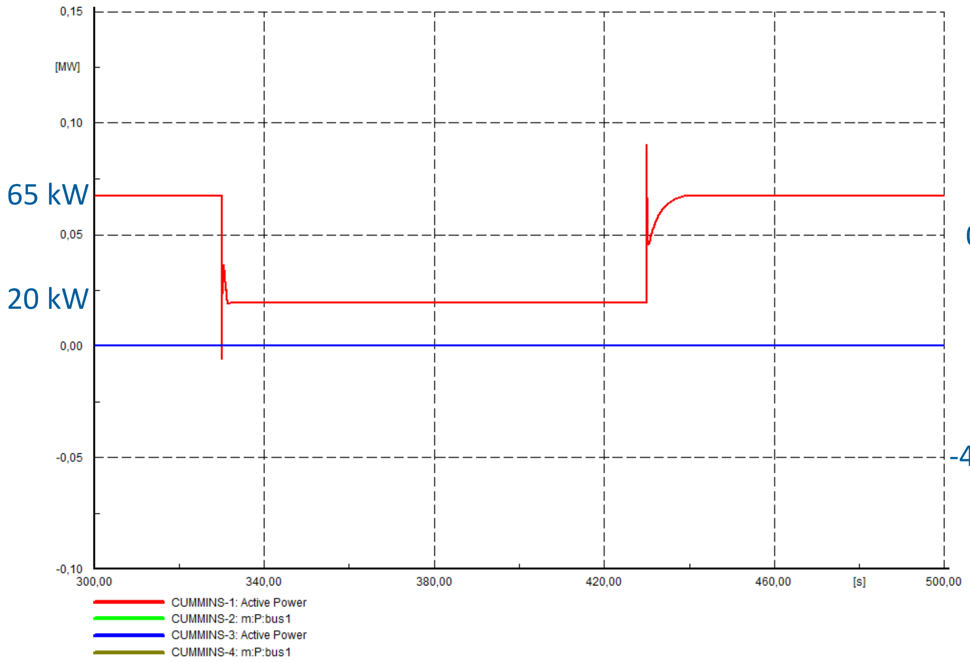


PV penetration > 80 % - is the system stable?

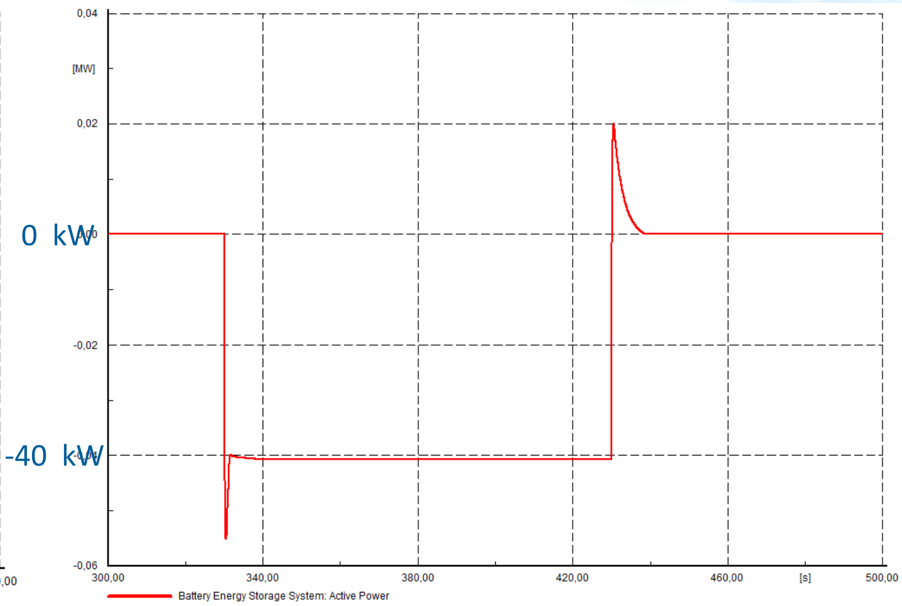
- Battery (200 kW/300 kWh) can balance out single site fluctuations
- Only one diesel running at 65 kW
- What happens if a disturbance is introduced to the system?

EXAMPLE: LOAD TRIP (1)

Diesel generation

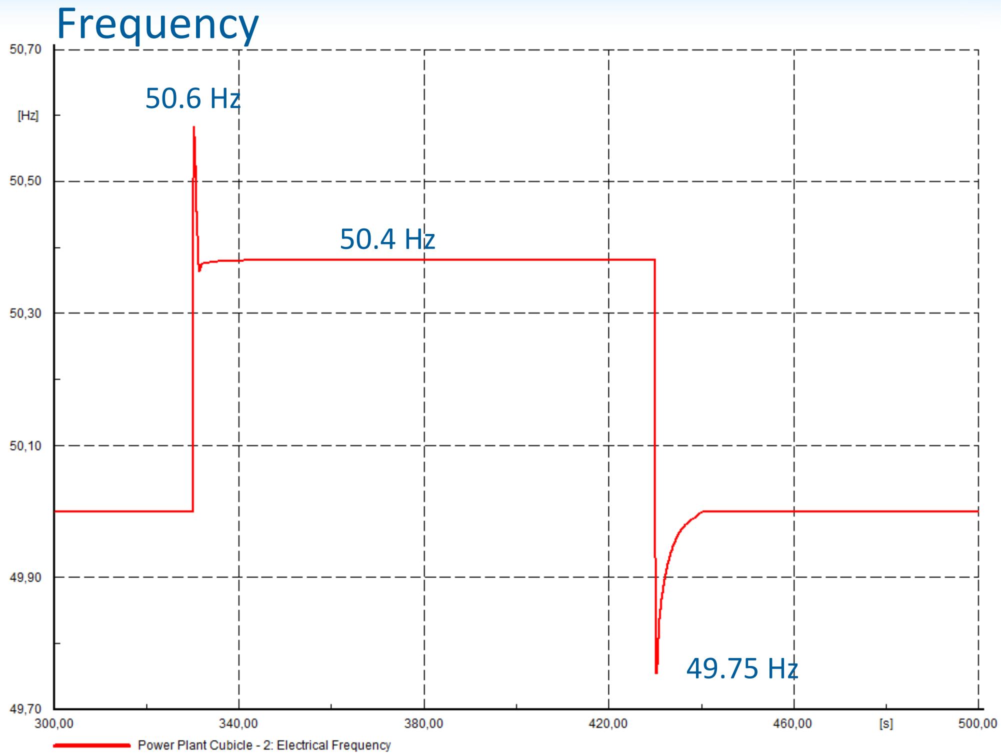


Battery output



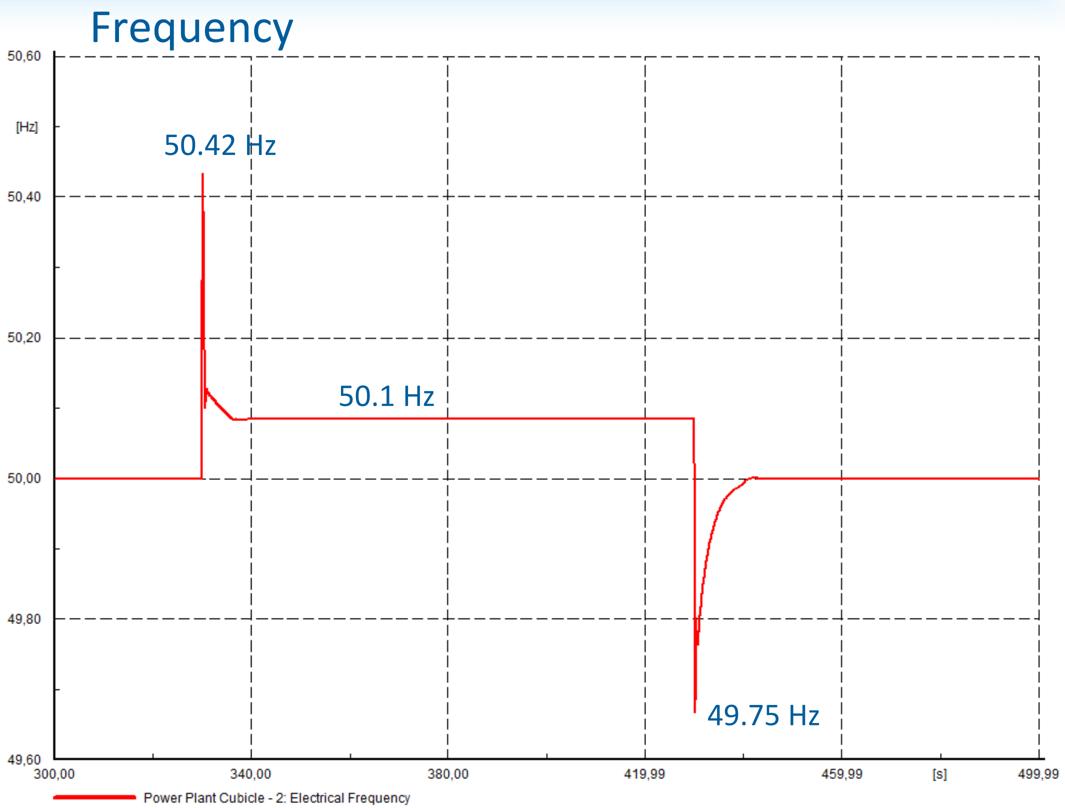
130 kW load switched off and back on again – diesel reacts, but runs into minimum output limit (20 kW), battery supports

EXAMPLE: LOAD TRIP (2)



Diesel and battery stabilize frequency, but it remains offset at 50.4 Hz – diesel runs into minimum load limit and battery into maximum charging power. Can we improve this?

EXAMPLE: LOAD TRIP (3)



If the PV is equipped with an overfrequency output reduction, frequency peaks during inertial response remain, but frequency is only offset to 50.1 Hz -> good!

Settings: 40 % output reduction per Hz deviation, deadband 0.02 Hz

7. ISLAND GRID CODES

BUNDLE YOUR RESOURCES!

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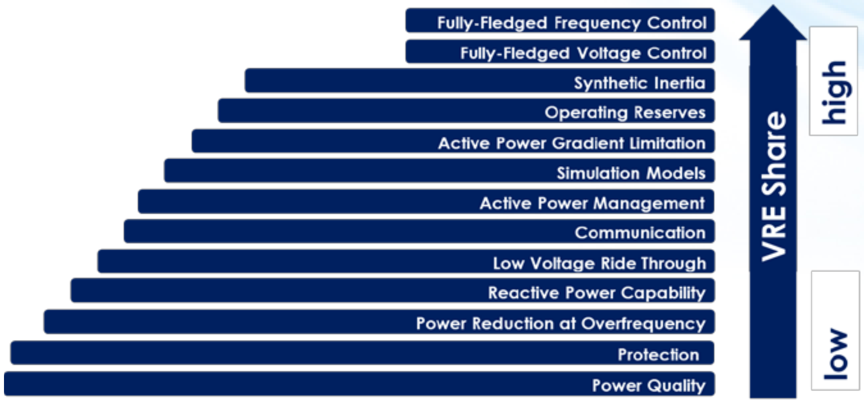
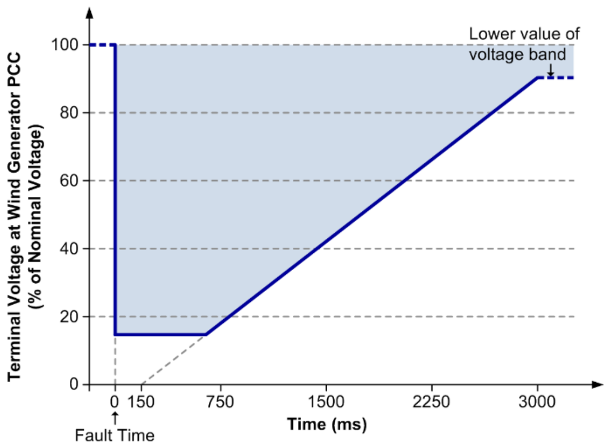
Island grids have special requirements

- Participation of VRE in voltage and frequency control is necessary much earlier than in continental systems
- Frequency quality is often worse, requiring wider operating ranges
- Curtailment / active power management is more frequent
- Regulation for energy storage needs to be introduced
- Market power (VRE) and financial capabilities of the utility mostly low

➢ **A grid code framework for islands, akin to the EU Network Codes, is a good idea!**





8. CONCLUSIONS

CONCLUSIONS

- **Carefully assess the available data**
- **Instead of trying to guesstimate answers to complex questions, answer the simple ones well**
- **Keep in mind the financial and technical capabilities of the local utility**
  - Storage and smart grid approaches are still far away from reality in many places
  - The basics of VRE integration and operational regimes need to be built up
  - Once some VRE systems do work and the operator knows how to deal with them, the
- **Encourage small steps along with better monitoring and data collection**
- **Encourage bundling of resources, especially when it comes to grid codes**

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THANKS FOR YOUR ATTENTION!