Island Systems with High Wind Penetration

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Dispatch Constraints of Wind-Diesel Systems

Diesel Generators:

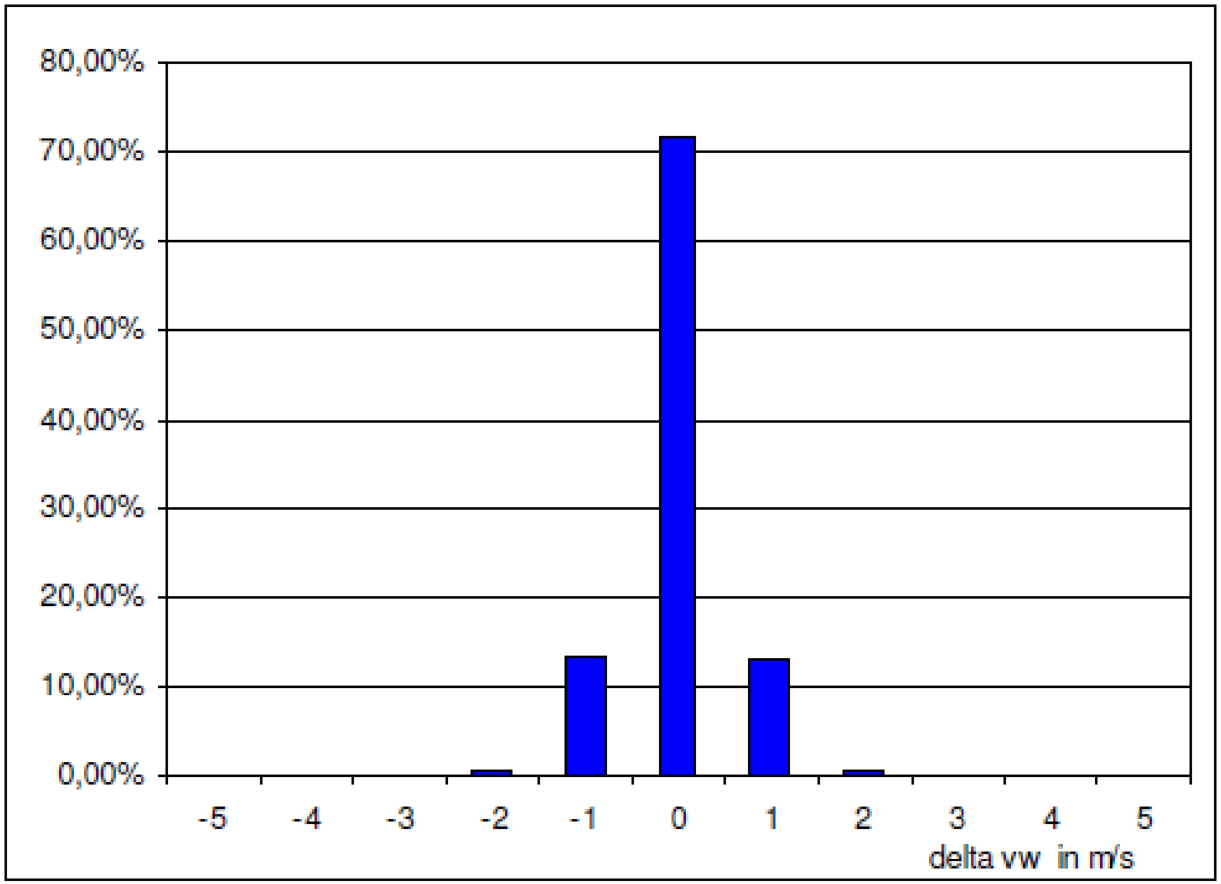
- Start-up time of diesel generators: <5min (hot stand-by)
- Very fast primary reserve
- Minimum power output of 20%....40% of rated power during continuous operation.

Wind Generators

- Variability of wind speeds
- Typically no contribution to system inertia (some WTG-manufacturers are now offering such a feature)
- Synchronize to the grid, cannot maintain voltage angle.

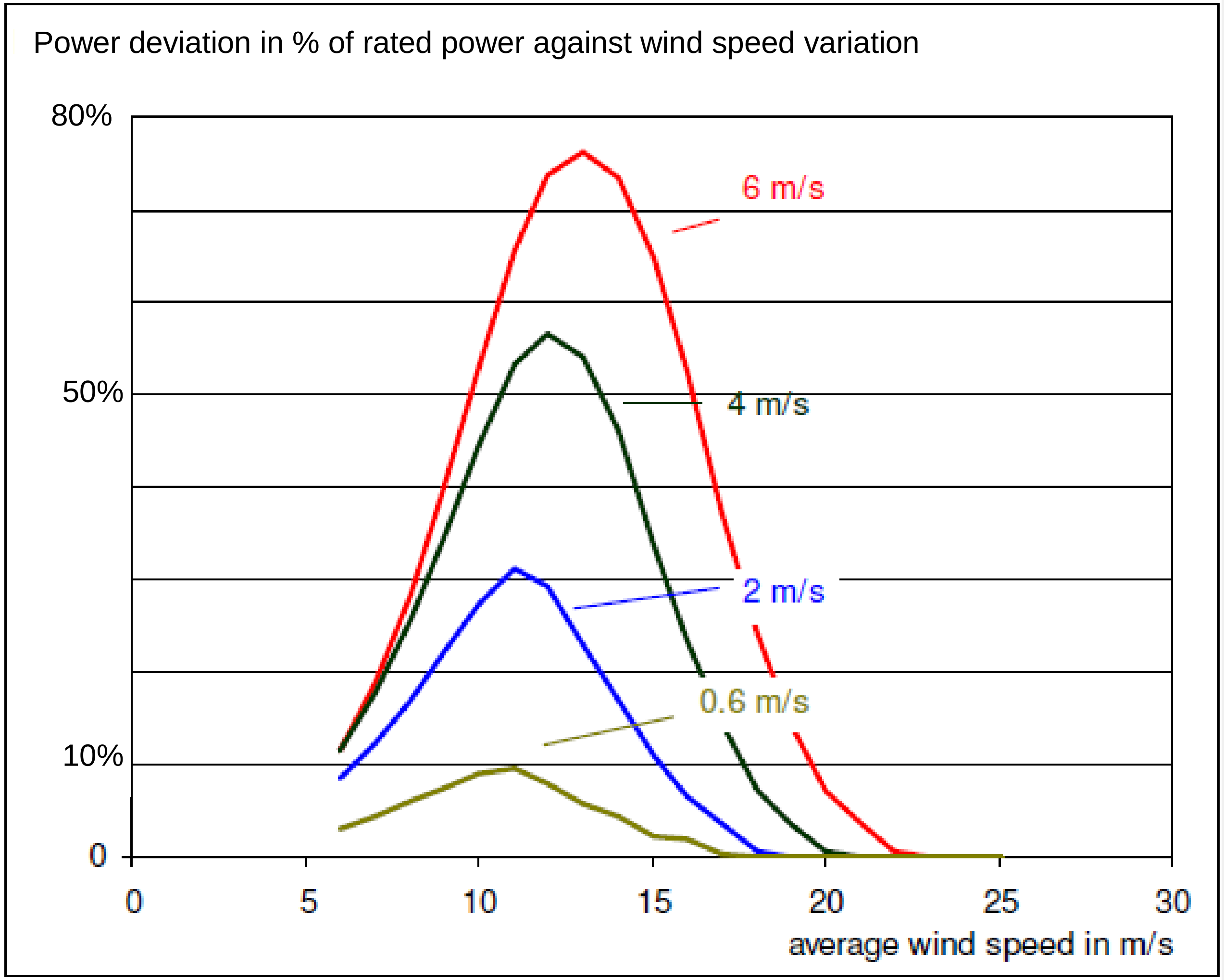
-> Maximizing wind penetration means minimizing the number of synchronized diesel generators.

Wind Variations

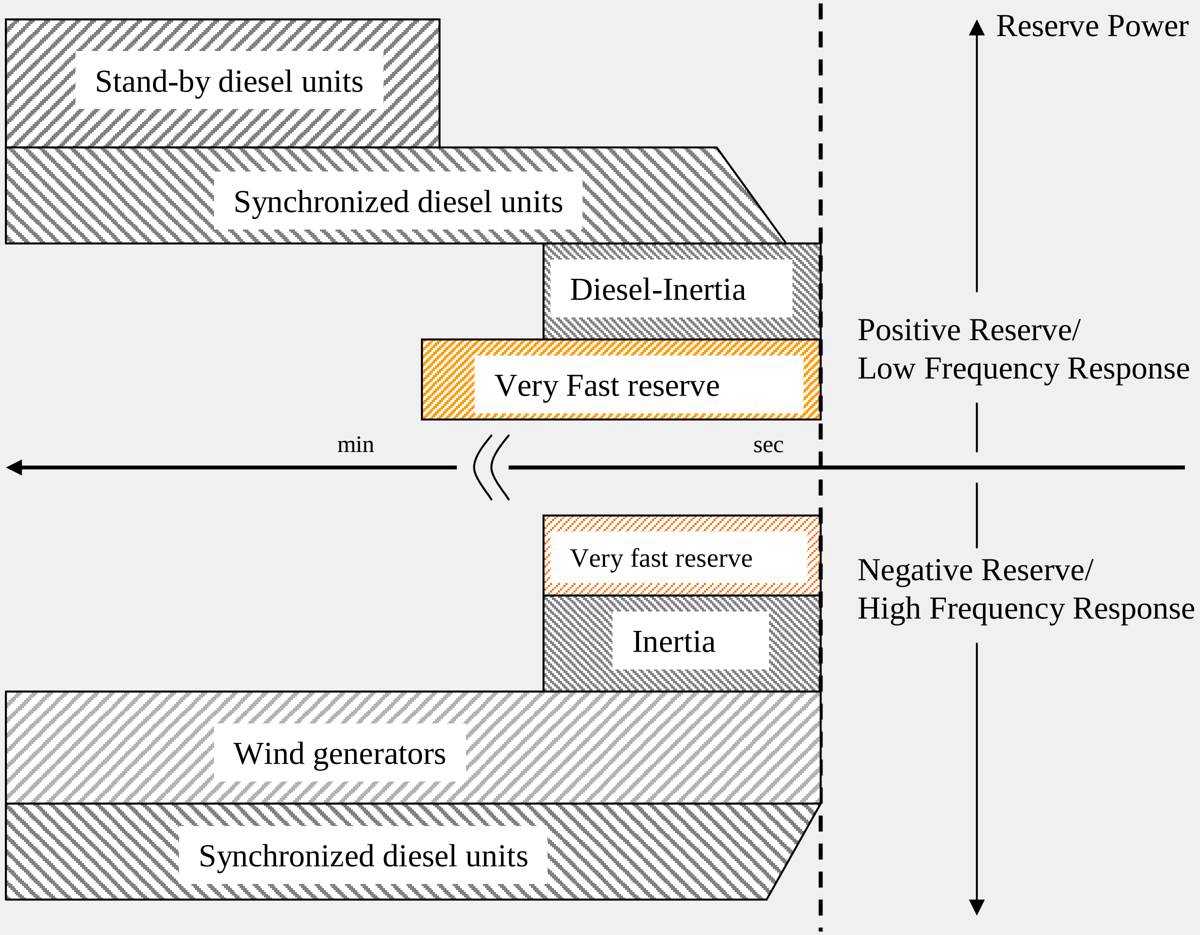


Wind speed variations between two consecutive 10min intervals

Wind Speed Variations – Power Variations



Active Power Balancing Concept



Active Power Balancing

- Initial reserve: provided by inertia of diesel generators
- Positive „primary“ reserve: Diesel generators
- Negative „primary“ reseve: Diesel + Wind generators

Restrictions with regard to wind penetration:

- Minimum inertia requires minimum number of dispatched diesel units
- Primary reserve requires sufficient number of dispatched diesl units
- Voltage angle requires the operation of min. 1 diesel generator (2 if n-1 secure operation required)

Generator Dispatch - Example

Operating Conditions:

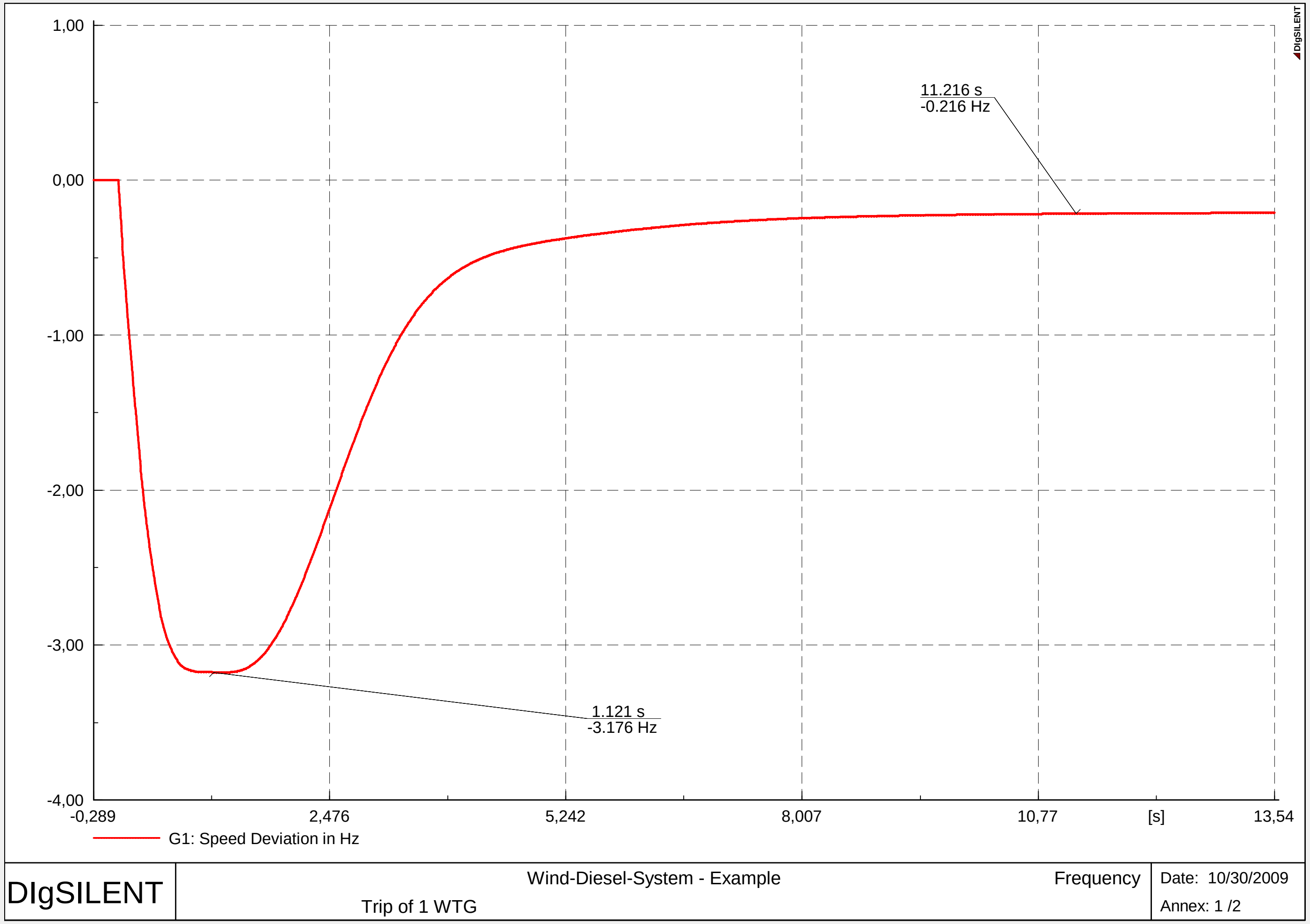
- Load: 5 MW
- 5 diesel gensets with 1MW each. Min. dispatch: 25%
- 5 MW wind farm
- Wind speed > rated wind speed.
- Available wind generation: 5MW

Generator Dispatch:

- Min. 2 diesel gensets must be dispatched: Pdiesel=0,5MW
- Wind generation: 4,5MW

-> 500kW of available wind generation cannot be used.

Generator Dispatch – Example – Loss of 1 WTG



Transient Frequency Deviation: -3Hz ->Inertia too low!

Generator Dispatch - Example

Operating Conditions:

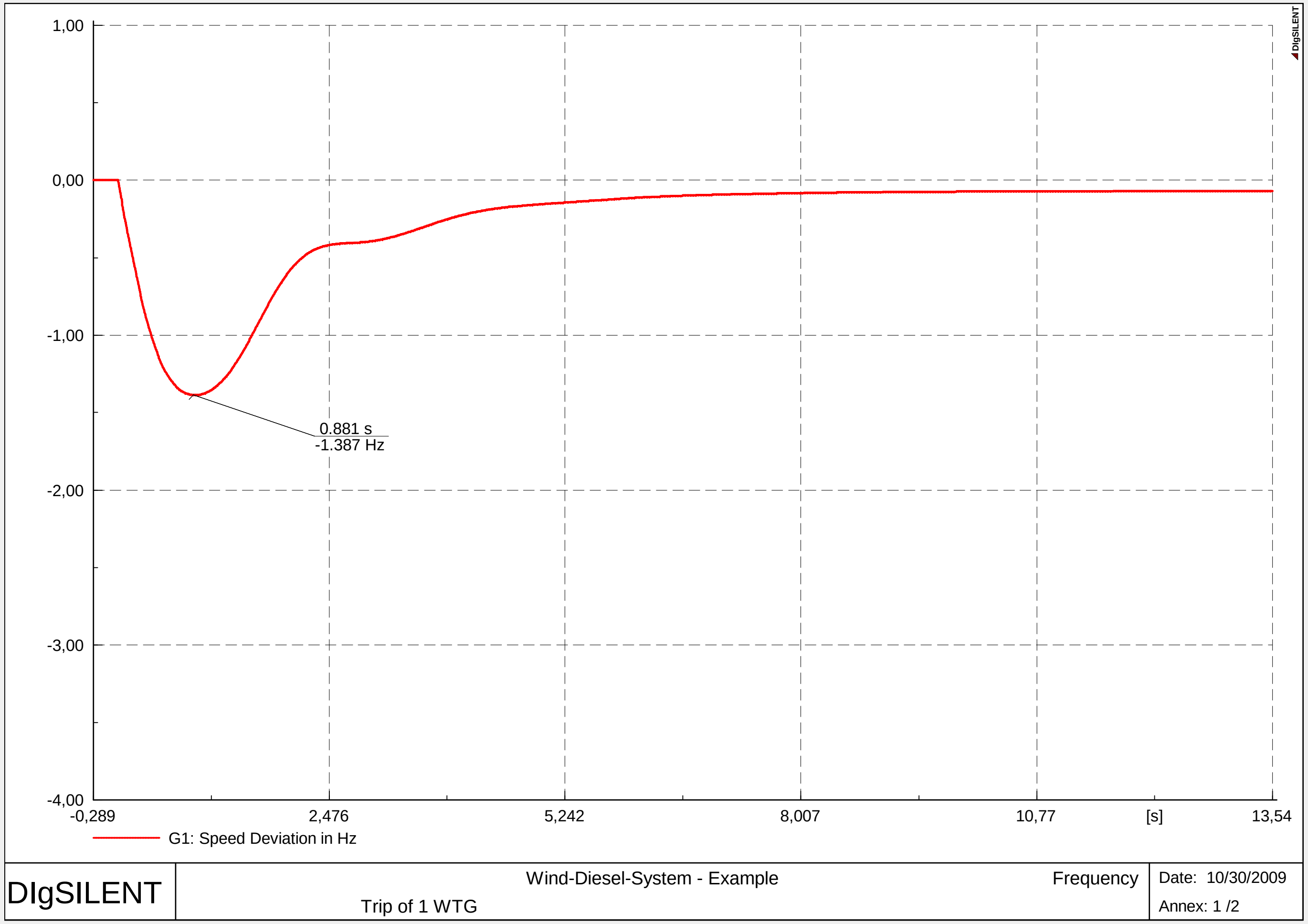
- Load: 5 MW
- 5 diesel gensets with 1MW each. Min. dispatch: 25%
- 5 MW wind farm
- Wind speed > rated wind speed.
- Available wind generation: 5MW

Generator Dispatch:

- Constraint: Inertia -> All diesel gensets must operate all the time
- Min. 5 diesel gensets must be dispatched: Pdiesel=1,25MW
- Wind generation: 3,75MW

-> 1,25MW of available wind generation cannot be used.

Generator Dispatch – Example – Loss of 1 WTG



Transient Frequency Deviation: -1,3Hz, acceptable (at the limit!)

Generator Dispatch - Example

- For reducing the inertia constraint: Additional inertia required
  - Flywheel
  - Battery Storage
- Flywheel can provide reserves in the time frame of seconds
- Battery storage can provide reserves in the time frame of minutes

-> For overcoming the inertia problem, flywheel sufficient

Generator Dispatch – With Flywheel - Example

Operating Conditions:

- Load: 5 MW
- 5 diesel gensets with 1MW each. Min. dispatch: 25%
- 5 MW wind farm
- Wind speed = rated wind speed.
- Available wind generation: 5MW

Generator Dispatch:

- Constraint: Backup of wind speed variations (30% of wind generation)
- Required spinning reserve: 1,5MW (30% of 5MW)
- Min. 2 diesel gensets must be dispatched: Pdiesel=0,5 MW
- Spinning reserve: 1MW -> too low!
- Min. 3 diesel gensets must be dispatched: Pdiesel=0,75MW
- Wind generation: 4,25MW

-> 0,75MW of available wind generation cannot be used.

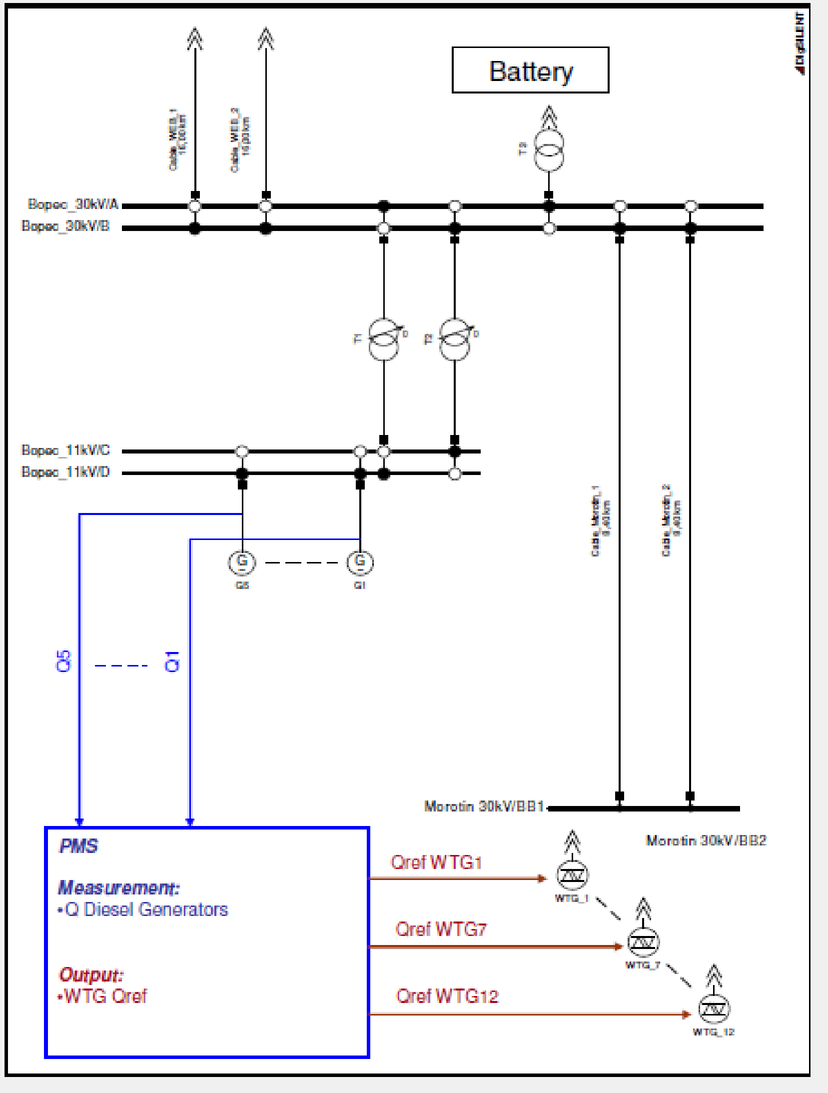
Generator Dispatch – With Flywheel - Example

- Assumption: Additional use of a battery
- Battery inverter can impose voltage angle
- Battery inverter and WTGs can cover required reactive power range

- Must-run diesel only depend on available reserve
- Depending on battery size, number of must-run diesel units can be equal to zero (one in hot standy-by)

- -> Entire wind generation can be used!

Reactive Power – Voltage Control Concept



Reactive Power – Voltage Control Concept

- Assumption:
  - Diesel generators control the voltage (AVR)
  - WTGs on reactive power control
  - No voltage control contribution of storage system
- Central power management system assigns reactive power to
  - Diesel gensets and
  - WTGs
- Control objective:
  - Maximize reactive power reserve on the diesel generators.

Reactive Power – Voltage Control Concept

- For reducing the number of diesel gensets
  - WTGs
  - Storage

  should be equipped with fas voltage control

- If diesel gensets, WTGs and storage are equipped with fast voltage control capability, the control objective of the PMS is:

  - Maximize reactive reserve on all generators (and storage)

Wind-Diesel Systems - Summary

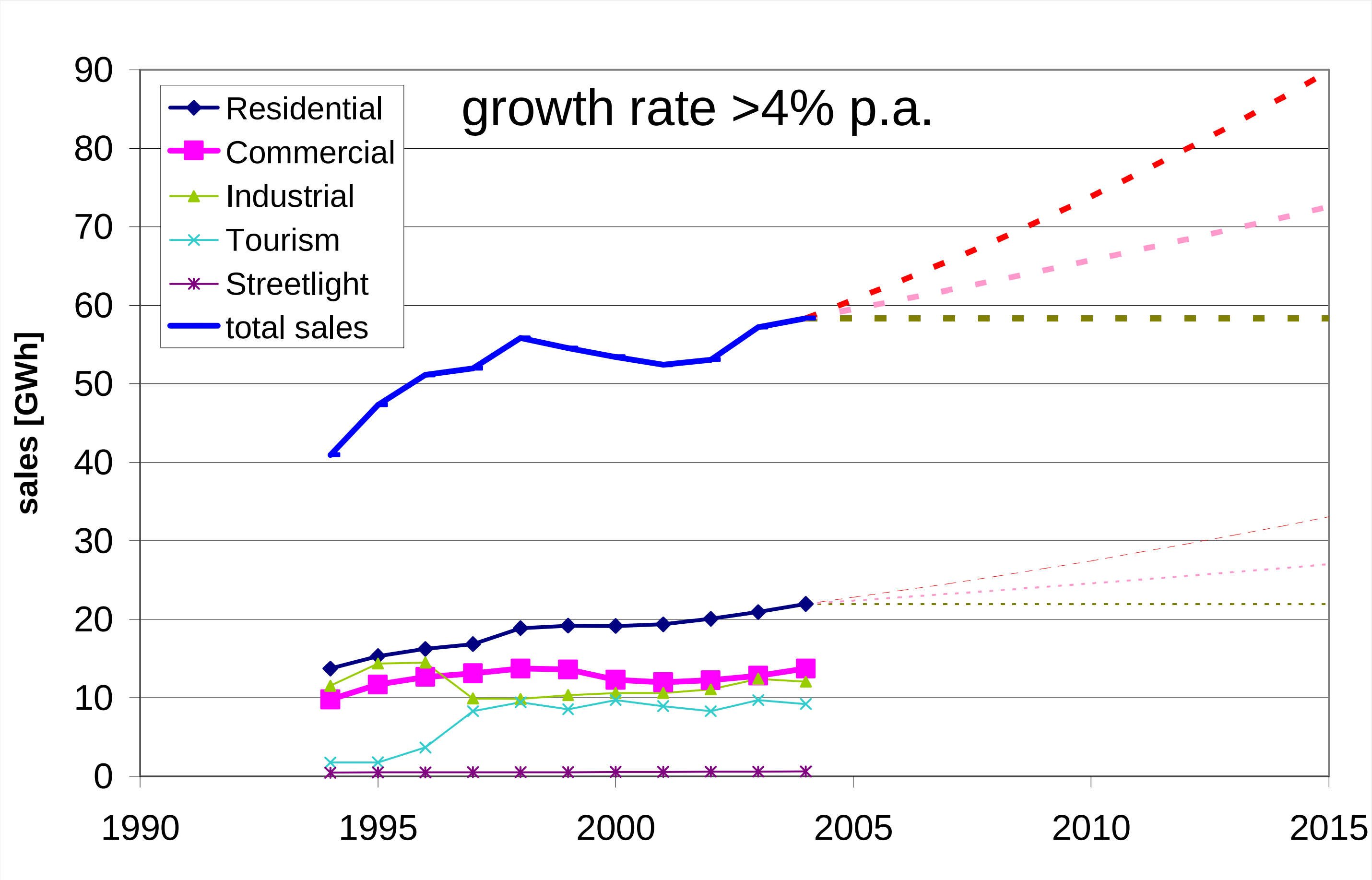
- Reserves must be provided for:
  - Compensating wind speed and load variations
  - Compensating loss of largest loaded diesel genset or WTG
  - Load steps.
- Objective during operation: maximize wind penetration
- Without storage, minimum number of dispatched gensets defined by inertia requirements.
- Storage removes constraints on the number of dispatched diesel gensets and allows increasing wind penertration.
- Flywheel: Relaxes inertia constraint (time frame of seconds)
- Battery: Contributes to the compensation of wind/load variations (time frame of minutes)

Example: Island of Bonaire

Project Background

- In 2006, WEB Bonaire tendered for proposals for developing new power generation at the island of Bonaire
- Target: min. 50% from renewables
- Lowering the dependence of fossil fuels -> keeping electricity prices at acceptable levels.
- Wind speeds >7 m/s making wind energy the most economical energy resource.
- Diesel gensets (fuelled by HFO, later by bio diesel) for balancing wind variations
- Target: Quality of supply shall be comparable to European standards .

Predicted Load Growth



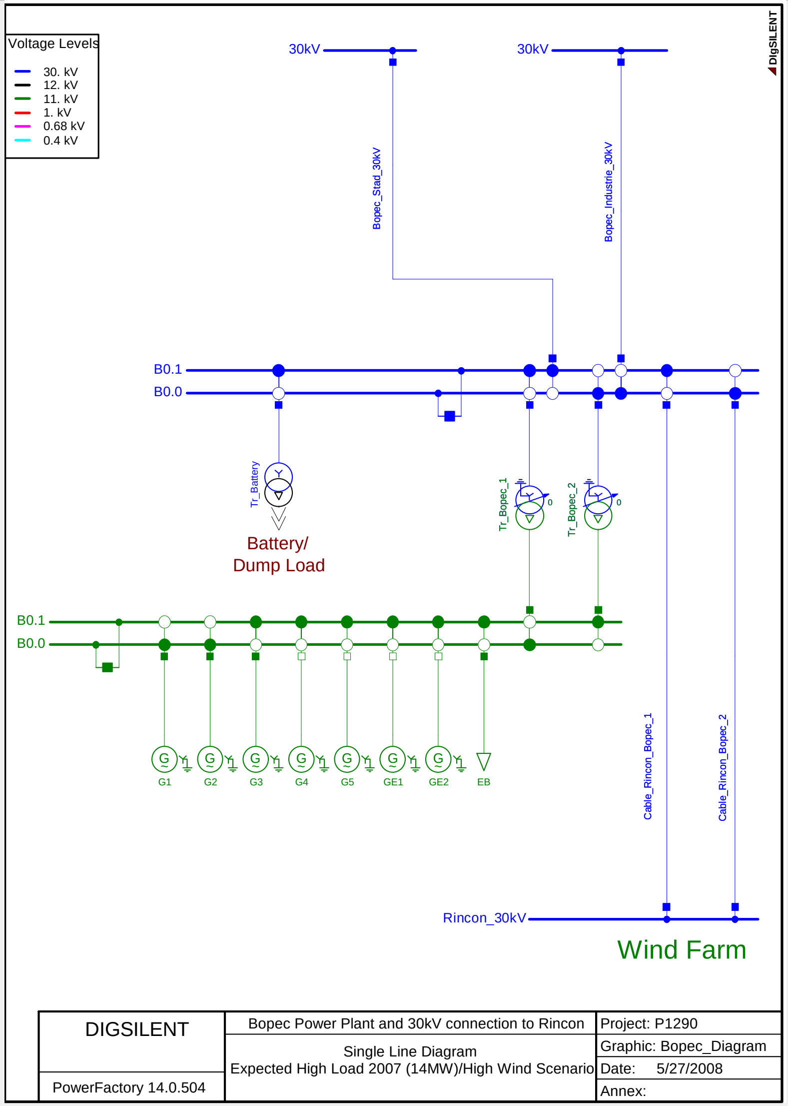
Capacity Planning

- Required outage rate < 6h/year (99,932%)

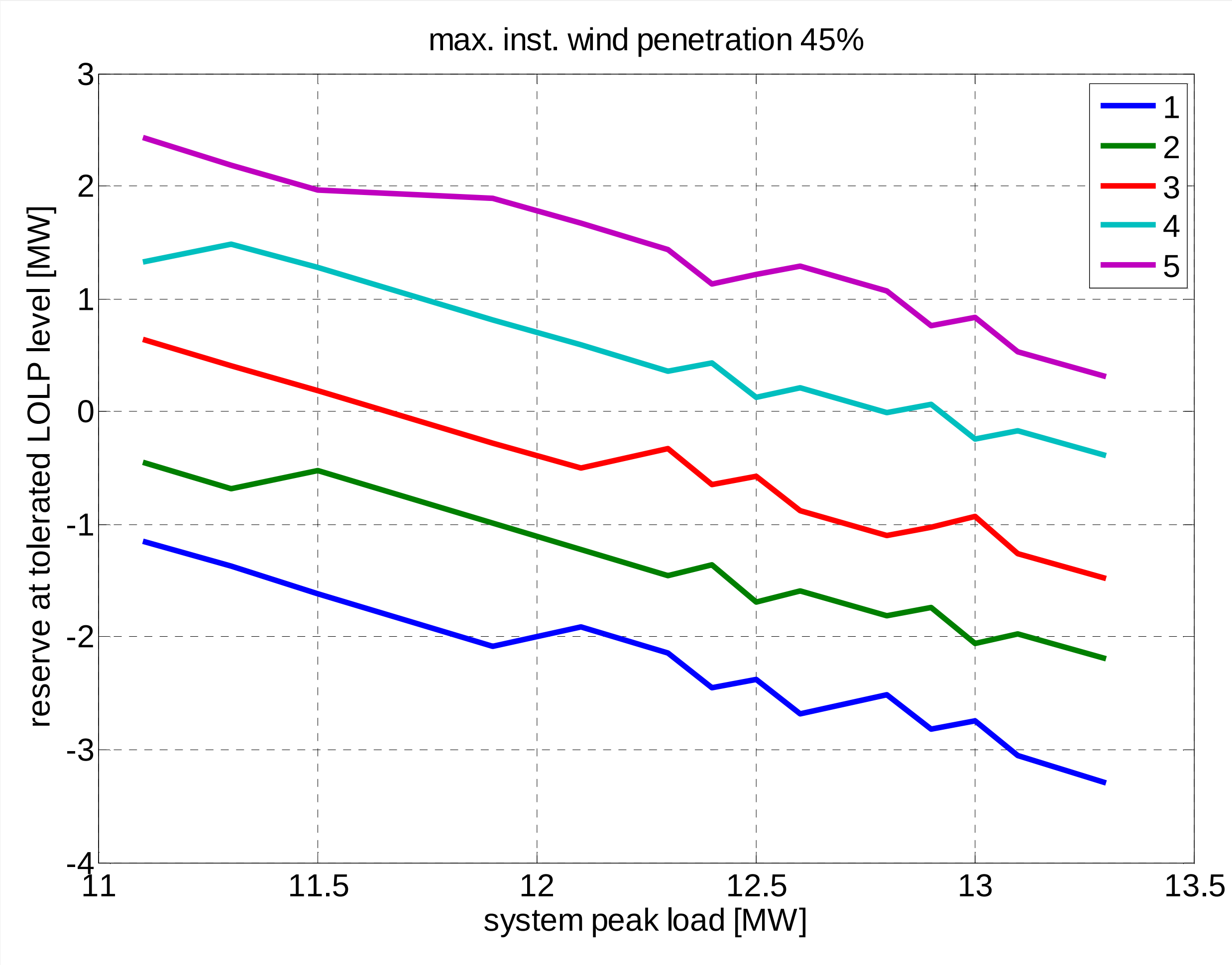
- 5 gensets with 2,88MW/each (HFO)
- 3 back-up gensets with 1MW/each (LFO)
- Wind-farm with 12 ENERCON E44 -> 10,8MW (rated power)

- Multi-year recordings of load
- Forced outage rate and maintenance schemes of diesel gensets
- Wind ressource assesments

Capacity Planning



Capacity Level at Required Outage rate



Active Power Control Concept

- Frequency requirements:
  - 49Hz < f < 51,5Hz within 3s
  - 49,75Hz < f < 50,25Hz continuously

- Design events – Normal Variations:
  - Wind speed variations
  - (Sudden) load change of 1MW

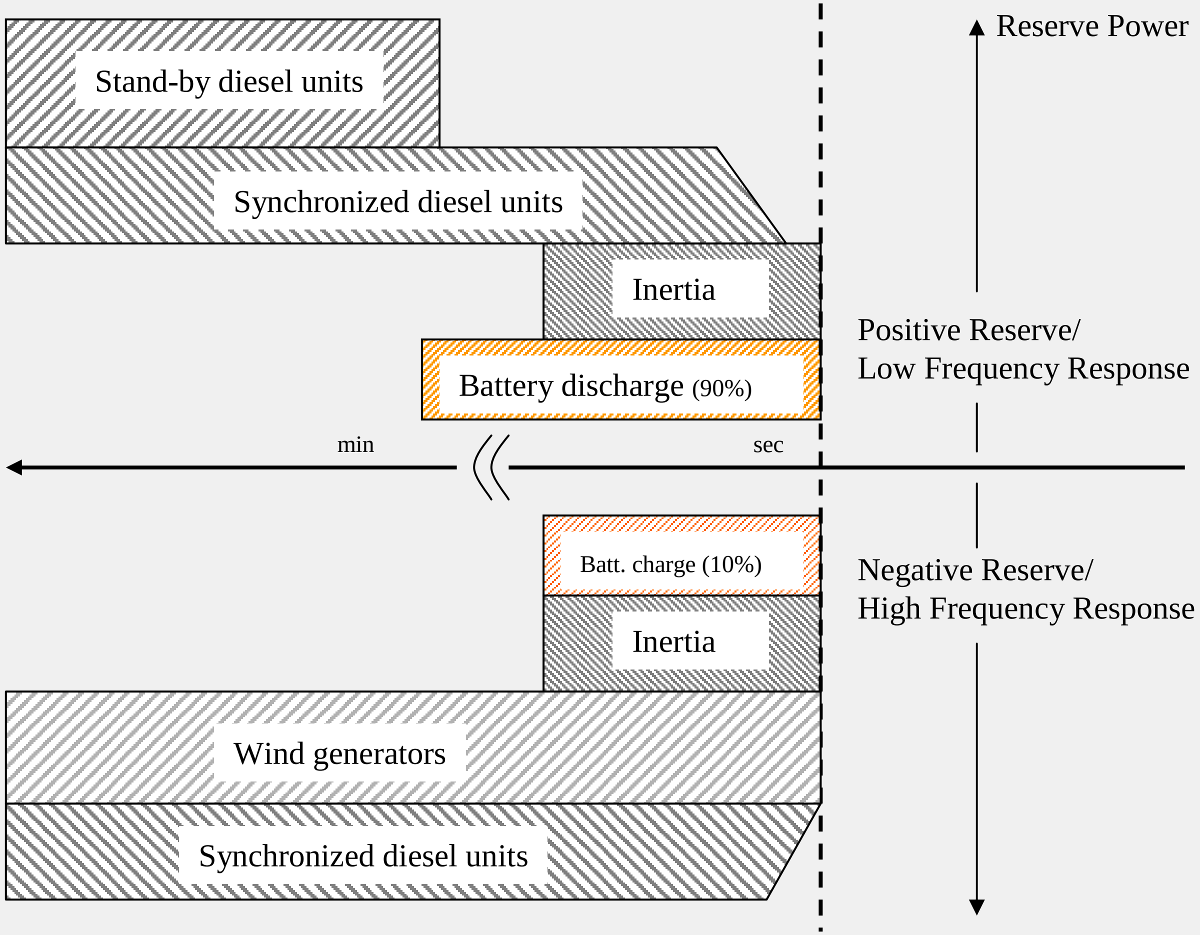
- Design events – Transient Deviations
  - Loss of highly loaded diesel genset
  - Loss of wind turbine running at full output
  - (Sudden) load variation of 2MW

Active Power Control Concept

- Battery/dump-load system proposed for complying with highly demanding requirements:
  - NC batteries, rating/capacity 3MW for 2minutes
  - Normally loaded at 90% -> dump load capacity is 10% of battery rating

- Battery helps:
  - Keeping frequency within required limits
  - Avoids „must-run“ units for limiting transient frequency excursions
  - Allows using stand-by diesel gensets for compensating „Normal Variations“

Active Power Balancing Concept



Reacitve Power Control Concept

- Voltage requirements – Normal Variations:
  - 98% < u <102% of rated voltage continuous operation

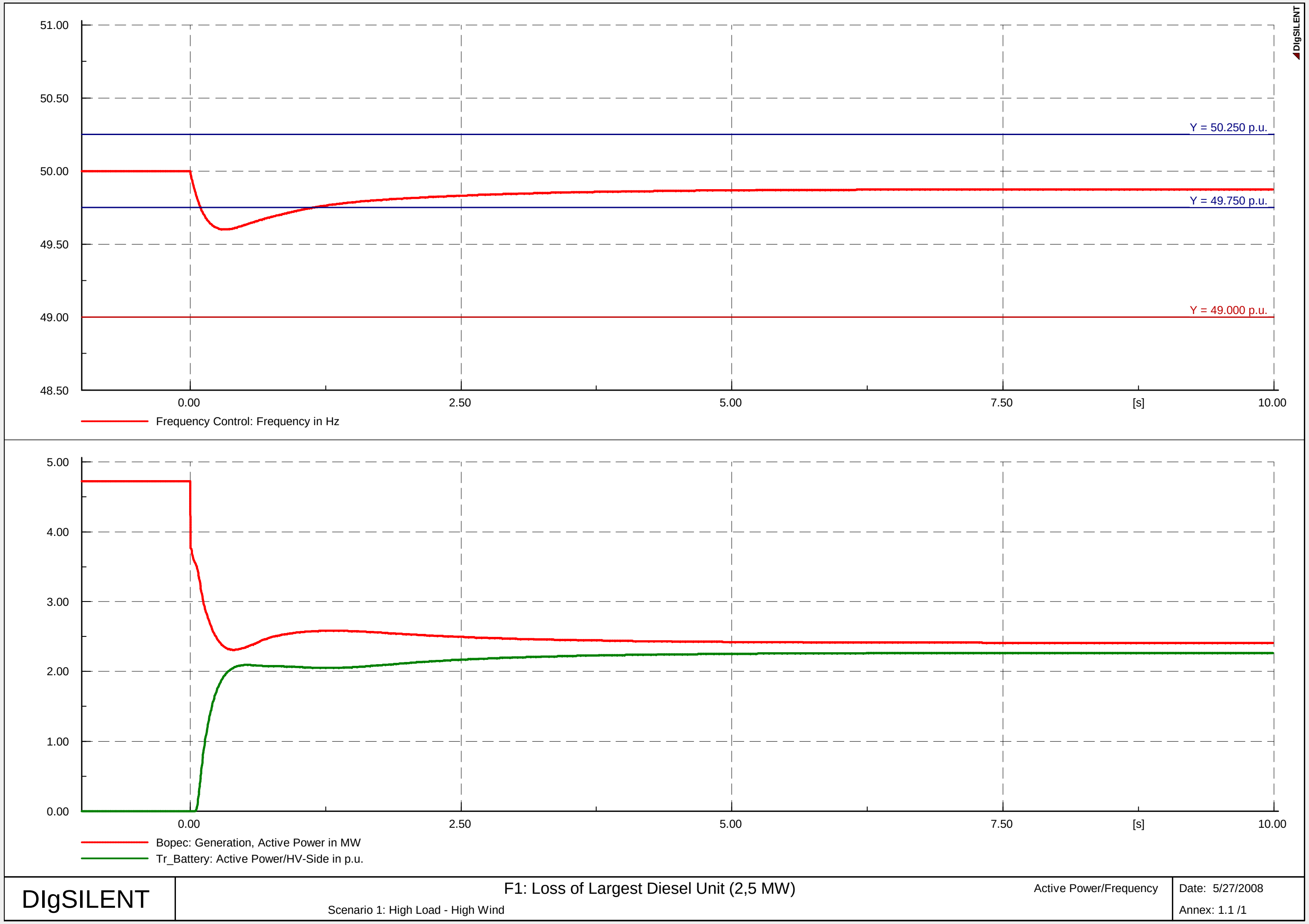
- Voltage requirements – Transient Variations
  - max. +/- 12,5% with a maximum duration of 2,5s
  - max. +/- 5% with a maximum duration of 4s
  - max. +/- 2% thereafter

- Reactive power supplied by
  - Cable capacitances (continuously)
  - Wind farm (slow control)
  - AVR of gensets (fast control)

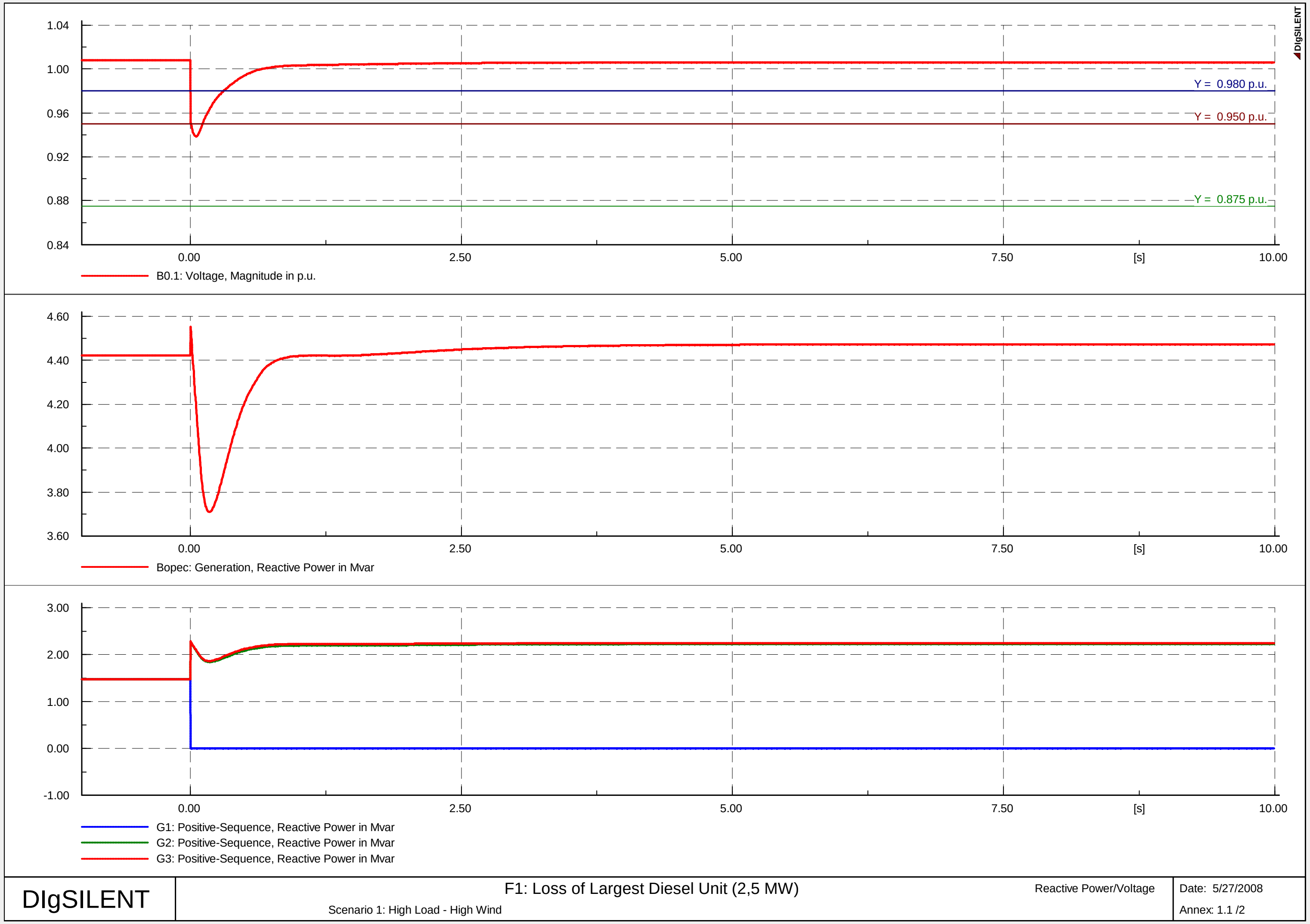
Dynamic Performance

- Model of the entire distribution system
- Dynamic model of ENERCON E44
- Dynamic model of
  - Diesel governors
  - Generators
  - Excitation system and voltage regulator
- Battery controller

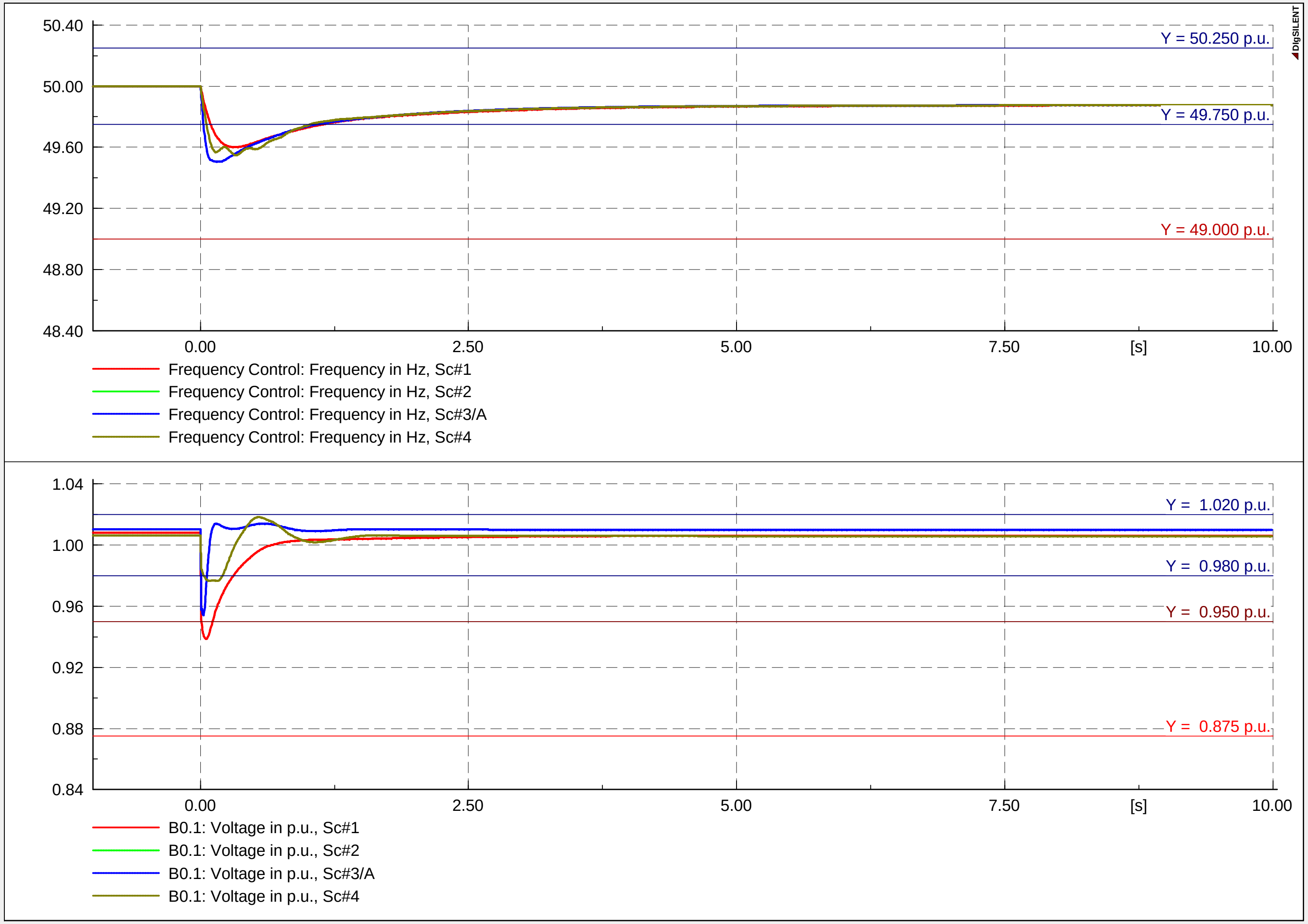
Turbine Trip – High Load, High Wind Case



Turbine Trip – High Load, High Wind Case



Turbine Trip – High Load, High Wind Case



Scenarios:
- Sc#1: HL-HW
- Sc#2: HL-NW
- Sc#3: LL-HW
- Sc#4: LL-LW

Summary

- Concept for a wind-diesel power plant for supplying up to 14MW of load on the island of Bonaire has been presented.
- Strict quality of supply criteria: Loss of load requirement: <6h/year
- Strict requirements with regard to voltage and frequency variations.

- Battery system will be used for supporting frequency,
- Active power balancing made by diesel generators and battery,
- Reactive power balancing made by wind generators (slow var-control) and diesel generators (fast var-control).
- Dynamic simulations validate the proposed concept against voltage and frequency requirements.

Thank You

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