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Planning for Island Grids with a High Share of Renewable Power



Roland Roesch

Agenda

- ENERGY TRANSITION TOWARDS RENEWABLES
- WIND POWER AND GRID STABILITY
- GRID STABILITY STRATEGIES
- MODELS

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ENERGY TRANSITION TOWARDS RENEWABLES

Energy transistion of Islands towards renewable power options

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- Some islands have completely transitioned or are transitioning soon:
  - Aruba (wind)
  - Cap Verde (wind, PV)
  - El Hierro (wind, pumped hydro)
  - Fiji (hydro, biomass, wind)
  - Graciosa (wind, PV, batteries)
  - Iceland (geothermal, hydro)
  - Tokelau (solar, batteries)
  - Tonga (PV, wind, wave)

- Transition is easier for larger islands (which may have hydropower) and volcanic islands (which can develop pumped hydro and geothermal)
- Coral islands have usually fewer „baseload“ opportunities

Energy transition towards renewable power on islands is eased by need to replace aging powerplants in service

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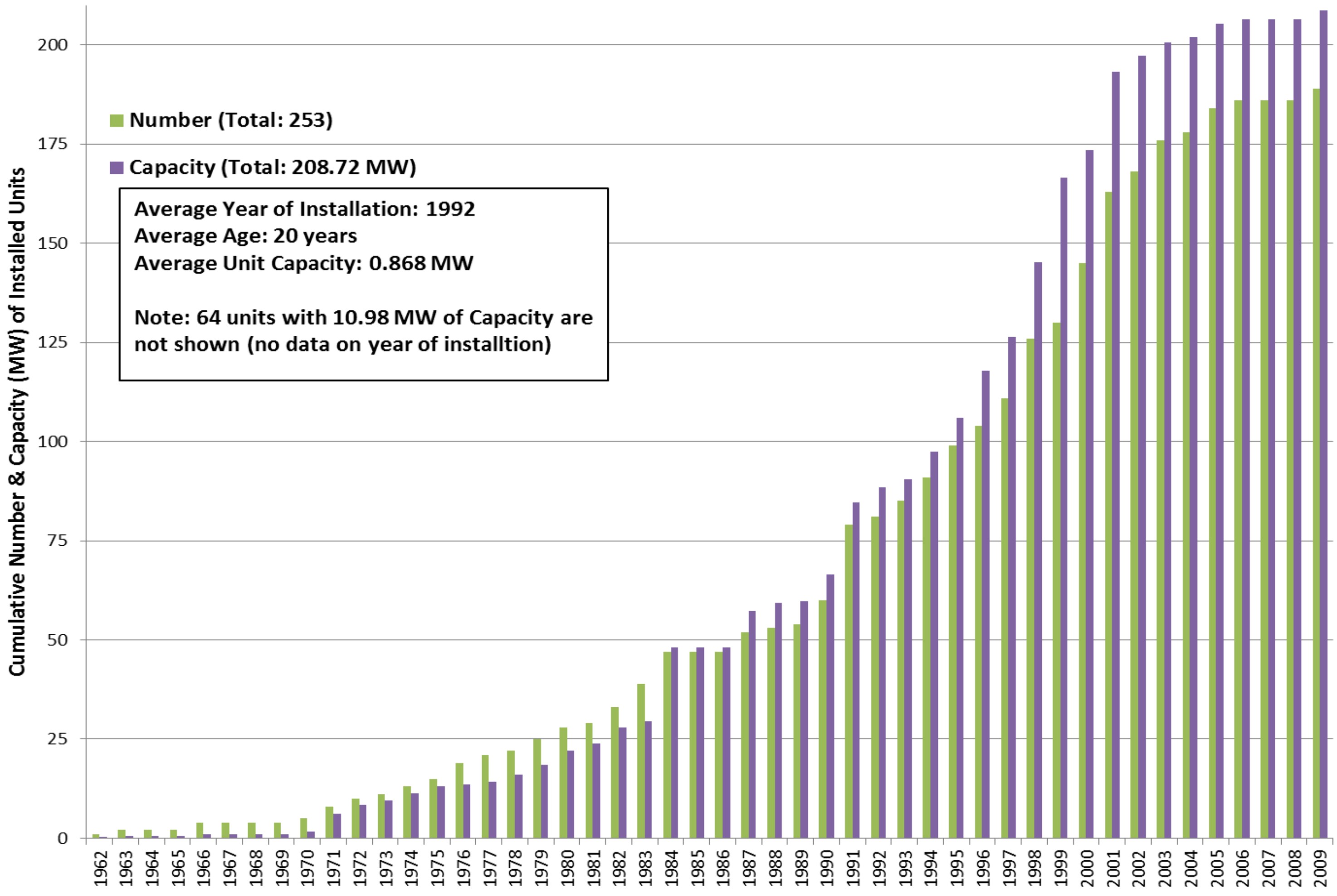
Cumulative capacity and age profile of current diesel generators on Pacific Islands (excluding Fiji and Papua New Guinea)



A greater share of renewable power raises technical issues of maintaining grid stability

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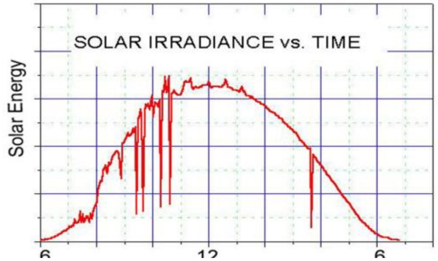
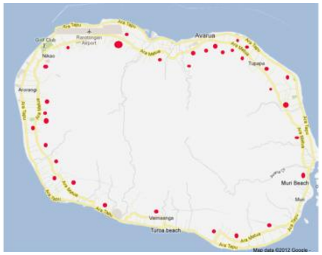
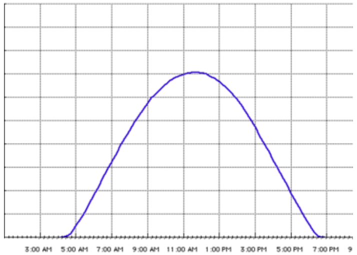
- Grid stability becomes an issue when higher shares of variable RE is introduced in existing grids, especially for small island grids
- Wind power can be more „variable“ than photovoltaic power on short time scale where stability issues play an important role
- Electricity supply must meet electricity demand at any moment in time
  →If not, blackouts will happen
- Frequency and voltage control are needed to fine-tune this equation
- Rapidly changing renewable power supply could create problems
- A range of technical solutions exist: **grid stability issues do not represent a show-stopper for a transition**







Spatial planning to deal with variability (example Rarotonga)

The generation profile of solar power tracks electricity demand well in some cases

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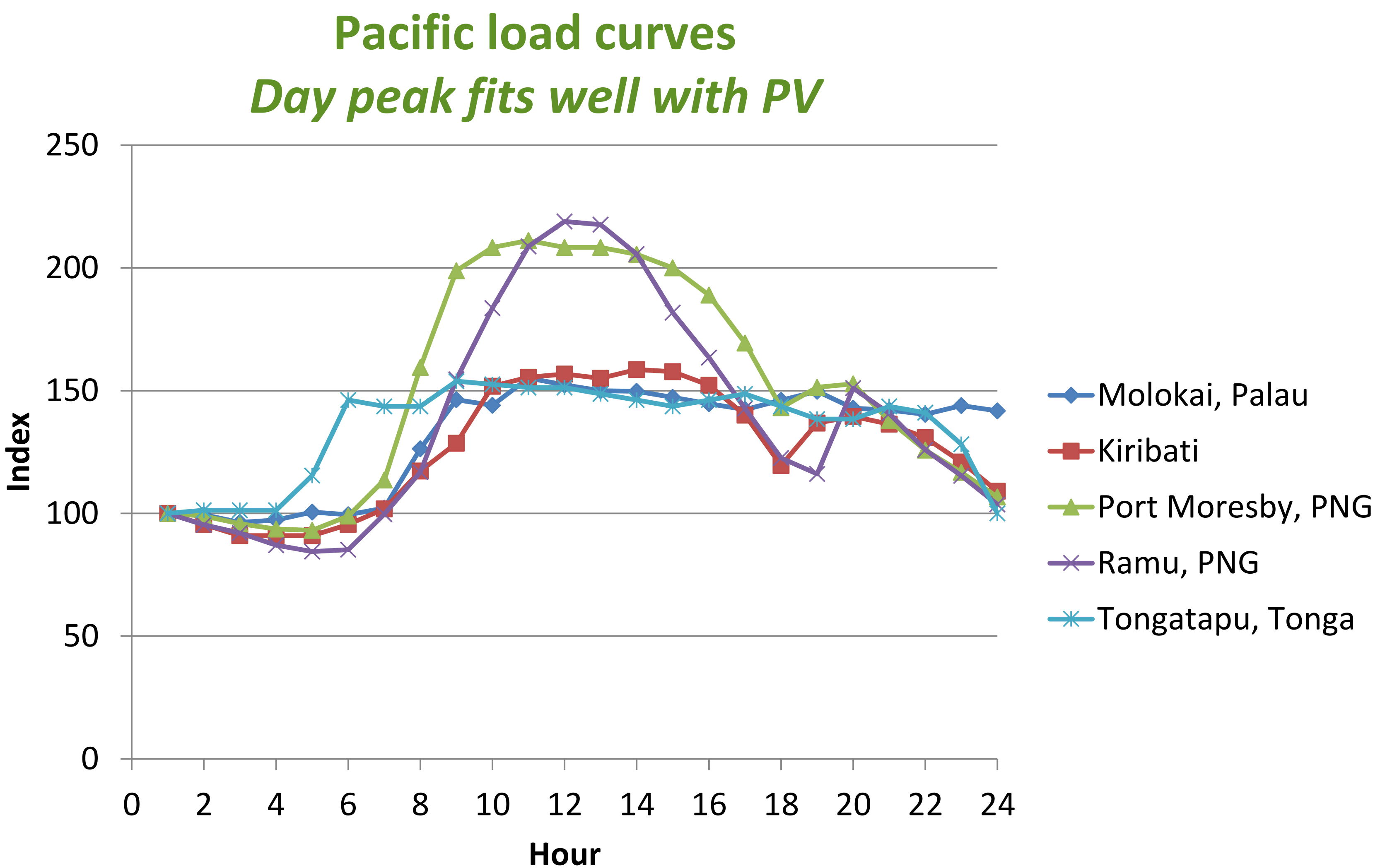
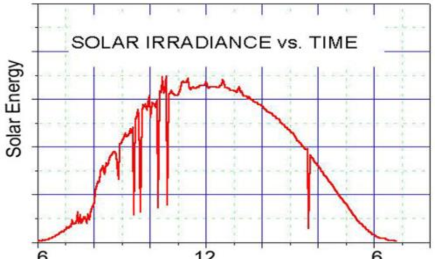
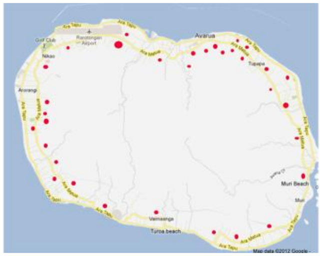
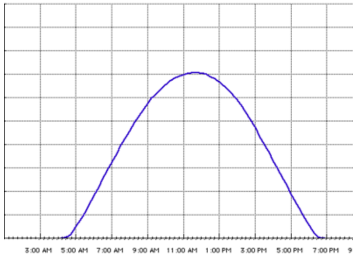


Source: IRENA, 2012

On-going and planned activities

- 24 March 2013: Launch of the GREIN initiative, Auckland
  - Malta Summit, June, 2012, Malta (Communiqué)
  - Identify global best practice: In 2013, expanding to Caribbean
- Grid stability assessment in collaboration with PPA – ongoing (Palau)
- Standards for grid integrated PV – 3 Pacific workshops in 2013
- RRA Fiji
- Capacity building (e.g. standards for grid integrated PV)
- Assessment of RE for transport and energy/water/land use nexus issues
- Set the stage for the Pacific regional roadmap – 15 DRAFT country reports

Spatial planning to deal with variability (example Rarotonga)

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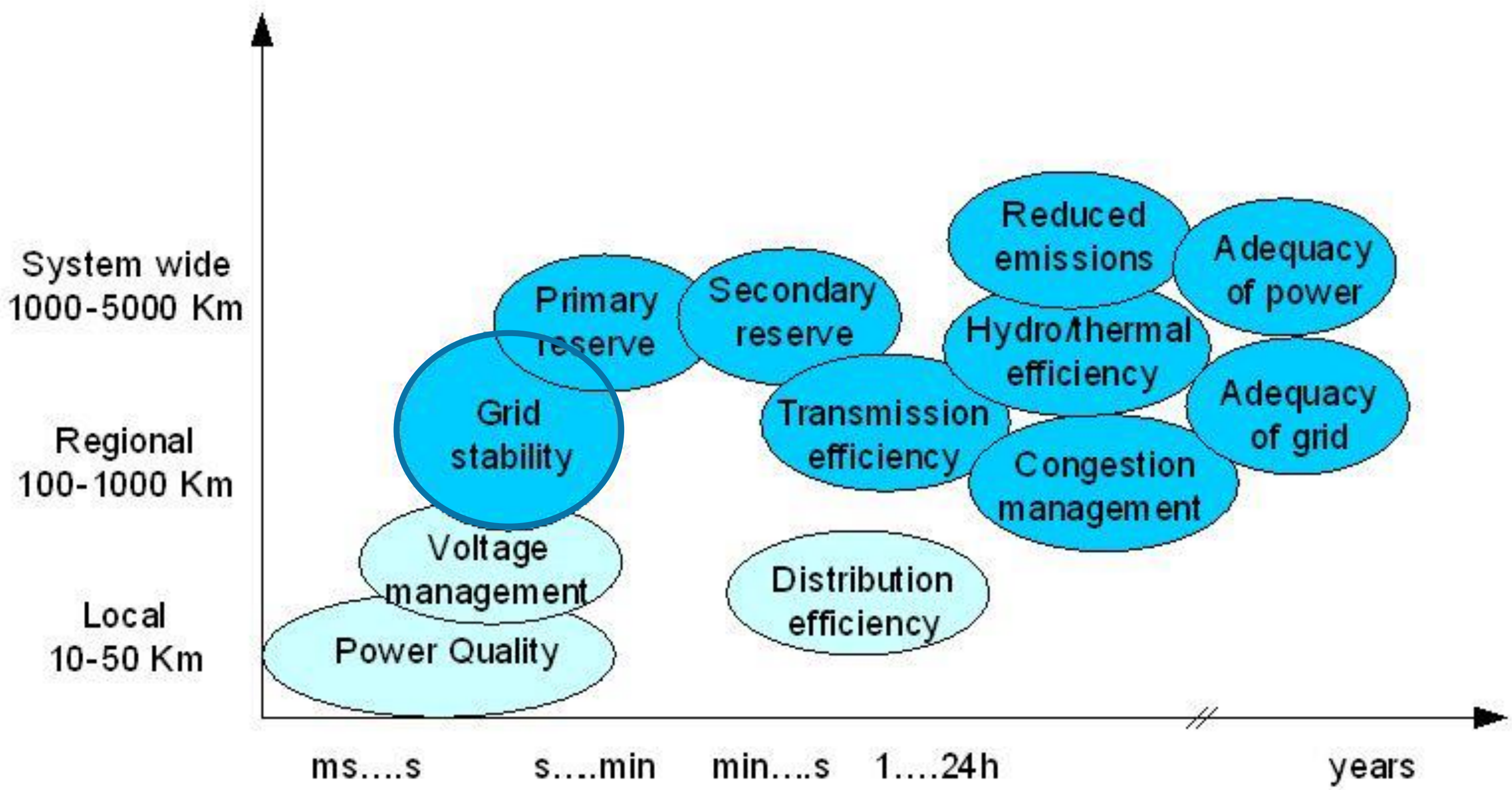
WIND POWER AND GRID STABILITY

Impacts of wind power on power systems

divided in different time scales and width of area

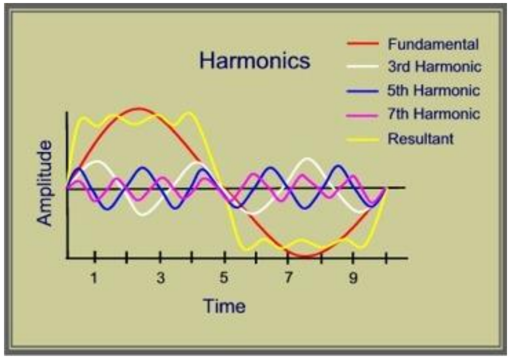


Source: http://www.intechopen.com/books/modeling-and-control-aspects-of-wind-power-systems/impacts-of-wind-farms-on-power-system-stability

Grid Stability and Wind Power

- Turbulences in the wind cause fluctuations in the wind energy output
  → Affect supply reliability and power quality of the grid
- Electrical conversion systems in wind turbines are new (induction generators) and their dynamical characteristics differ from classical generating technologies (synchronous generators)

- **Main problems on a local level: Voltage variation**
  - Flicker: Rapid and small voltage changes caused by variable power output of the turbines
  - Harmonics:
    - Distortion of the grid's sine wave
    - Caused by power electronics (e.g. rectifier)
    - Increase the current
    - Can cause equipment failures or interfere with communication systems

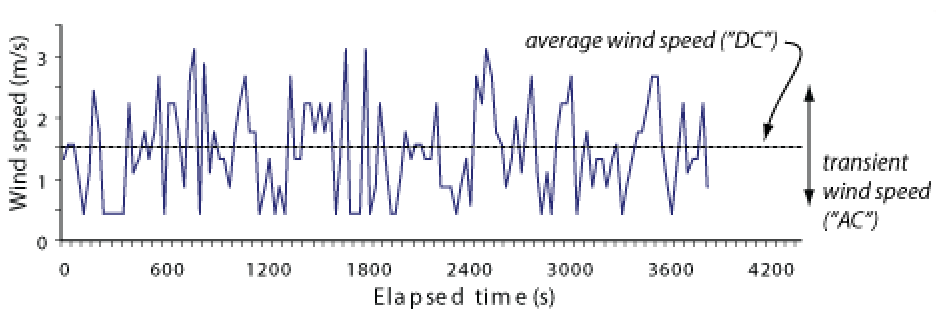


Source: http://www.hersheyenergy.com/images/Harmonics_Graph.jpg

Sources:
Adapted from: Sudira, A. et al. Universitat Politècnica de Catalunya. *Wind Turbine Grid Connection and Interaction.* Centre for Technological Innovation in Static Converters and Drives <http://www.icrepq.com/full-paper-icrep/309-SUMPER.pdf>
Adapted from: Van Hulle, F. *Large scale integration of wind energy in the European power supply:analysis, issues and recommendations*. European Wind Energy Association (EWEA). 2005.
Adapted from: *Wind Turbine Operation in Power Systems and Grid Connection Requirements.* Deutsches Windenergie-Institut. Wilhelmshaven, 2001

Grid Stability and Wind power

- **Short-term variability:** Very important regarding the grid integration
  - Minutes to hours
  - Depends on: Short-term wind variation and geographical spread of single plants
  - Impact on the grid depends on:
    - Volume of wind power in the grid
    - General generation mix
    - Long-distance transmission capacities
  - Variations within a minute: Fast fluctuations are barely noticeable
  - Variations within the hour:
    - Significant affects on the grid
    - Relation to demand fluctuation must be checked
    - Great geographic diversity evens out!
  - Greatest impact: Passage of Storm → Turbines shut down at very high wind speeds



Source: http://www.esf.edu/efb/turner/termitePages/termiteACDC.html

Source:
Adapted from: Van Hulle, F. *Large scale integration of wind energy in the European power supply:analysis, issues and recommendations*. European Wind Energy Association (EWEA). 2005.

Grid Stability and Wind power

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Wind is a variable energy source and leads to fluctuating energy output.

- **Long-term variability:** Not important for daily operation but future planning → Strategies
  - Months to years
  - Determined by seasonal meteorological schemes (variations between years)
  - Affects grid operation
  - Monthly/Seasonal variations:
    - Important for planning the contribution of wind power to the grid security (“capacity credit”)
  - Annual variations:
    - Important to observe to identify expected fluctuations in the future and long- term changes in energy output of wind projects
    - Influenced by market growth and projected ratio of onshore/offshore

Source:
Adapted from: Van Hulle, F. *Large scale integration of wind energy in the European power supply:analysis, issues and recommendations*. European Wind Energy Association (EWEA). 2005.

Grid Stability and Wind power

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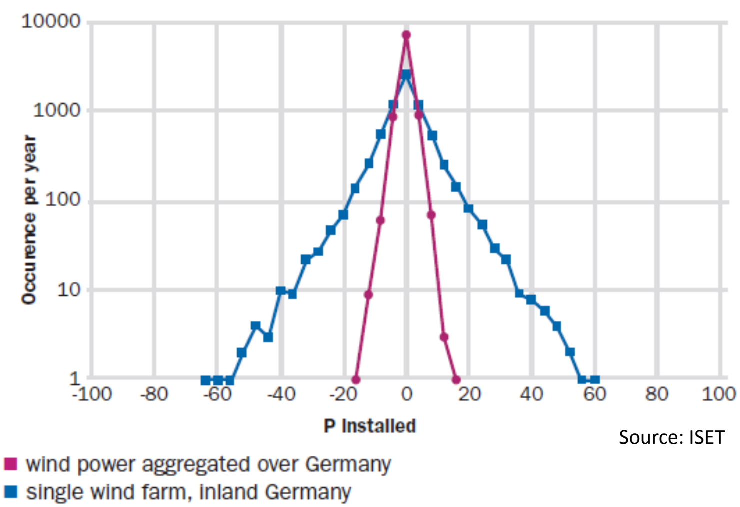
Geographical spread of wind turbines

- Geographical spread lowers wind power fluctuations → The more wind farms and the bigger the distant the less impact variability of wind power has on a system
- Geographical spread increases the general wind power output → Wind does not blow everywhere and always at same speed
- Islands usually do not offer a wide geographical spread for siting wind turbines

  → Grid stability needs to be secured!

Frequency of occurrence of hourly wind power variations

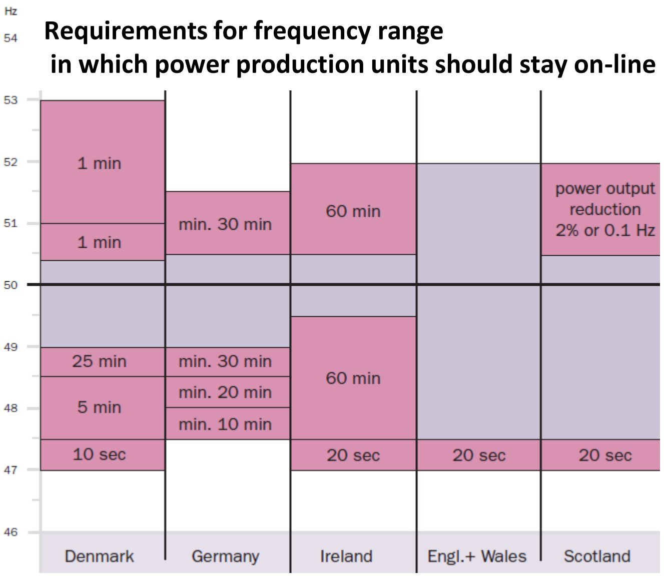


Source: ISET

Source:
Adapted from: Van Hulle, F. *Large scale integration of wind energy in the European power supply:analysis, issues and recommendations*. European Wind Energy Association (EWEA). 2005.

Grid Stability and Wind Power: Grid Codes for wind farms

- Active power control: Wind farms are required to be able to increase or decrease the power station's active power output in accordance with requirements of frequency by the TSO →Related to frequency control
- Frequency control: Certain limits are set to secure the supply, prevent overloading of electic equipment and keep the power quality standards.
- Voltage control/quality: Turbine should operate continuously at normal rated output within the arranged voltage range and stay connected during voltage step changes in the arranged range. It also includes requirements for reactive power compensation
- Fault ride-through: Request for certain capability by the generator to stay connected to electricity networks if voltage is below nominal to provide reactive power
- Transient fault situation: If power is stopped the fault disappears after restoring → Not permanent



Source: A. Badelin ISET, 2005

Sources:

- Adapted from:Muyeen, S.M. (Ed.) Impacts of Wind Farms on Power System Stability, Modeling and Control Aspects of Wind Power Systems,, InTech, 2013
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Grid Stability and Wind Power: Grid Codes for wind farms

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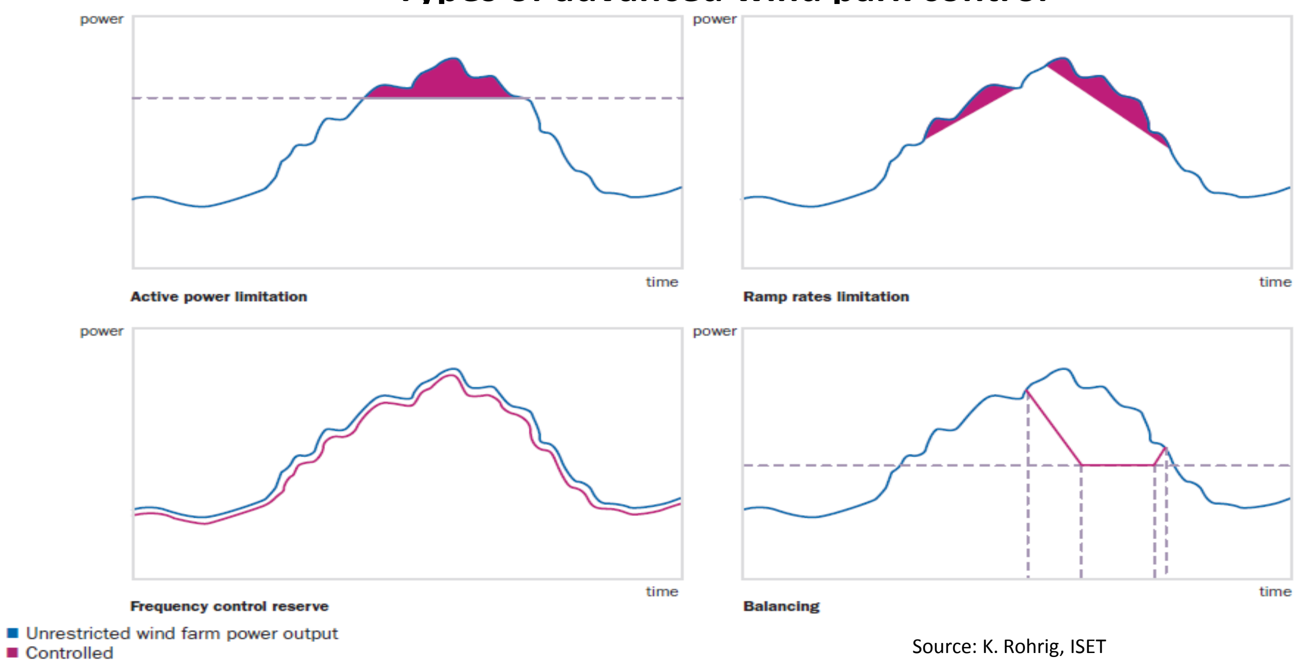
Example for local requirements: Eltra (Denmark)

- Active power control: Turbine must be able to be reduce power to less than 20% of the nominal power within less than 2 seconds
  → 40% reduction per second
- Fault ride-through: Turbines must stay stable/connected under permanent 3-phase faults and transient 2-phase fault on every arbitrary line. They have to be controllable for up to 3 faults within 2 minutes or 6 faults within a delay of 5 minutes in between the faults .
- Transient fault situation: Full power must halt
- Frequency: Disconnect if <47 Hz or > 53 Hz within 300 ms
- Reactive Power: Must be provided at every operating point to control the voltage

Sources:
- Adapted from:Muyeen, S.M. (Ed.) Impacts of Wind Farms on Power System Stability, Modeling and Control Aspects of Wind Power Systems,, InTech, 2013
- Adapted from: Sudira, A. et al. Universitat Politècnica de Catalunya. *Wind Turbine Grid Connection and Interaction.* Centre for Technological Innovation in Static Converters and Drives <http://www.icrepq.com/full-paper-icrep/309-SUMPER.pdf>

Grid Stability and Wind Power: Wind park control

Types of advanced wind park control



Source: K. Rohrig, ISET

- **Active power limitation:** Cut back of the power output above a fixed point → Loss of energy
- **Ramp Rates limitation:** Works similar to active power control but fixed points at certain times. Sudden wind power reductions can be reduced by forecasts and the output limited ahead.
- **Frequency control reserve:** Wind power output is partially cut back, either via pitch mechanism or shutting off some turbines of a wind park. Forecasting is needed to plan the cut backs.
- **Balancing**: Not common due to high losses.

Sources:

Adapted from: Van Hulle, F. *Large scale integration of wind energy in the European power supply:analysis, issues and recommendations*. European Wind Energy Association (EWEA). 2005.

Grid Stability and Wind Power: Example Island Grid Bornholm (Denmark)

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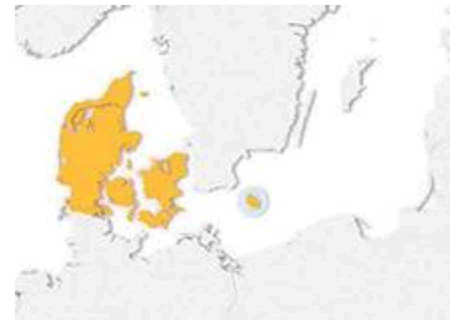
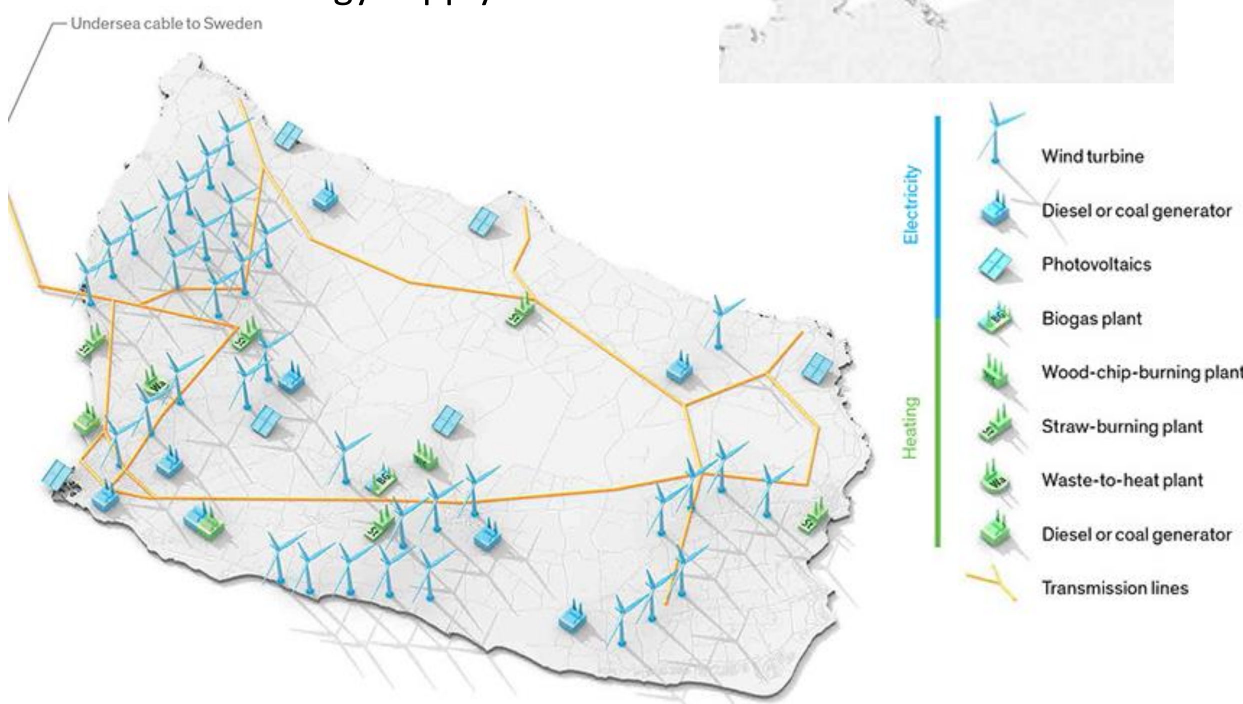
- 41,000 residents
- One of the world's advanced smart grids (households can immediately react to price change)
  → Project supported by EU to show energy future
- Up to 30 MW wind power (Peak demand is 55 MW)
- Grid:
  - Undersea cable from Sweden to secure energy supply
  - 60 kV grid 131 km
  - 10 kV grid 914 km
  - 0.4 grid 1.887 km





Source: http://spectrum.ieee.org/energy/the-smarter-grid/the-smartest-greenest-grid

Source: Kumagai, J. *The Smartest, Greenest Grid*. April 29, 2013. IEEE Spectrum. May 28, 2013 <http://spectrum.ieee.org/energy/the-smarter-grid/the-smartest-greenest-grid>

Grid Stability and Wind Power: Example Island Grid Bornholm (Denmark)

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- Problem: If wind power share is high and suddenly the wind speed dies 50 Hz frequency can rush down → Worst case: Blackout
- September 17, 2013:
  - Cable to Sweden was shut down because of maintenance
  - Turbines were shut down to keep the grid balanced
  - 6 Turbines where turned on again, in few minutes their share of the island’s power supply rose to 15 %
  - Frequency dropped sharply to 49.8 Hz
  - Monitoring team was able to step in and increased conventional energy output (Wind share of 10%)

Source: http://spectrum.ieee.org/energy/the-smarter-grid/the-smartest-greenest-gric

→Idea of new smart grid: Cut down demand instead of increasing conventional energy

Source: Kumagai, J. *The Smartest, Greenest Grid*. April 29, 2013. IEEE Spectrum. May 28, 2013 <http://spectrum.ieee.org/energy/the-smarter-grid/the-smartest-greenest-grid>

GRID STABILITY STRATEGIES

Best stability strategies depend on the level of renewable integration

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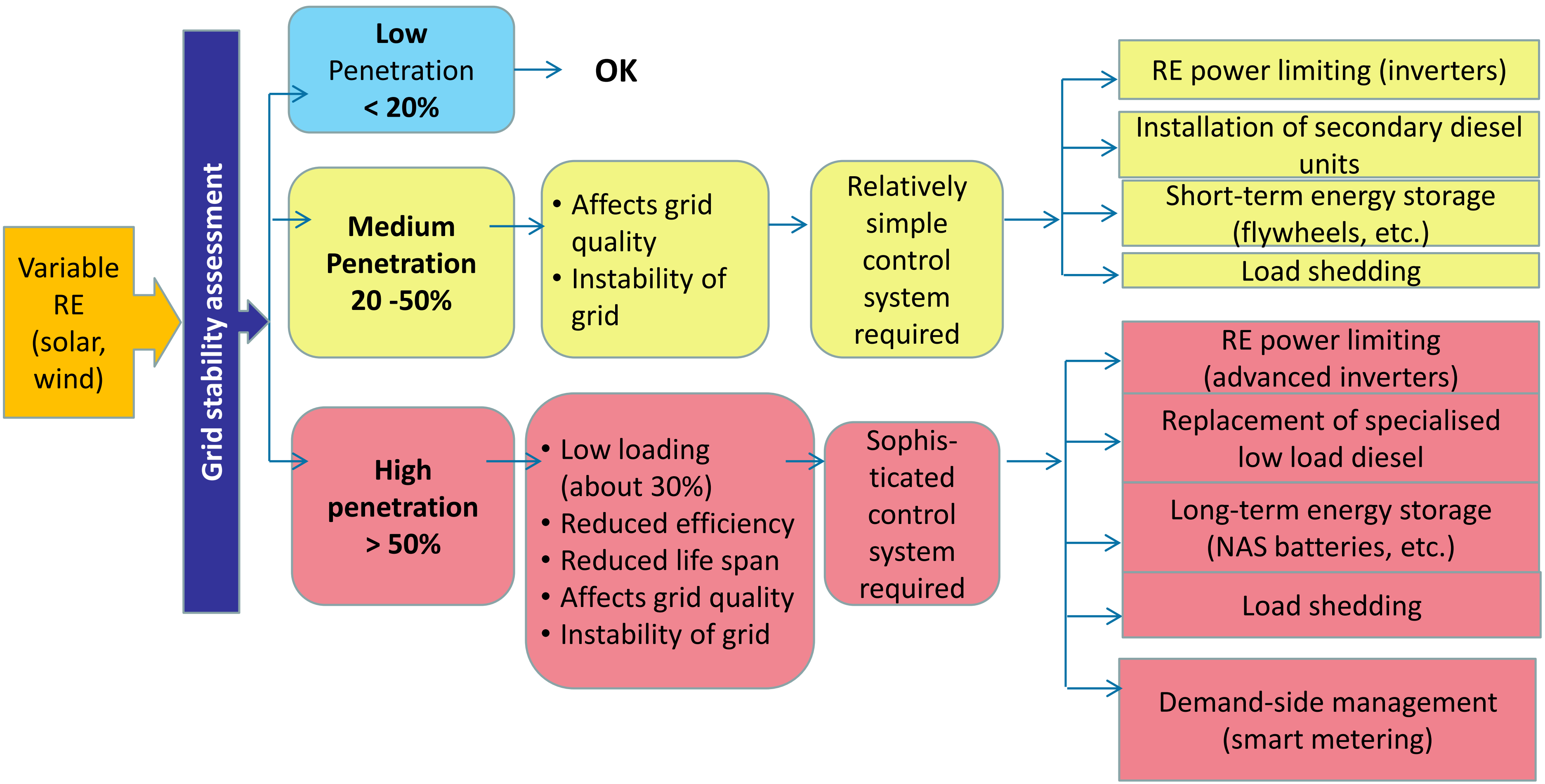

Some Technology Strategies to Deal with Power Variability

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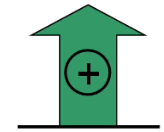
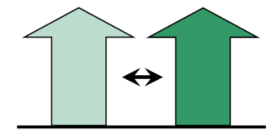
- ***Additive Generation:***
  - Application: rare short-term peak
  - Technology solutions: Secondary/emergency diesel generators.

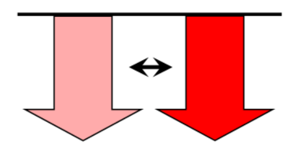


- ***Dispatchable Generation:***
  - Application: frequent short, high peak
  - Technology solutions: Advanced controlled (inverters) diesel generators.

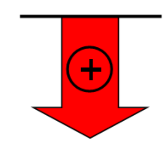


- ***Energy Storage:***
  - Application: daily cyclical balance of load and generation
  - Technology solutions: Decentralized batteries, flywheels.

- ***Dispatchable Load:***
  - Application: compensate frequent short, high production peaks
  - Technology solution: Air conditioning.



- ***Additive Load:***
  - Application: compensate rare production peaks
  - Technology solutions: District and local heating/cooling.



Sources: Adapted from: Fraunhofer UMSICHT, Hybrid urban energy storage, (May 2012)

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GRID STABILITY: MODELLING

Models Can Help Islands Assess Grid Stability with a Greater Share of Renewable Power

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- Models can help assess such potential problems by identifying the levels of RE integration and find solutions ahead of time
  - IRENA has assessed various suitable models
  - *PowerFactory* is one of them
- Software training: 26-28 February, Bonn
- First pilot study for Palau in collaboration with PPA: Workshop 10-12 April, Palau
- Four more case studies in 2013
  - 2 in cooperation with Pacific Power Association
  - 2 outside the Pacific region

  → Goal is to identify heuristics and to develop a methodology for the grid stability assessment

Dynamic Modelling for Grid Stability Assessment

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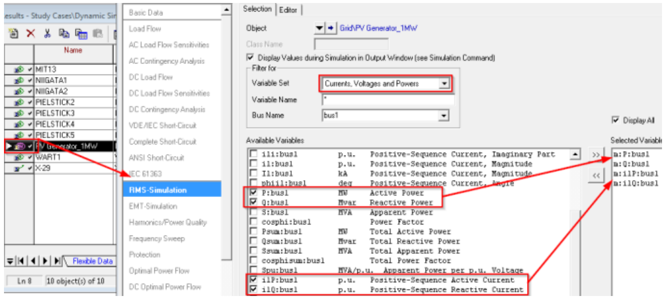
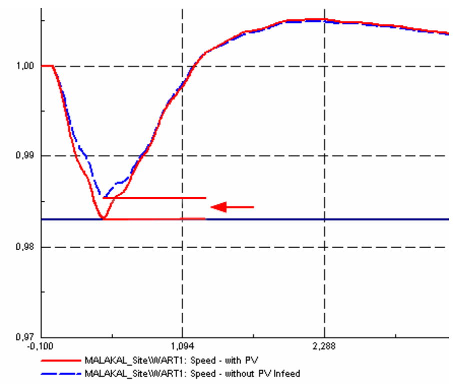
- For grid stability, *voltage stability* and *frequency stability* are critical.
- Dynamic modeling simulates the effects of frequency and voltage under the varying load conditions by renewables on second/minute scales.
- *PowerFactory* is one of the software for dynamic modelling suitable for hybrid systems with ability to simulate key components including advanced inverters and batteries.
- Modeling requires specific skills and experience.



- Aims of IRENA study:
  - Provide islands with better understanding of the levels of variable RE integration without affecting the power quality (energy planning).
  - Develop capacity in islands to conduct grid stability assessment.
  - Develop a comprehensive methodology for the grid stability assessment.
  - Provide technological options for grid stability and RE integration.



Source: *PowerFactory*

Grid Stability Methodology

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Steps	Experts and Science Community	IRENA	Regional entity/utility (e.g. PPA)	Islands	Technical provider (e.g. DiGSILENT)
Data collection				Data collection	
Build a model in the *PowerFactory*			Build the model or support (based on island capacity)	Build the model (based on the capacity of an island)	Software Support
Dynamic model simulation/results		Support	Run the model or support (based on island capacity)	Run the model (based on the capacity of an island)	Software Support
Validation of the model/results	Support	Support	Support	Validate the model/results	Software Support
Recommendations on strategies and technology solutions		Support	Assessment	Assessment	
Quality assurance of recommendation	Confirmation	Support			

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THANK YOU !

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