Technische Universität Braunschweig

MODELLING RETROFITTING OPTIONS FOR AUTONOMOUS ISLAND POWER SYSTEMS TO MAXIMIZE PENETRATION OF VRE

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Content

Scope

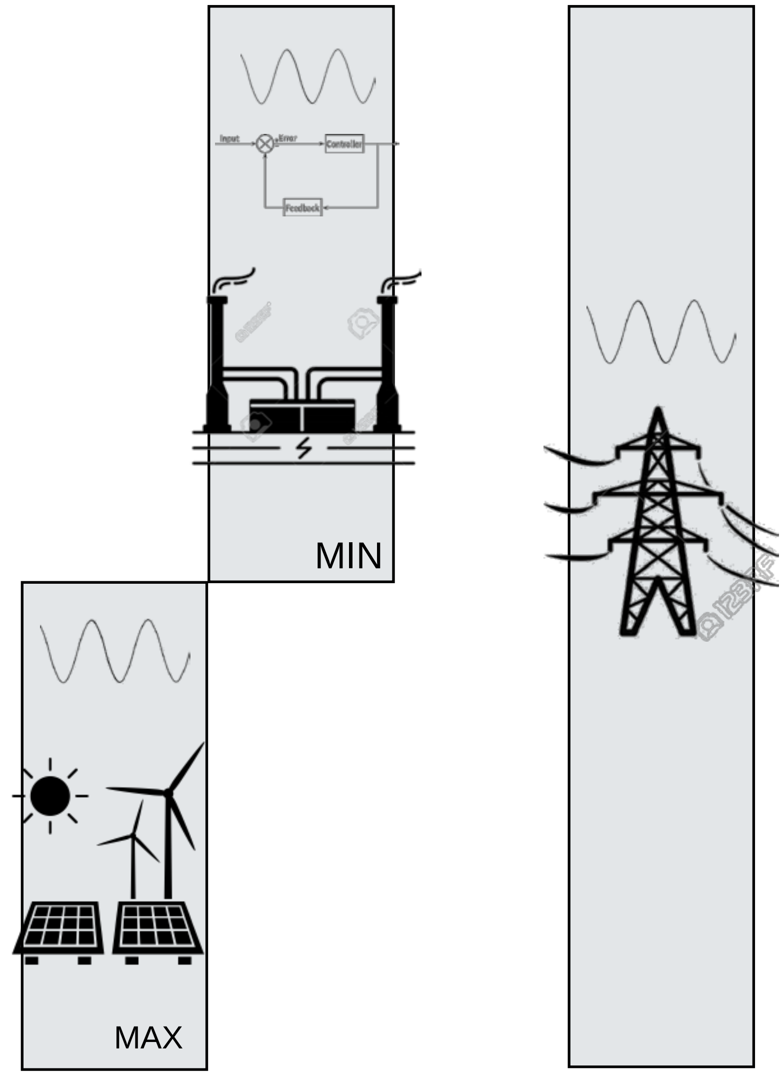
VARIABLE RENEWABLE ENERGY (VRE)	AUTONOMOUS ISLAND POWER SYSTEMS
› Non-Dispatchable Renewable energy sources	› no connection to neighboring and/or continental grid
› no contribution to system interia, primary- and secondary control	› Aggregated Model on single node
› Herein considered: wind turbine generators (WTG), photovoltaic (PV), (Run-of-River hydropower)	› Characteristics: heavy dependent on fossil fuels, small scale generation of electricity, high distribution cost, low VRE utilization compared to potential

Problem identification

To maintain a safe system operation,

- sufficiently controllable capacity must be maintained in the network, which ensures frequency and voltage stability („Must-run-units“)

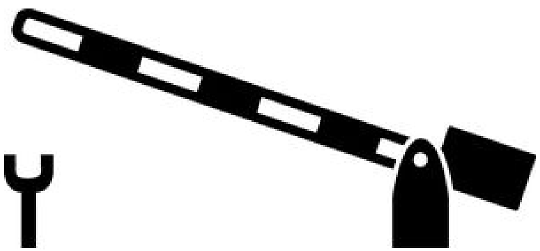
- thus the penetration of VRE has to be limited in relation to these generating units.



Power Generation Power Demand

Problem identification

VRE integration in existing autonomous island power systems.
System operators have following options:



CONSTRAIN

- Limiting installation of VRE generation facilities to the technical system boundary.

CURTAIL

- Preventing excessive amount of electricity from VRE by early down regulation.

RETROFIT

- Using engineering measures to increase the system limit for VRE (termed “retrofit options”).

Objective

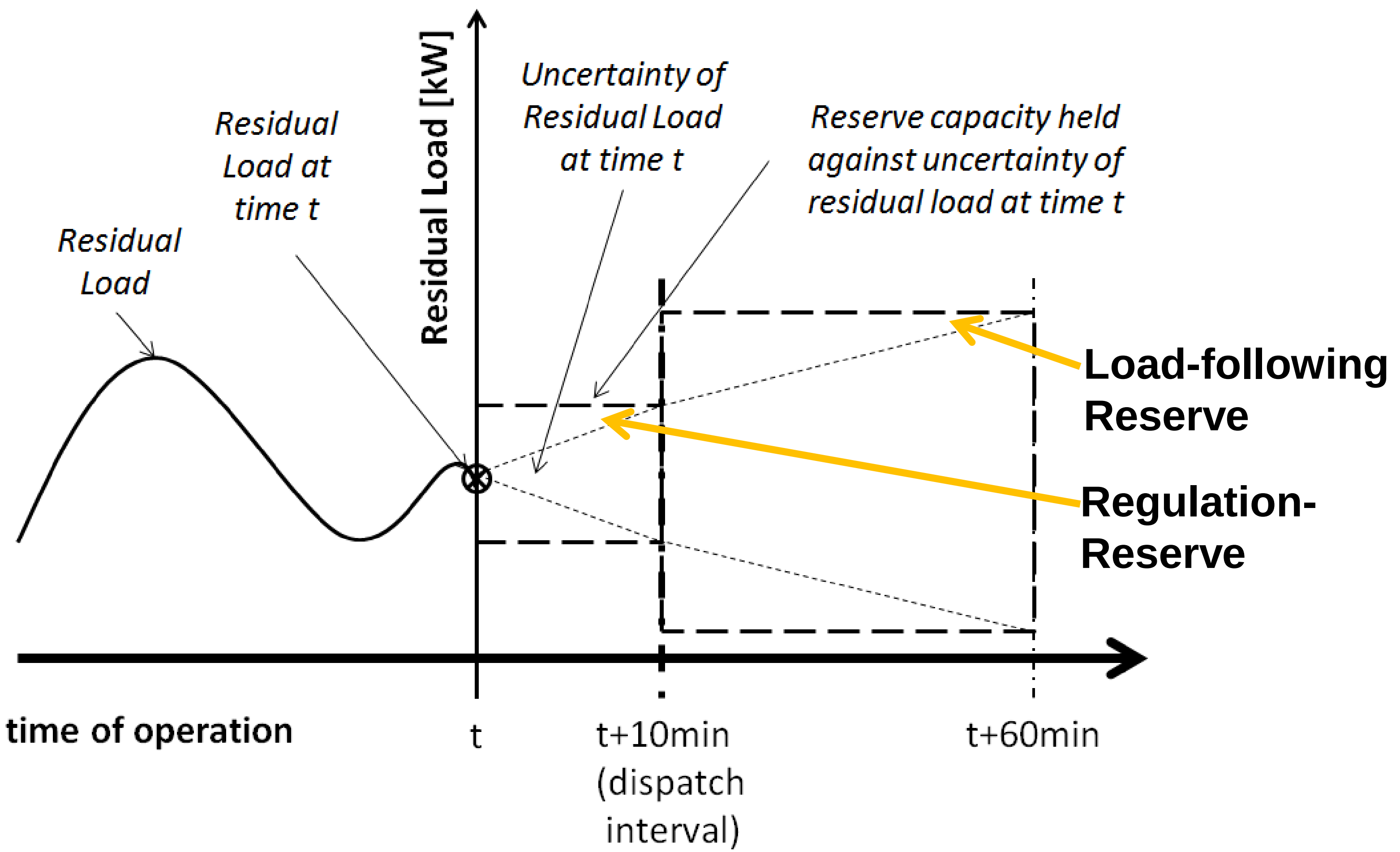
Technical - economic simulation model to determine optimal VRE expansion taking into account the optimal retrofit scenario

The following questions are addressed :

- What restriction is there for the VRE integration?
- What is the need for operating reserves depending on the VRE deployment?
- What retrofit options are available to work around these limitations?
- What economic benefits does VRE integration provide and at which stages of deployment is retrofitting of advantage?

Consideration to the model

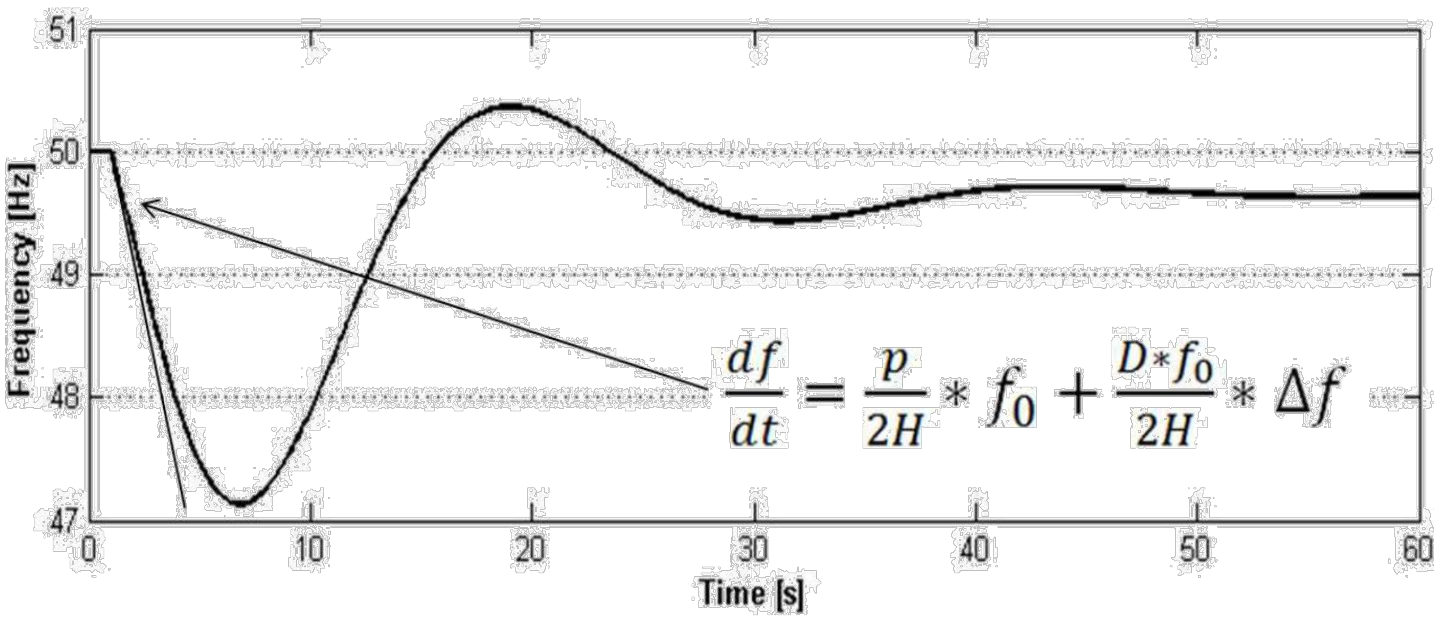
Adressing uncertainty in residual load using regulation and load following-reserve:



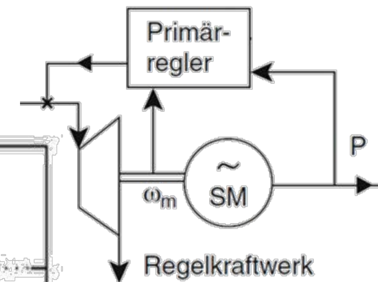
Consideration to the model

Influence of VRE on rate of change of frequency (ROCOF):

- VRE penetration replaces synchronized rotating energy, which contributes to system interia (H)
- results in increasing ROCOF and frequency deviation after Load change



$$\frac{df}{dt} = \frac{p}{2H} * f_0 + \frac{D * f_0}{2H} * \Delta f$$



Simulation of autonomous island power systems

The simulation model herein proposed may be divided into three technical sub-models and one economic model :

- **Reserve model**:

Time interval: 1 hour, 10 minutes, 30 seconds

Methodology: Reserve calculated as difference of forecasted to actual value in each time step (1hour-forecast to 10minute-actual as Load following, 10minute-forecaste to 30second-actual for regulation). Data set generation by randomly generated forecast errors added to an underlying linear interpolated time series, Forecast error derived from Probability density function

Output: Regulation and Load-following reserve, Spinning reserve setting

- **Operation model (Actual dispatch):**

Time interval: 10minutes

Methodology: Energy balance in each time step, Unit prioritization: VRE (penetration limits apply), Storage, Conventional generation,

Output: Capacity factors all generation units, Thermal start-up, VRE curtailment, Fuel consumption, Residual ramping reserve

Simulation of autonomous island power systems

The simulation model herein proposed may be divided into three technical sub-models and one economic model :

- **Short-term Operation model:**

Time interval: 30seconds

Methodology: see Operation model

Output: Residual ramping reserve, Ramping speed, Additional VRE curtailment, Load curtailment

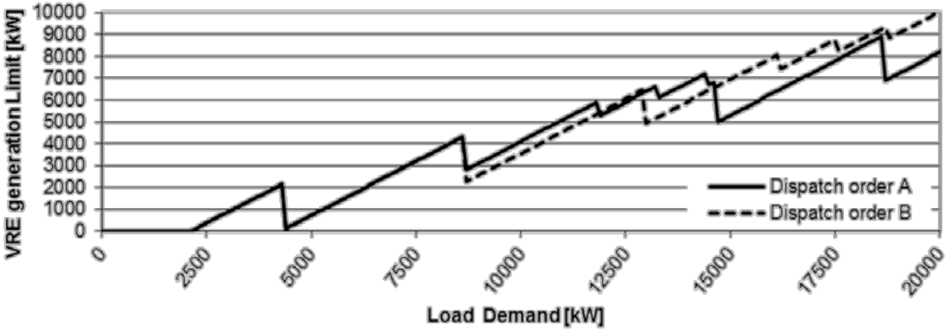
- **Economic model:**

Methodology: Discounted cash flow calculation, VRE integration cost considered: thermal unit start-up, VRE curtailment, partial loading of thermal units, cost-benefit calculation

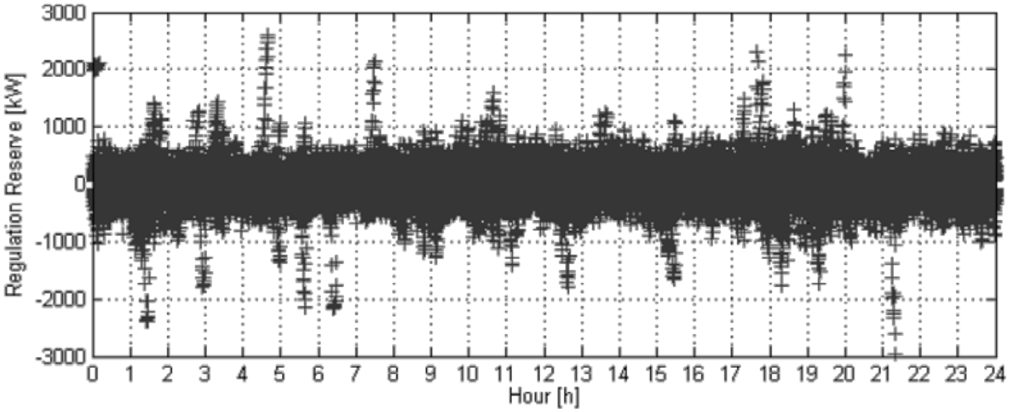
Output: LCOE (each unit), System- LCOE, net benefit curves, retrofit benefit curves

Limitation of VRE in the simulation model

- **Conventional generation units loading limits :**
  - operation of these units is constrained by their loading limits.

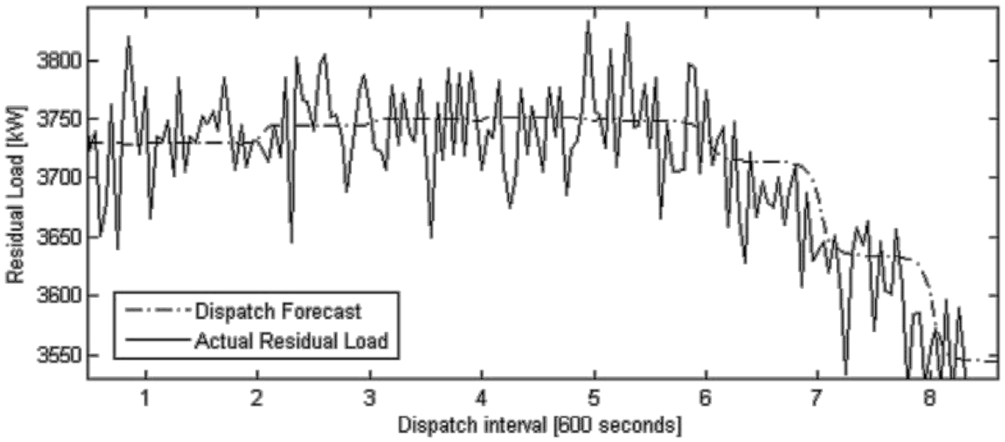


- **Spinning reserve demand:**
  - provided by conventional and storage units
  - Loading limits of these units to be considered

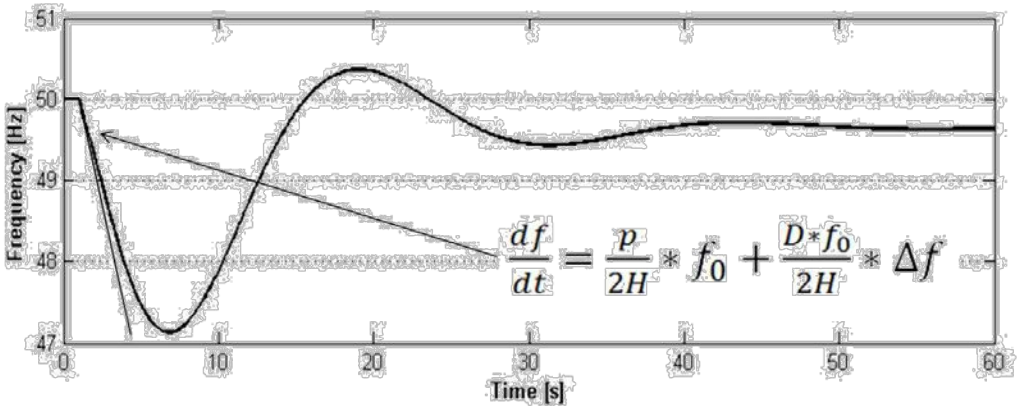


Limitation of VRE in the simulation model

- **Ramp rate of units providing frequency control:**
  - increasing rate of VRE-penetration increases change rate of residual-load.
  - Limits of maximum ramp rates applies.



- **Dynamic Limit:**
  - to limit the maximum ROCOF, the ratio of VRE to interia providing power plants has to be constraint



Case study- Suðuroy / Faroe-Island

Case study:

Simulation model is applied to the autonomous island power system of Suðuroy, the southernmost of the Faroe Islands.

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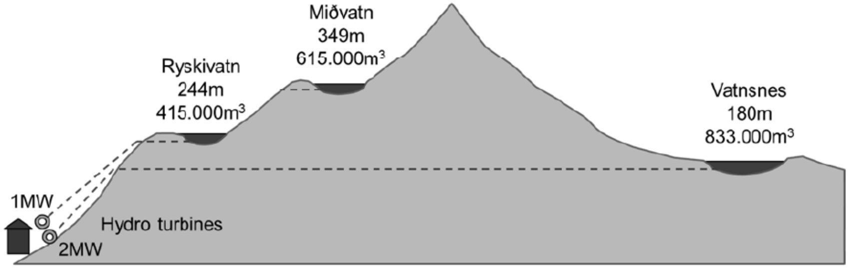
System setup:

Thermal power plant:

- Heavy fuel- 2x 2,7 MW; 4,15 MW
- Diesel- 2 MW

Water power:

- Pelton-Turbine 1 MW
- Francis-Turbine 2 MW



Retrofit scenario:

- Pump hydro storage with two operating scenarios (A1, A2)
- Short term storage for Spinning reserve (B)
- WTG-Installation of 0 kW to 10.000 kW (in 1.000 kW steps) are investigated

ID	*Retrofit Option*
Base	No retrofit
A1	Pumped hydro storage as "Stand-alone"
A2	Pumped hydro storage as "WTG to grid"[a]
B	Short-term Storage for Spinning reserve

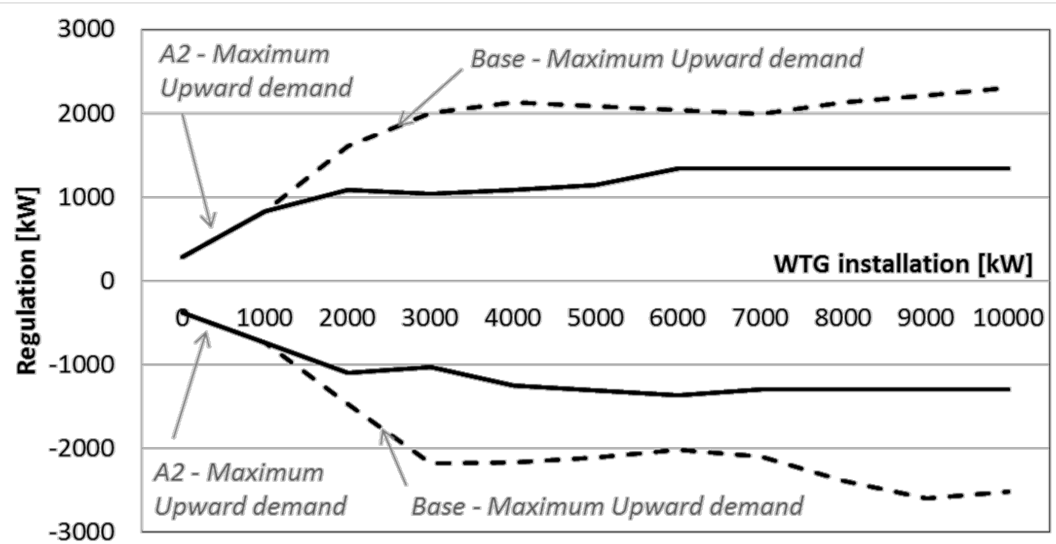
a. max. WTG to grid 25% power penetration

Case study- Suðuroy / Faroe-Island

- **Reserve model**:

  Regulation per WTG installation

  for base and retrofit scenario A2



- **Short-term Operation model:**

  Maximum WTG installation based on

  short term Ramping ability [kW] [b]

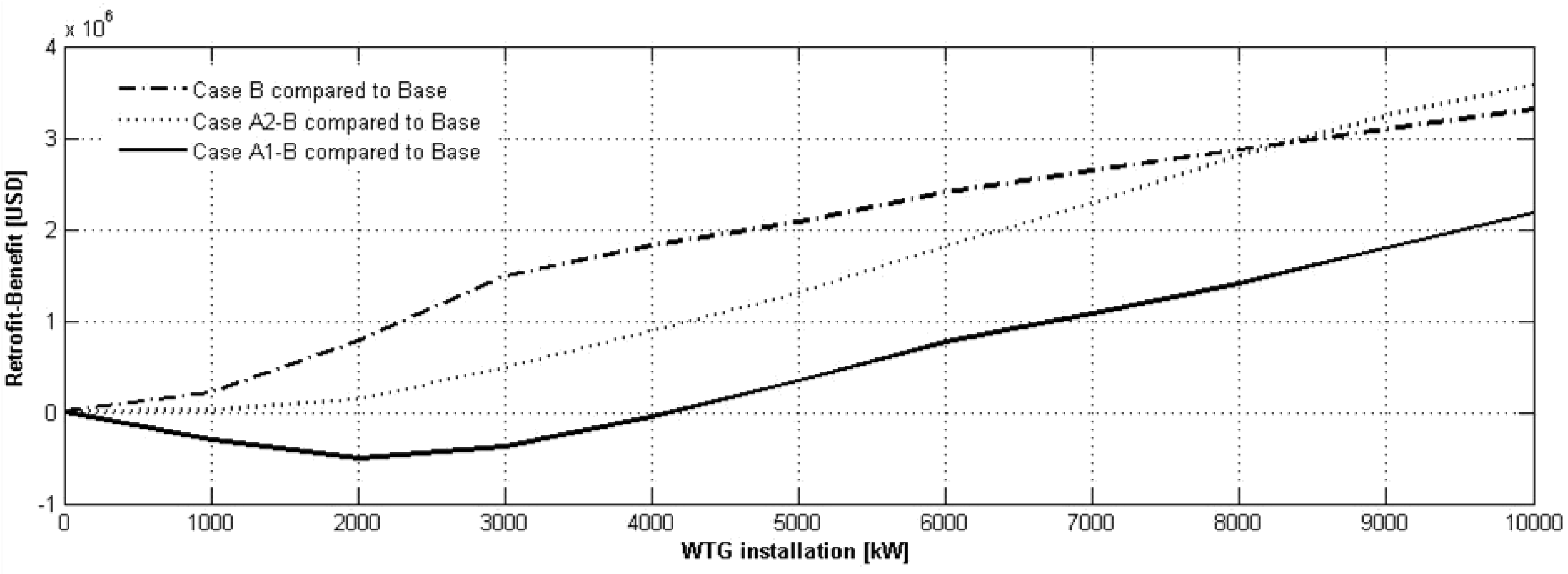
ID	*Maximum WTG installation based on short term Ramping ability of the system [kW]* [b]
Base	2.000
A1	9.000
A2	4.000
B	>10.000
A1-B	>10.000
A2-B	>10.000

b. Setup: maximum change in conventional generation of 25% rated capacity per Minute

Case study- Suðuroy / Faroe-Island

› **Economic model:**

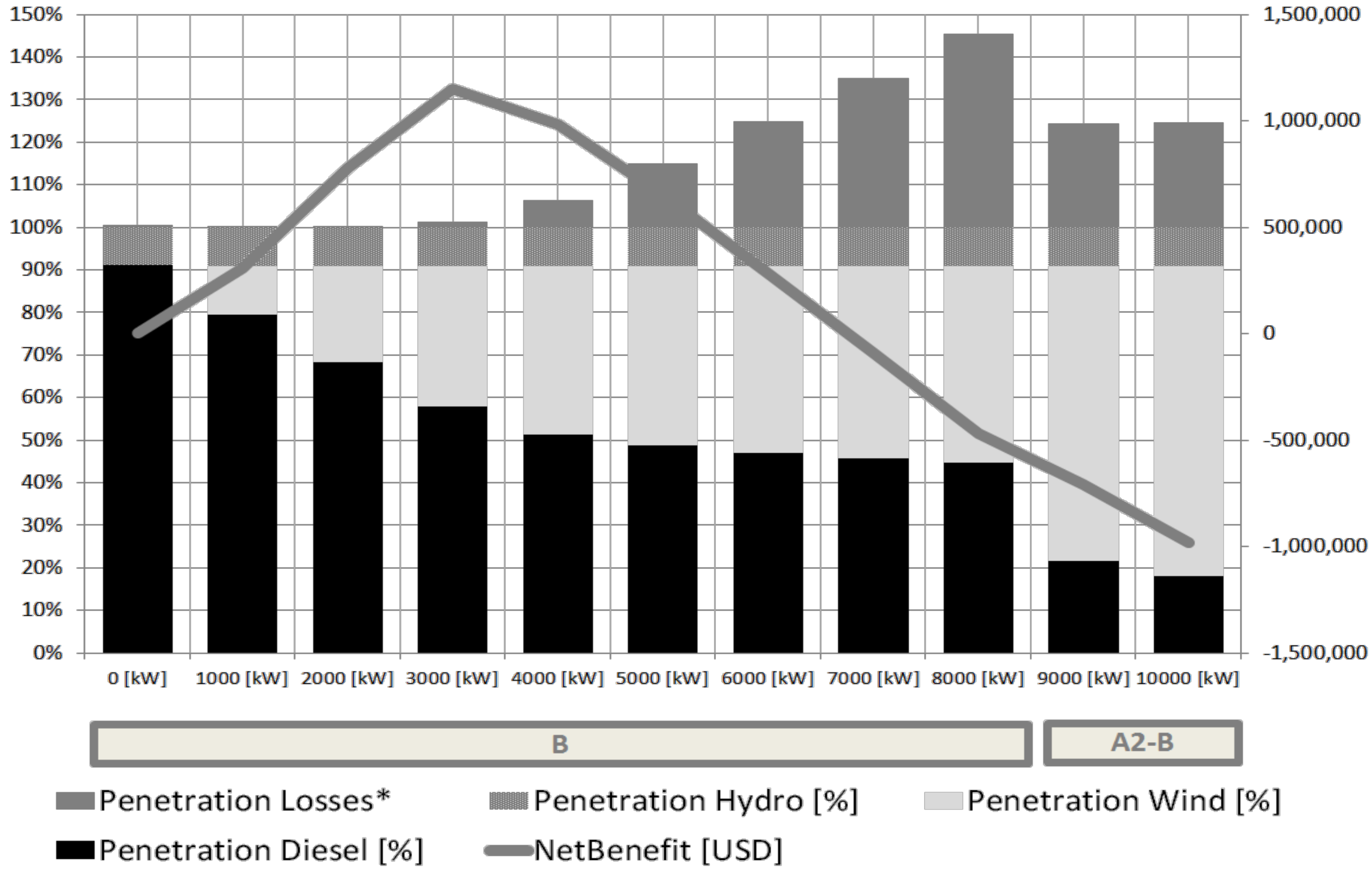
- Retrofit-benefit curves of retrofit case B, A1-B and A2-B compared to the base-case scenario



Case study- Suðuroy / Faroe-Island

› **Summary:**

- Retrofit option with maximum annual net benefits depending on the installed wind power capacity



Conclusion

- **The presented simulation model enables the determination of the optimal retrofit and VRE deployment for autonomous island networks at every stage of development.**
- **System reliability and safety are ensured by adherence to technical and operational limits.**
- **Regulation- and Load following – Reserves can be determined**
- **High-resolution time series allow to assess the effects of short-term VRE variability on ramp reserve and speed.**
- **In addition, a cost-benefit analysis has been proposed, which allows to examine different options for retrofitting with regard to their net benefits.**
- **Retrofit options can be compared and their benefits quantified using the Retrofit Benefit benchmark.**

Thank you very much!

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