Economic and operational assessment of established and new reserve methods and metrics for systems with high shares of renewables

Master Project Advisors: Prof. Dr. Reinhard Madlener | Dr. Jared Garrison | Dr. Turhan Demiray
Author: Gonca Gürses
01.12.2016

Agenda

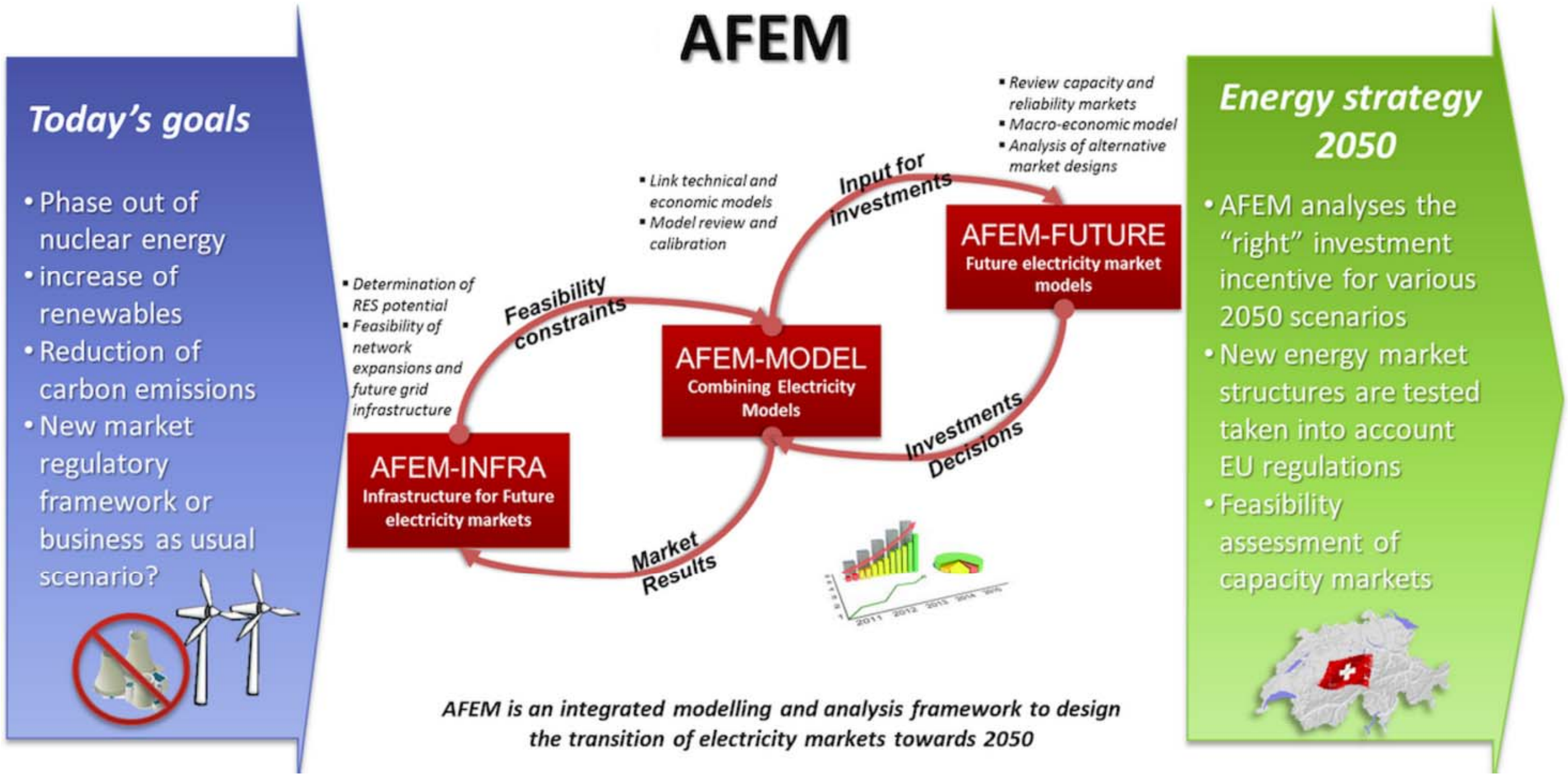
- Motivation
- Applied Reserve Methodologies
- Performance Metrics
- Simulation Process
- Exemplary Results
- Outlook

IDEA-League Cooperation and Research Grant

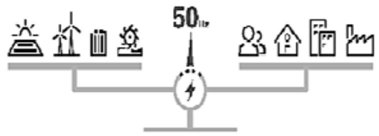
- **RWTH Aachen Institute FCN: Future Consumer Needs (Prof. Madlener)**
- **Master Project Cooperation**

- **ETH Zürich Institute PSL: Power Systems Laboratory (Prof. Hug-Glanzmann)**
- **Research Center for Energy Networks (FEN) and Energy Science Center (ESC) with Project: „Assessing Future Energy Markets (AFEM)“**

Project „Assessing Future Energy Markets (AFEM)“



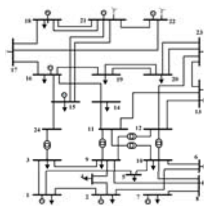
Roadmap



Target:
- Maintaining system stability with higher shares of renewables
- Which Methodology results in best reliability/cost trade off ?

Research:
- Identifying typical Reserve Products and Markets
- Analyzing established and new Reserve Dimensioning Methodologies

Focus:
- Identifying costs (Energy dispatch, procurement & deployment)
- Finding adequate Performance Metrics



Evaluate:
- Applying Methodologies on Example Grid & adding Renewables as Variation
- Comparing each Method’s Results with regard to Metrics: Reliability, Cost & ACE

Motivation – Cost & Reliability Trade Off

Extreme imbalances can lead to following consequences

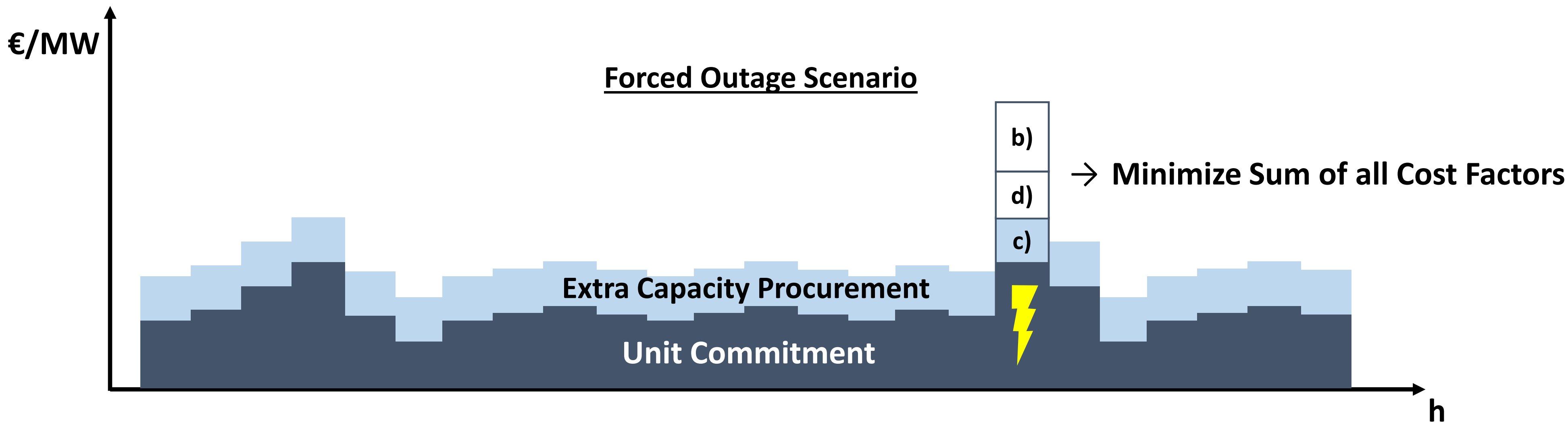
a) Supply >> Demand : Need to take generator off the grid & Negative Impact on the Energy Price

b) Supply << Demand : Demand can not be covered, Import expensive Capacities or Load Shedding

In order to prevent a) and b), control reserves need to be purchased

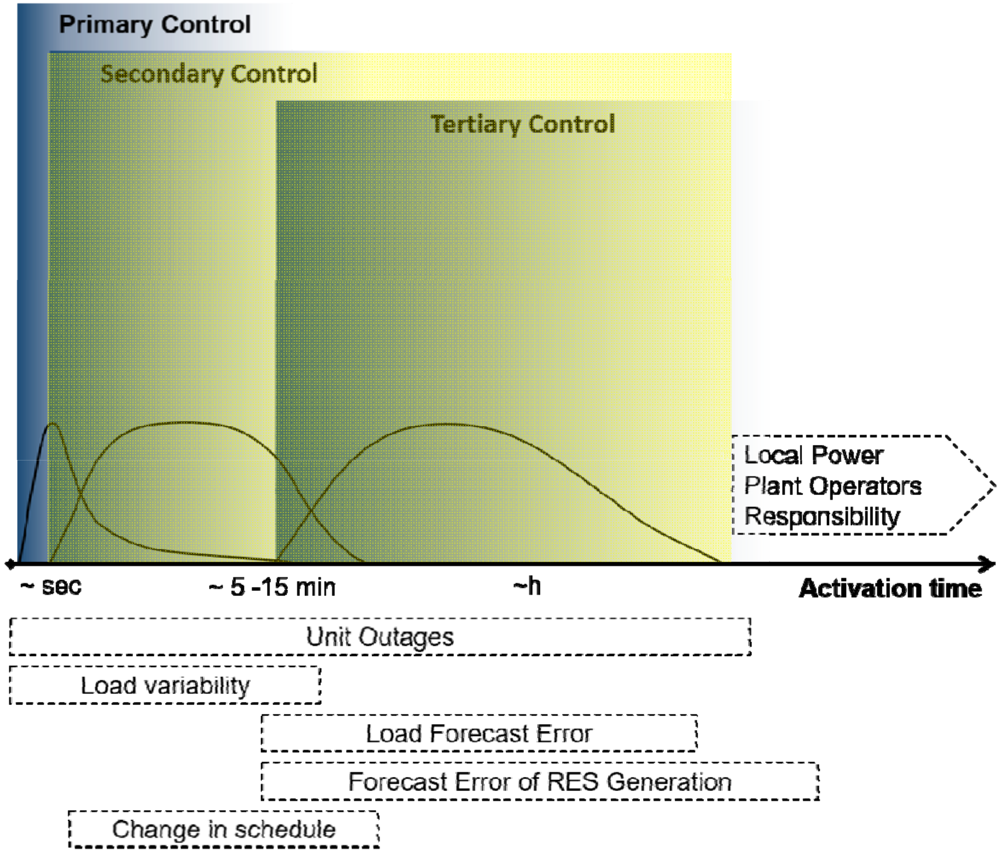
c) Price for the availability of short term capacities (Remuneration of Procurement)

d) Price for Utilization of these balancing capacities



Motivation – Focus on Reliability through Reserves

- Quantify system stability by the frequency
- When Supply = Demand → nominal $f_0 \approx 50$ Hz
- Uncertain stability issues with regard to future grid:
  - Greater amounts of intermittent generation by Renewable Energy Sources (RES)
  - Over forecasting of RES e.g. leads to a lack of energy supply
  - Instantly, balancing capacities need to be activated
- Activation of control reserves reduces the frequency deviation



Exemplary Methodologies – Deterministic / Probabilistic

Typical deterministic methods:

- largest unit reserve
- percentage reserve
- n-1 reserve-method

Examples

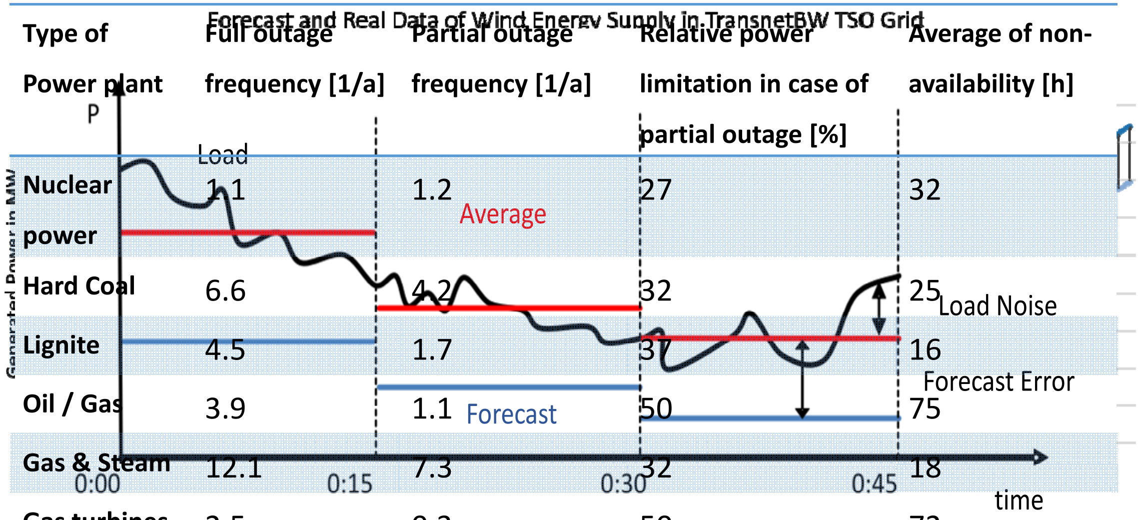
Deterministic ENTSO-E Requirement for Secondary Control Reserves

$$P_{Secondary} = \sqrt{a \cdot L_{MAX} + b^2} - b$$

Empirically determined parameters a (10 MW) and b (150 MW)

Probabilistic Approaches include:

- Power plant outage probabilities
- RES generation forecast error probabilities
- Load variability and
- Load forecast uncertainty



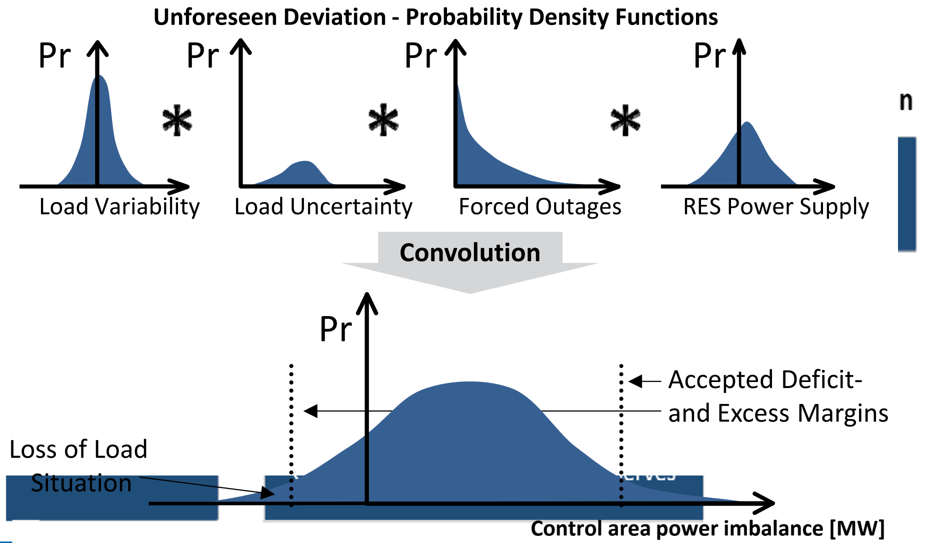
Type of Power plant	Full outage frequency [1/a]	Partial outage frequency [1/a]	Relative power limitation in case of partial outage [%]	Average of non-availability [h]
Nuclear power	1.1	1.2	27	32
Hard Coal	6.6	4.2	32	25
Lignite	4.5	1.7	37	16
Oil / Gas	3.9	1.1	50	75
Gas & Steam	12.1	7.3	32	18
Gas turbines	2.5	0.3	50	72

Source: Study by VGB Powertech GmbH & EEX

Exemplary Methodologies – Details Probabilistic Approach

Current Central European Methodology

- Application of a convolution algorithm on the influencing factors
- Reserve determined by covering a fix margin of the imbalance probability (ENTSO-E Recommendation: Pr_D=0.1%)



Subject of Research (NREL)

Accounting for frequency deviations by:

- Load Variability
- Solar Energy Supply Uncertainty (PV-FE)
- Wind Energy Supply Uncertainty (W-FE)

- Fast reserves should cover: 95%

$$\sqrt{(1\%\ \text{Load})^2+(\text{PVFE}_{10min})^2+(\text{WFE}_{10min})^2}$$

- Slower reserves should cover: 70%

$$\sqrt{(3\%\ \text{Load})^2+(\text{PVFE}_{1hour})^2+(\text{WFE}_{1hour})^2}$$

- Neglecting load forecast error due to its minor effect

Performance Metrics

Static Reliability Index

- Expected energy not served (EENS) by applying a capacity outage probability table
  - Each Capacity Shortfall has a Probability: Partial (50% derated) and Full Outages
  - Determination of combined Outage Probabilities via Convolution: Applying Fast Fourier Transf.
  - Energy Index of Reliability (EIR) = $\frac{\text{EENS [MWh]}}{\text{Total Energy Demand in Period [MWh]}}$

Dynamic Performance Indicator

- Area Control Error [ACE] = Tie Line Deviation – Frequency Deviation

≈ – 10B · Δf (frequency bias B = 1% of yearly peak demand per 0.1Hz)

- Control Performance Standard = $100\% \cdot (2 - \Delta f_{\text{minute-to-minute}} \cdot \text{ACE}_{12\text{months}}) \overset{!}{>} 100\%$

Simulation Process

1) Grid data: IEEE 39 Reliability Testsystem

- BASE VERSION: Conventional + Wind & PV (each 1% of System Load)
- HIGH SHARES OF WIND: Conventional + Wind & PV (25% and 1% of System Load)
- HIGH RES MIX: Conventional + Wind & PV (each 15% of System Load)

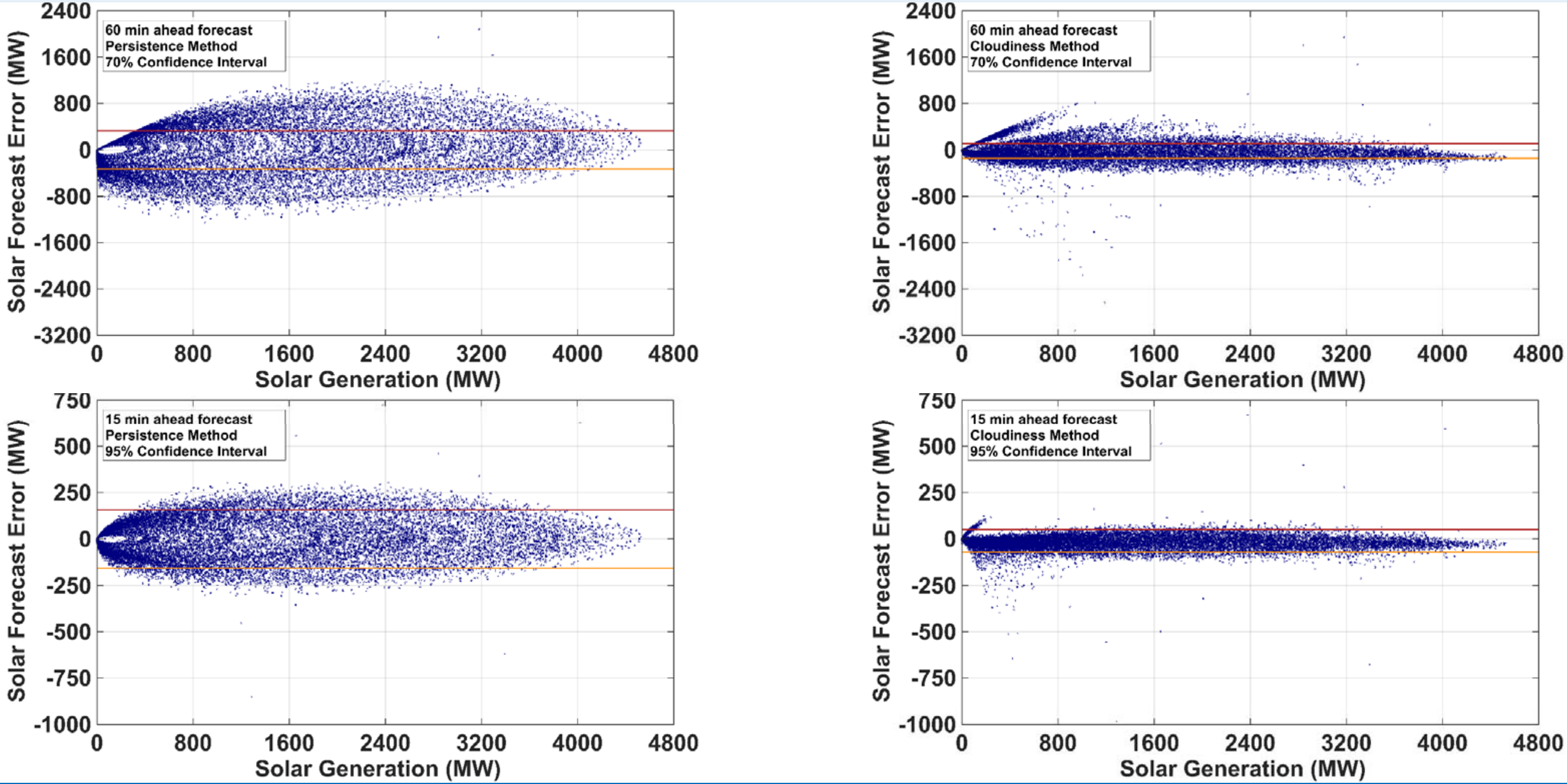
2) Methodology

- Deterministic: Using ENTSO-E formula for Secondary Quantification, n-1 Criterion for Tertiary Quantification
- Probabilistic 1: Central European Approach – Convolution of Outage, Load-Noise, Wind & Solar Probability Density Functions
- Probabilistic 2: NREL Approach – Secondary & Tertiary each include ratios of underlying Load Curve & RES Errors

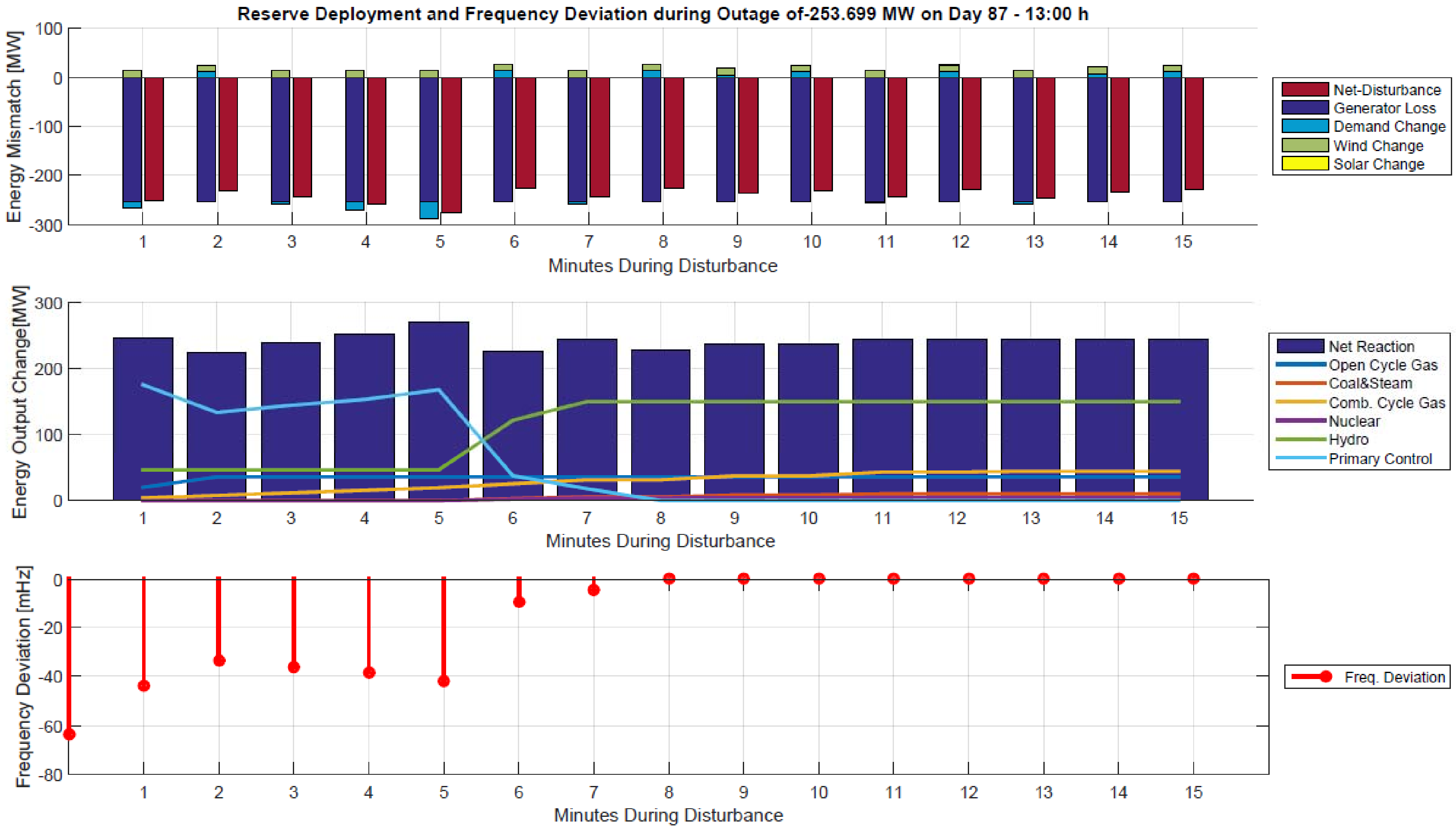
3) Simulation

- Daily Unit Commitment including optimal Reserve Procurement over the course of 1 year
- Include Periods of planned and maintenance Outages & co-optimize energy and reserve planning
- Allocate randomly forced Outage times and calculate frequency drop
- Simulate minute by minute frequency development after Activation of Secondary and Tertiary Control

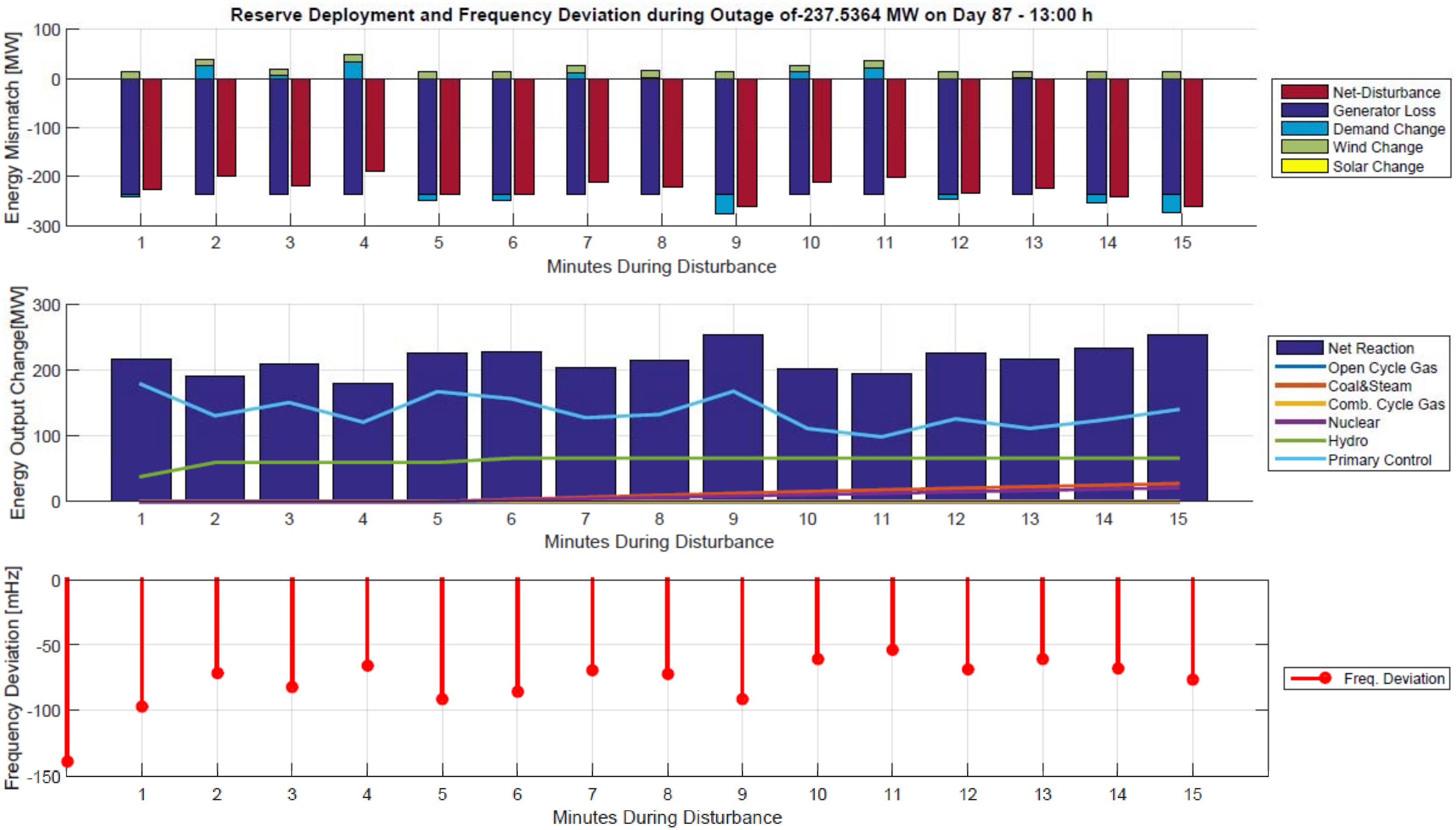
PV Persistence Forecast- Corrected by Clear Sky Factor



Scenario: Central EU Reserves & 25% Wind



Scenario: NREL Reserves & 25% Wind



25% Wind Scenario

	ENTSO-E (deterministic)	Central EU (probabilistic)	NREL (probabilistic)
Static Reserve Performance Metrics			
Secondary Procured (MW)	76	103	59
Tertiary Procured (MW)	259	277	88
Average Energy Price (€/MWh)	12.45	14.79	7.28
Total Energy Cost (Mio. €)	102	102	102
Reserve Proc. Cost (Mio. €)	95	131	17
Average Outage Size (MW)	40	40	38
Energy Index of Reliability	0.9946	1.0	0.9191
Dynamic Reserve Performance Metrics			
Secondary Deployed (MWh)	114	120	106
Tertiary Deployed (MWh)	123	103	100
Average ACE (MW)	64	55	194
Total Unserved Energy (MW)	252	254	789
Re-Dispatch Costs (Mio. €)	11	11	34

Outlook

NEW INSIGHTS

- No justification for deterministic approaches (Vorspools, K. 2005)
- Short term updates on needed reserve amounts reduces cost of procurement
- Solar forecast error can increase the tertiary requirement for the 4 - hour reserve blocks around midday
- Central EU method yields the best reliability metrics but also the highest reserve costs
- Lack of a N-1 generator outage criteria causes the NREL probabilistic method to underperform

FURTHER RESEARCH

- Sensitivity analysis on actual cost values (cost for dispatch, energy price, startup cost…)
- Changing the Grid Structure (degree of interconnection)
- Preprocessing of unit commitment (simplifies the OPF-calculation->reduces runtime)
- Increasing Number of Simulations (to guarantee convergence)
- Contrasting theoretical reserve determination process to established real TSO process

THANK YOU FOR YOUR ATTENTION

Contact

Gonca Gürses
RWTH Aachen University
gonca.guerses@rwth-aachen.de

Prof. Reinhard Madlener
FCN –RWTH Aachen University
rmadlener@eonerc.rwth-aachen.de

Prof. Gabriela Hug-Glanzmann
PSL- ETH Zürich
ghug@eeh.ee.ethz.ch

Dr. Jared Garrison
Research Center for Energy Networks (FEN)
garrison@fen.ethz.ch

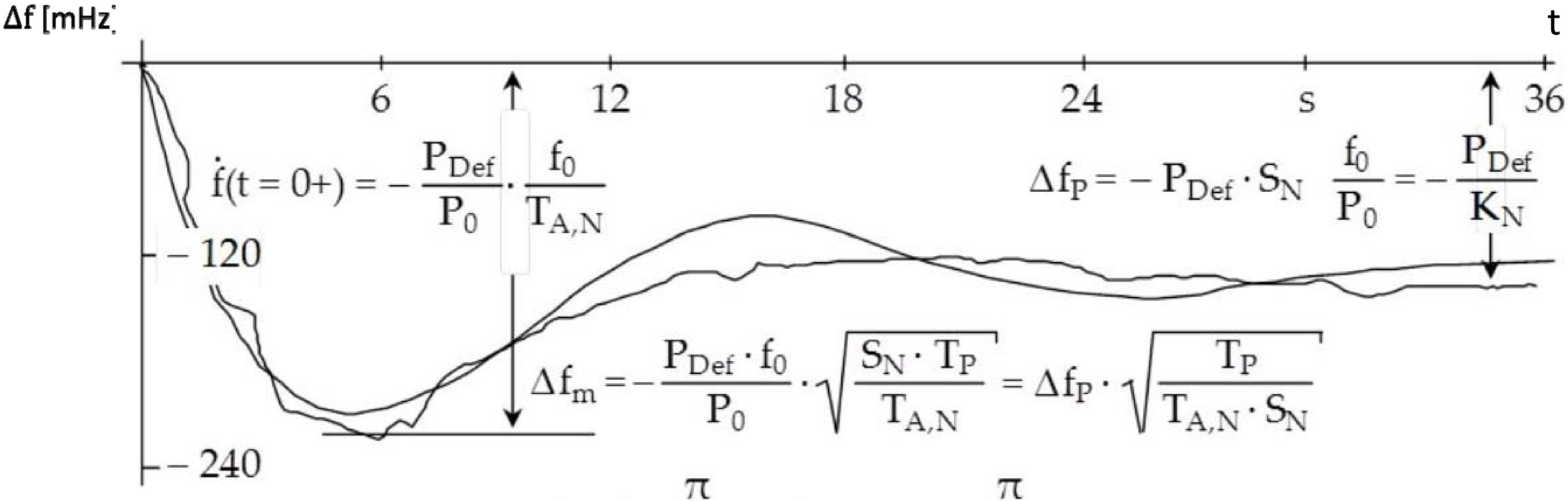
Dr. Turhan Demiray
Research Center for Energy Networks (FEN)
demirayt@fen.ethz.ch

Dr. Christian Schaffner
Energy Science Center
schaffner@esc.ethz.ch

Updated Reliability Test System (Max Load = 2850 MW)

Plant Type	Natural Gas CT	Natural Gas CC	Coal / Steam	Nuclear	Hydro
Total Number	9	6	9	2	6
Max. Capacity [MW]	40-72	80-180	54-140	400	50
Min. Capacity [MW]	14-32	69-75	155-350	200	10
Ramp Rate [MW/min]	10-18	1.3-2	0.4-0.9	1.04	12.5
Costs [€2015 /MW]	90-100	69-77	21-22.5	4.42	0.001

Primary frequency containment after Generation Loss



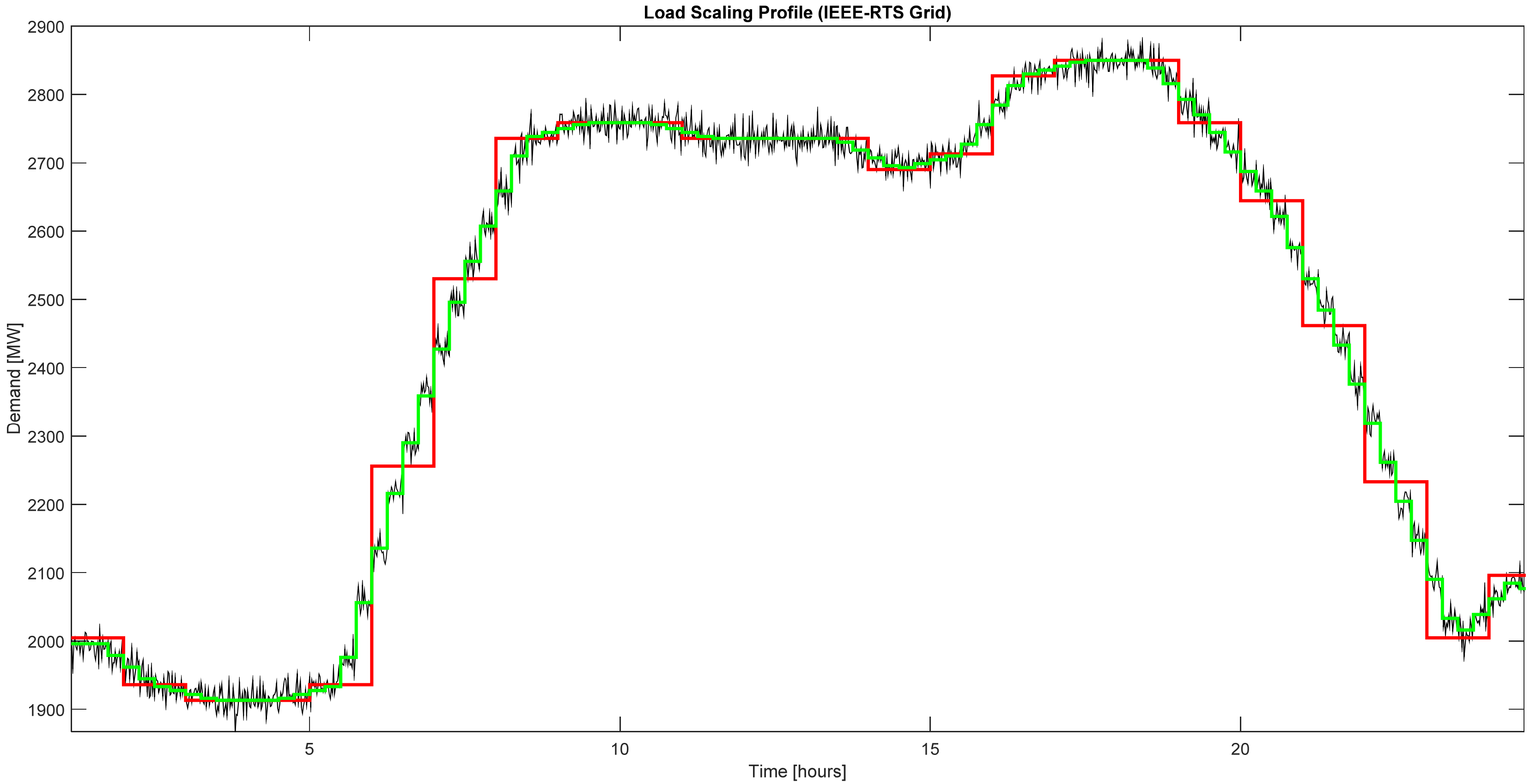
$$\dot{f}(t=0+) = -\frac{P_{Def}}{P_0}\cdot\frac{f_0}{T_{A,N}}$$

$$\Delta f_P = -P_{Def}\cdot S_N\,\frac{f_0}{P_0} = -\frac{P_{Def}}{K_N}$$

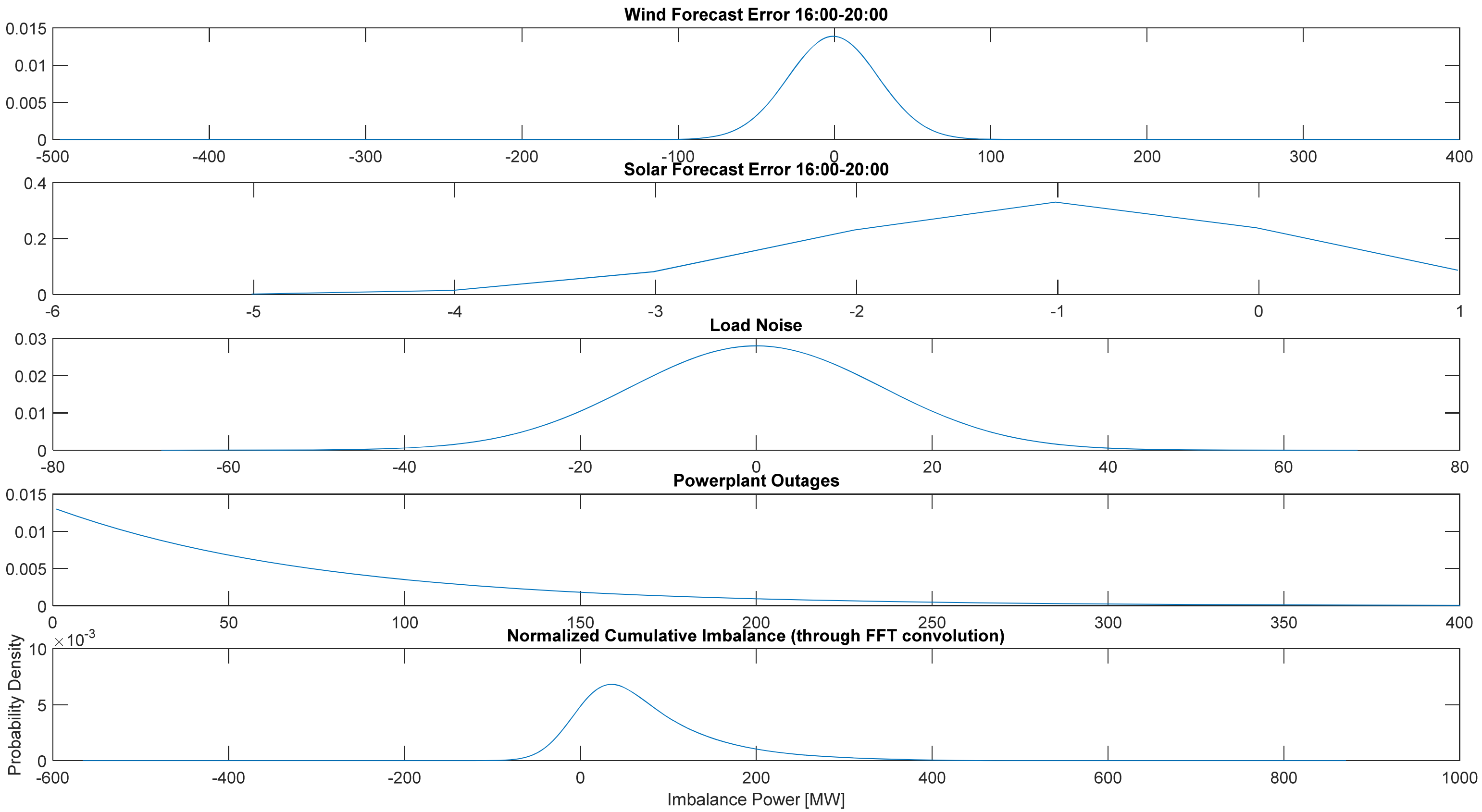
$$\Delta f_m = -\frac{P_{Def}\cdot f_0}{P_0}\cdot\sqrt{\frac{S_N\cdot T_P}{T_{A,N}}} = \Delta f_P\cdot\sqrt{\frac{T_P}{T_{A,N}\cdot S_N}}$$

$$t_m \approx \frac{\pi}{2\cdot\omega_d} \approx \frac{\pi}{\frac{1}{T_P}\cdot\sqrt{\frac{4\cdot T_P}{S_N\cdot T_{A,N}}-1}}$$

Exemplary Methodologies – Load Variability Simulation



Example: Cumulative Reserve (Base Grid-Central European M.)



Example: Cumulative Reserve (Base Scenario-Central European)