GRAPHICAL ANALYSIS METHOD TO IDENTIFY POWER - BALANCED GRID AREAS FOR INTENDED ISLANDING OPERATION

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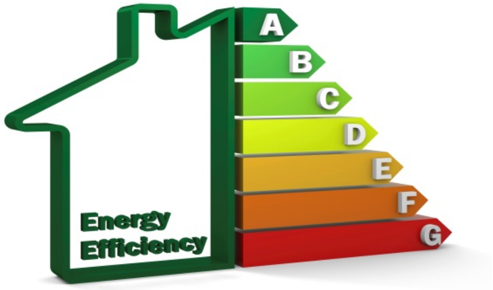
Agenda

1. Introduction
2. Aim of investigation
3. Model design
4. Applying model
5. Conclusion

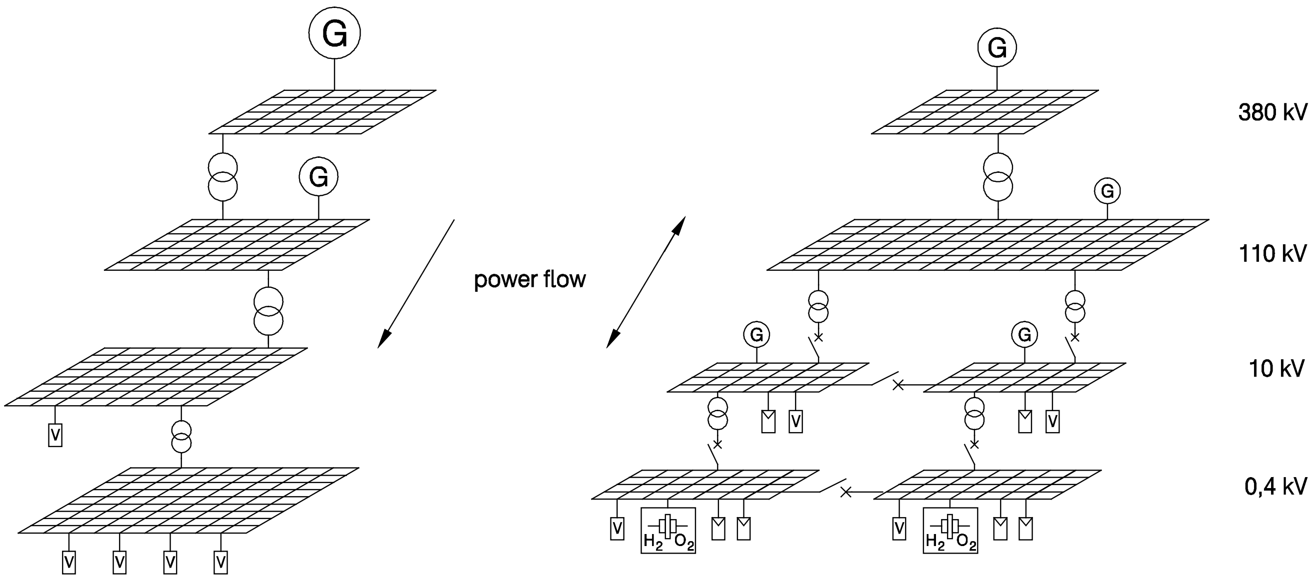
Introduction

- Major concerns of German energy policy:
  - supply reliability
  - the economic efficiency and
  - the environmental impact
- German goals: 20-20-20 (GHG-RE-EE) up to 2020



sources:
http://www.renewableenergyinstaller.co.uk/2013/01/uk-on-track-to-hit-2020-targets/
http://enformable.com/2013/02/energy-storage-systems-are-focus-of-demand-for-future-power-grids/
http://www.phillippebuilders.com/about-us/energy/

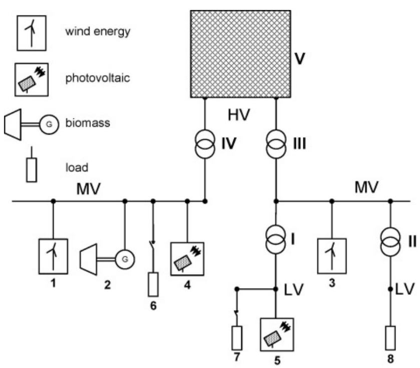
Aim of investigation



- Changing power flow : unidirectional to multi-directional
  → Power balanced grid areas
  → → vary over time due to weather conditions
- Simplify power flow investigation over different voltage levels
- Possible objective: Enables distribution system operators /planner to identify or extract critical grid areas (only active power flow)

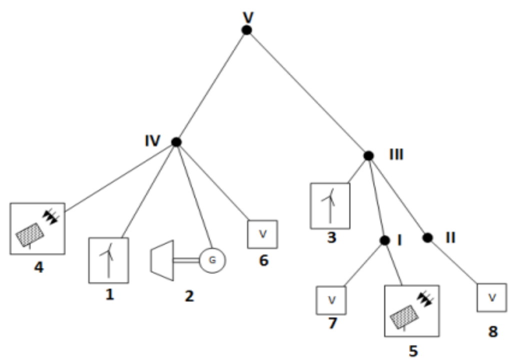
Model Design

Starting Point



Energy Supply System

Stage 1



Tree Graph

Stage 2

$$AK = \begin{bmatrix} 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$K = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 \end{bmatrix}$$

$$P = \begin{bmatrix} P1 \\ \vdots \\ Pn - 1 \\ P8 \end{bmatrix}$$

Math

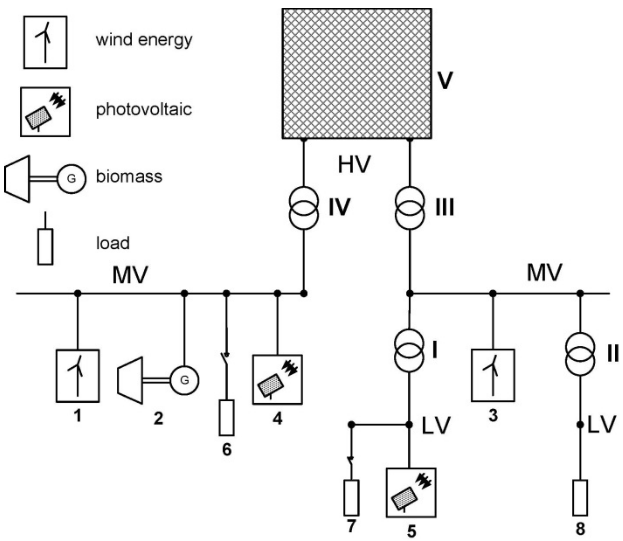
Step 1

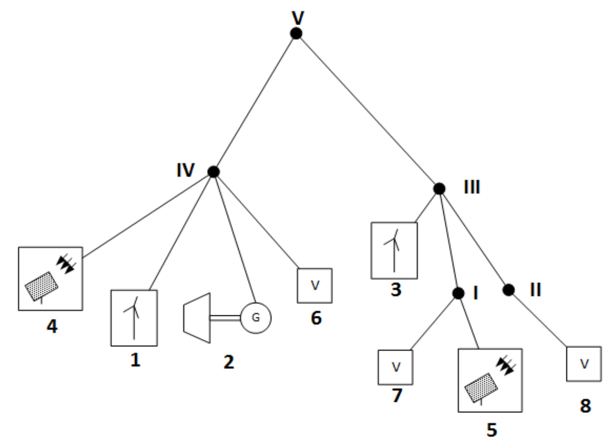
Step 2

Power Flow Calculation

Model Design: Step 1

Real — Tree graph

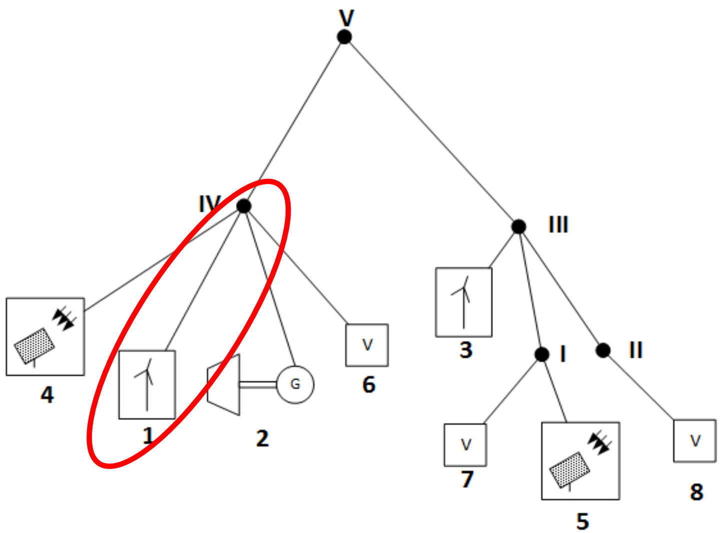




- Background of traditional network models, also tree model
  → lot of different network characteristics
  → vast computational and human resources to analyze network structure and operating equipment (scenarios)
  → time invariant network structure → changes due to load and power production variations
- Reduction of existing energy supply networks to tree topology allows a first approximation of the network's active power flow
- Network as tree-graph over all voltage levels

Model Design: Step 2

Tree graph —● Matrix



1 → 8

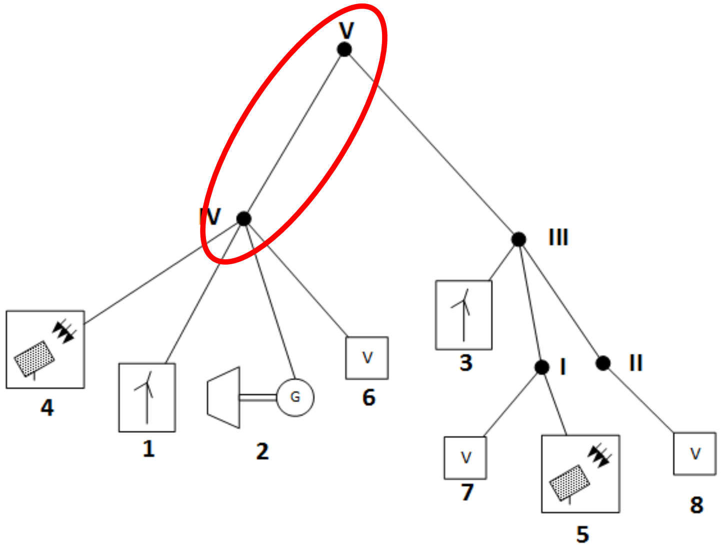
$$AK = \begin{bmatrix} 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

I ↓ V

- Description of the connection of leafs to inner nodes
- ***m x n-matrix AK*** links a power unit of the system ***n*** (leafs 1 to 8) with its corresponding PCC (nodes I to V) ***m***
- Existing meshes in the network with constant power flow are separated at the node with minimal voltage.

Model Design: Step 2

Tree graph → Matrix



I → V

$$K = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 \end{bmatrix}$$

I ↓ V

- ***Square matrix K (n x n)*** describes the inner connection of the grid
- Meshes, so multiple edges to the same node, are not captured by the model
- Each single connection is marked by a “1” and only once in the downer triangle

Model Design: Step 2

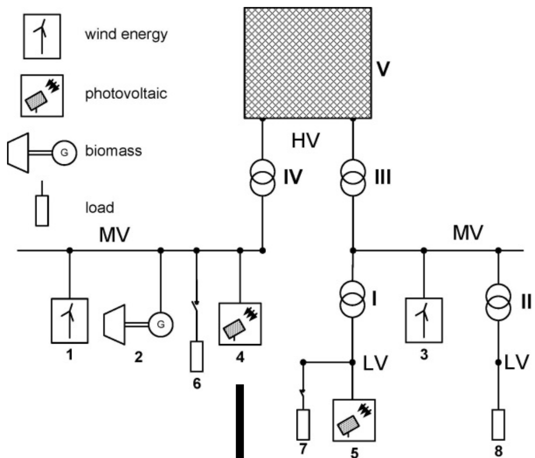
Matrix / Vector	Description	Preference	Range of Numbers
$AK = \begin{bmatrix} 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$	Connection of consumers /loads to each node → Outside margin	static	m,n = 0 or 1
$K = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 \end{bmatrix}$	Interconnection of considered energy supply system → Inside interconnection	static	m,n = 0 or 1
$P = \begin{bmatrix} P_1 \\ \vdots \\ P_7 \\ P_n \end{bmatrix}$	Description of node-elements → assignment	variable	$P_{(n)} \in \mathbb{R}$

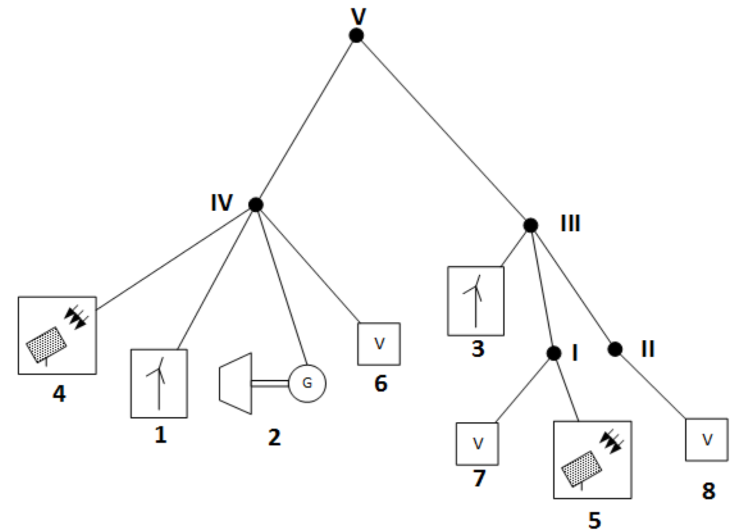
Model Design: Power Flow Calculation

$$K = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 \end{bmatrix} \qquad \mathrm{AK} = \begin{bmatrix} 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \qquad P = \begin{bmatrix} P_1 \\ \vdots \\ P_7 \\ P_\mathrm{n} \end{bmatrix}$$

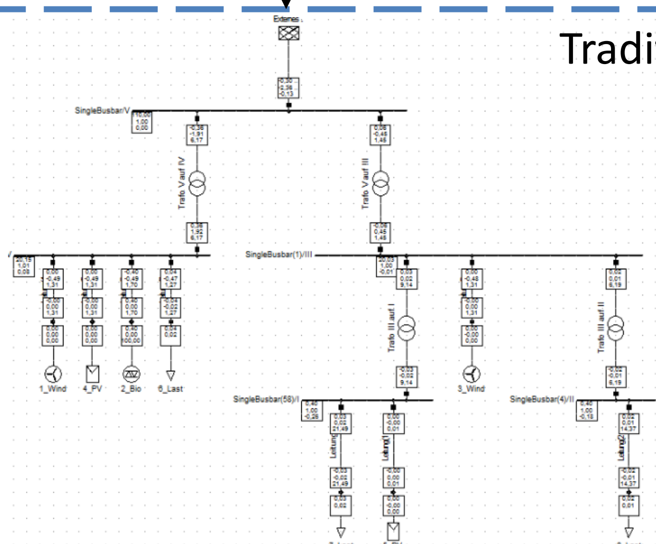
- $\mathrm{P_K = AK \cdot P}$
  → direct injected power of each node
- $\mathrm{P_{KA} = (I + K + K^2 + \cdots + K^n) \cdot AK \cdot P}$
  → overall power of each node
- The matrix $\mathrm{K^n}$ is singular, if the network graph contains no loops
- In a typical three or four level energy supply system containing high-voltage, mid-voltage and low-voltage level the third or the fourth power of K is a singular matrix.

Network Characteristics



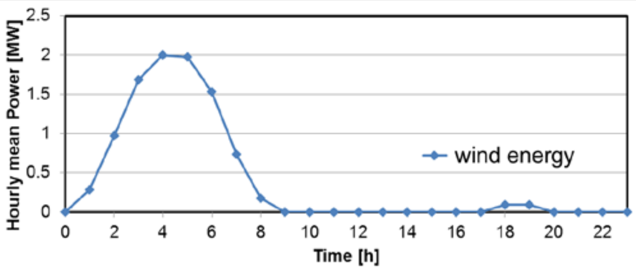


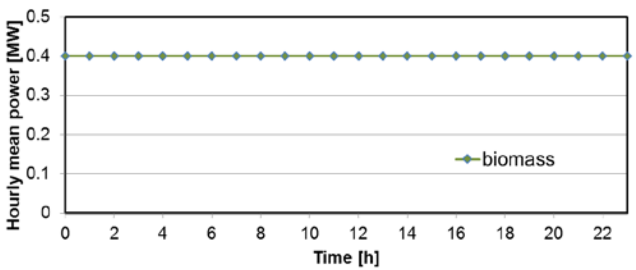
Traditional grid simulation

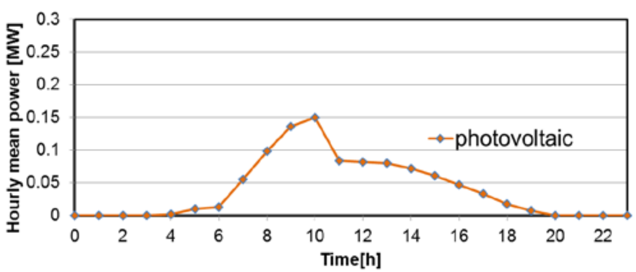


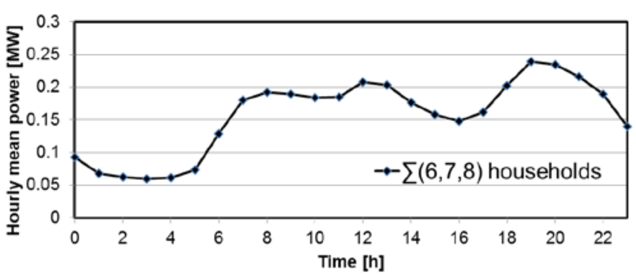
Voltage level	Grid characteristics			
	Network operating resource	Characteristic I	Characteristic II	Annotation
LV	Cable	NAYY 4x120 mm²	Length = 0.5 km	ε = 1
LV	Transformer	S = 0.4 MVA	LV/MV	u_K = 4 %
MV	Cable	NA2XS2Y 3x1x150 mm²	Length = 5 km	ε = 1
MV	Transformer	S = 31.5 MVA	MV/HV	u_K = 12 %

Power & Load Profiles





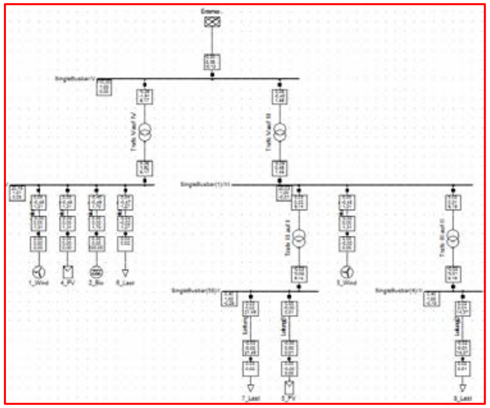


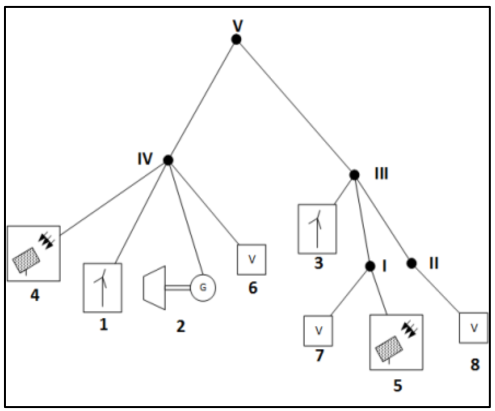


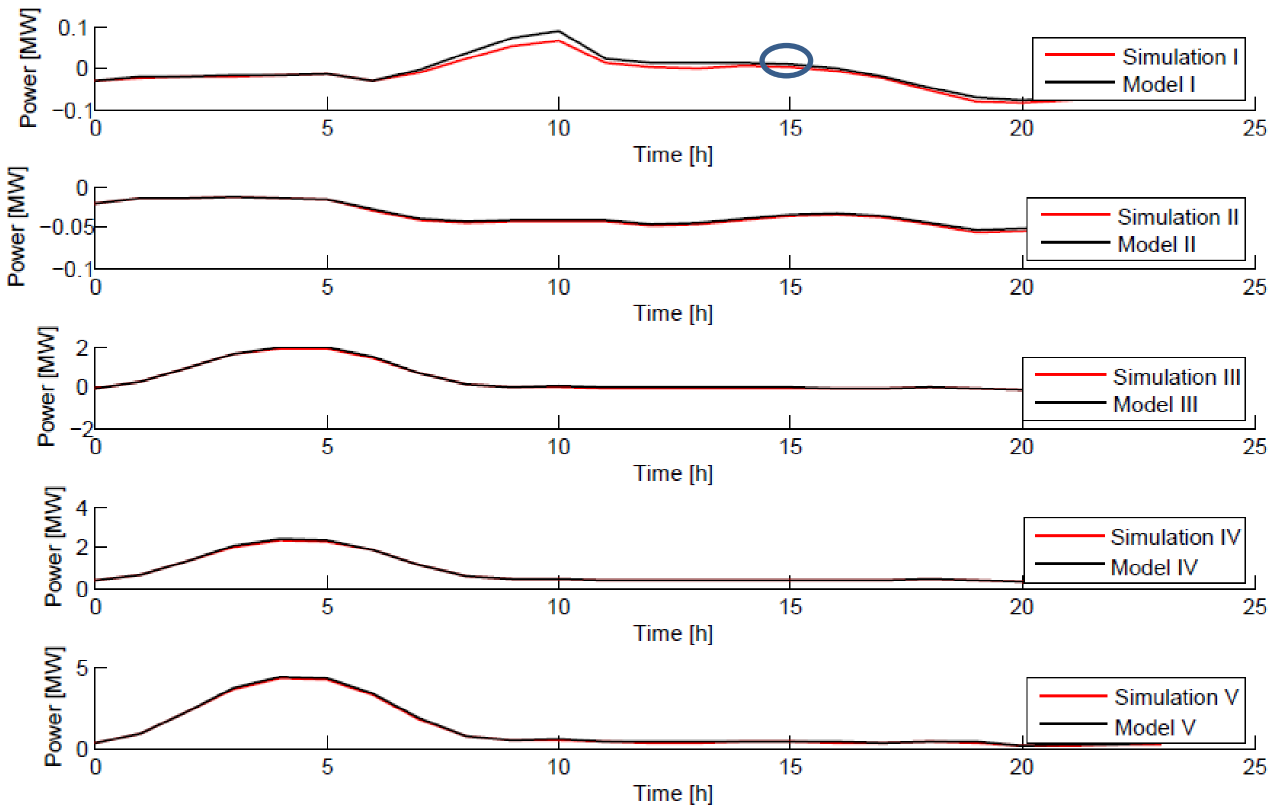
Nodes	Power and load characteristics		
	Power/load costumer	Peak power [MW]	Quantity
I	Consumption / households	-	150
I	Generation / photovoltaic	0.15	-
II	Consumption / households	-	100
III	Generation / wind energy	2	-
IV	Generation / photovoltaic	0.15	-
IV	Generation / wind energy	2	-
IV	Generation / biomass	0.4	-
IV	Consumption / equivalent households	-	200

- Power generation: resemble the feed in characteristics of Northern Germany (normalized and scaled)
- Load characteristics: standard load profile H0 – Germany, household with 2.5 residents, hourly mean power

Simulation Results







- Quasi-stationary grid simulation with DIgSILENT PowerFactory software compared the calculations with graphical analysis model
- Simulation period is one day $t = 24\ h$ / 24 Monitoring points per node
- Possible, time-variant power-balanced grid area

Cumulated area power gap: $\Delta P_{|\mathrm{M-S}|} \sim 2\ \%$

Conclusion

- Analysis method of power-balanced grid areas for intended islanding operation

- Presented model describes a way to simplify parts of an energy supply system over different voltage levels → gross simplification of an existing energy supply network
- Minor differences are due to cable and inverter losses mostly
- Adaption of the compiled model with losses is made up easily →only one more matrix is needed (information on the losses and the cable length)
- Tree graph is a possible way to identify potential power-balanced gird areas → does not replace a complete power flow simulation
- No specific software tool is needed to simulate a certain or complex network

Next steps:

→ Must be shown that the computational effort is less compared to traditional network calculation method

→ Want to fed the model with real-time data of measurement units like smart-meters or current sensors, for online detection of overloaded cables or transformers

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THANK YOU FOR YOUR ATTENTION!
ANY QUESTIONS?