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Department of Electrical Engineering and Information Technology

Institute of Power Systems and Power Economics

Influences of Wind Energy on the Operation of Transmission Systems

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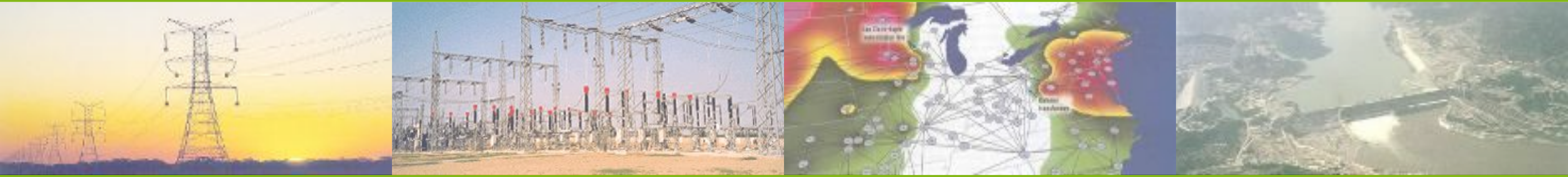

Outline

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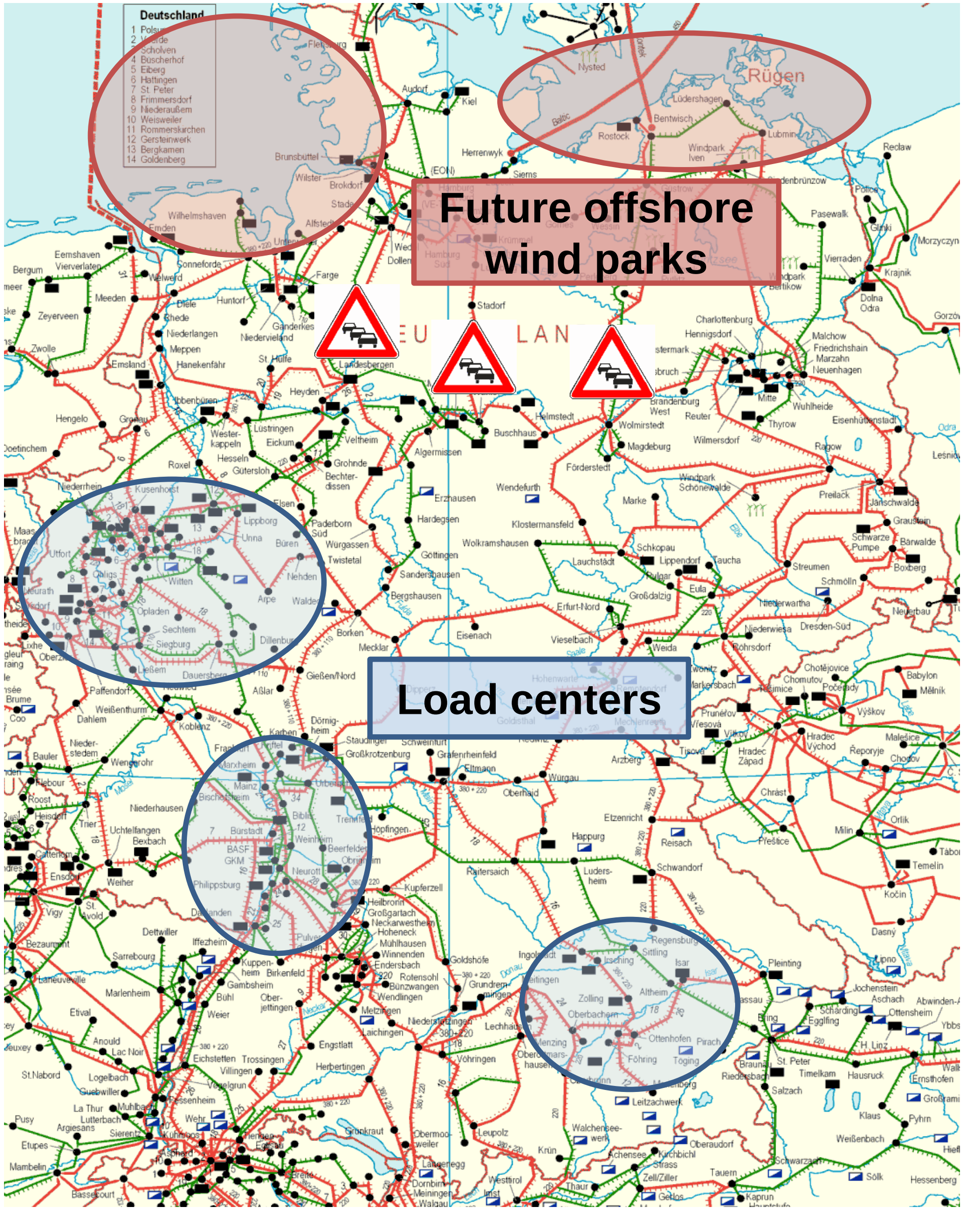
- Sample network
  - Required network data
  - Generator cost functions
- Estimation of the redispatch costs
  - Weighting of the calculated situations
  - Congestion frequency and redispatch costs
- Coordination of power flow controlling devices
  - Allocation of the devices in the network
  - Dynamic simulations
- Conclusions

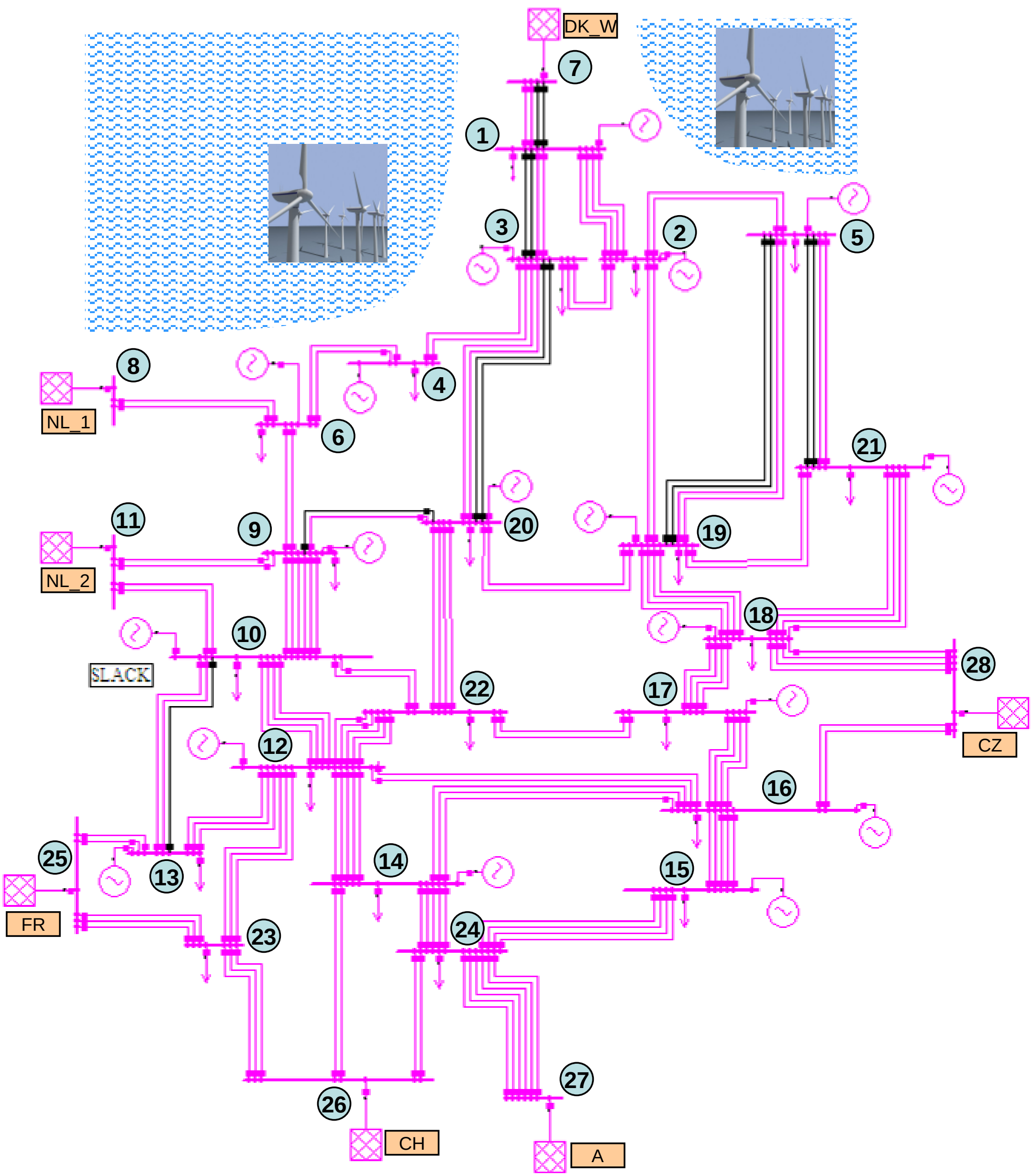
German transmission system



Source: UCTE (2006)

- Regional mismatch of generation and load
- Time mismatch due to fluctuations of the wind feed-in
- System is not designed for high transits
  → increasing risk of congestions
- Possible solutions
  - Generation redispatch
  - Installation of power flow controlling devices
  - Development of new lines

28-node sample network



- Detailed network data is not publicly available
- Regional aggregation of the real network nodes
- Estimation of the line lengths from network maps
- Modeling of the wind feed-in in the northern nodes
- Load distribution according to population density
- Imports and exports modeled as positive or negative network supplies

Development of the power plant mix in Germany

- Detailed dataset of power plants for the present situation (installed capacity, fuel type and age) → assigned to the network nodes
- No overall and exact prognoses for future development of every single station are known
- Allocation of power plants according to global data and planned investments

		2005	2010	2015	2020
Nuclear	Inst. capacity	21.5	17.4	14.1	7.1
	Removal		-4.1	-3.3	-7.0
	Change		-19.1%	-34.4%	-67.0%
Lignite	Inst. capacity	22.0	21.2	16.1	15.3
	Installation		2.7	1.1	0.0
	Removal		-3.5	-6.2	-0.8
	Change		-3.6%	-26.8%	-30.5%
Hard coal	Inst. capacity	29.4	30.8	33.9	30.1
	Installation		10.4	4.6	0
	Removal		-9.0	-1.5	-3.8
	Change		4.8%	15.3%	2.4%
Natural gas	Inst. capacity	23.3	29.7	36.3	47.6
	Installation		13.4	9.3	12.1
	Removal		-7.0	-2.7	-0.8
	Change		27.5%	55.8%	104.3%
Wind energy	Inst. capacity	18.4	24.4	28.4	32.7
	Installation		6.0	4.0	4.3
	Change		32.6%	54.3%	77.7%
Total	Inst. capacity	114.6	123.5	128.8	132.8
	Change		7.8%	12.4%	15.9%

Values in GW,
according to EWI, Prognos (2007)

Marginal costs of the regarded power plants

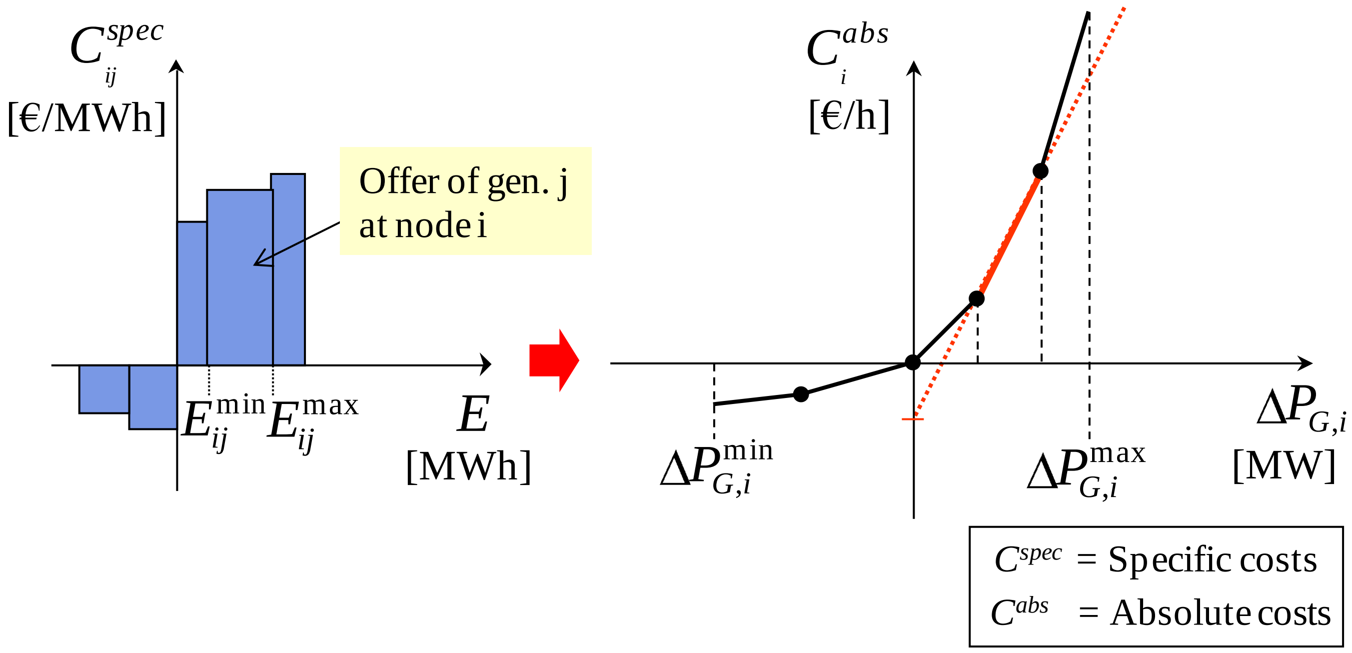
- Feed-in of every generator calculated with a merit order based on marginal costs (CO_2-emissions rated with 20 €/t)
- Costs for redispatch: ±10 % of marginal costs

	Fuel price €/MWh	η %	Fuel costs €/MWh	CO_2-em. t/MWh	CO_2-costs €/MWh	Marg. costs €/MWh
Nuclear	3.00	33	9.09	0.00	0.00	9.09
Lignite (new)	3.00	44	6.82	0.92	18.48	25.30
Lignite (old)	3.00	37	8.11	1.10	21.97	30.08
Hard coal (new)	9.50	46	20.65	0.73	14.54	35.20
Hard coal (old)	9.50	37	25.68	0.90	18.08	43.76
Gas-steam (new)	23.10	58	39.83	0.35	6.94	46.77
Gas-steam (old)	23.10	45	51.33	0.45	8.95	60.28
Gas turbine (new)	24.30	35	69.43	0.58	11.51	80.94
Gas turbine (old)	24.30	28	86.79	0.72	14.39	101.17

Derivation of the nodal redispatch costs

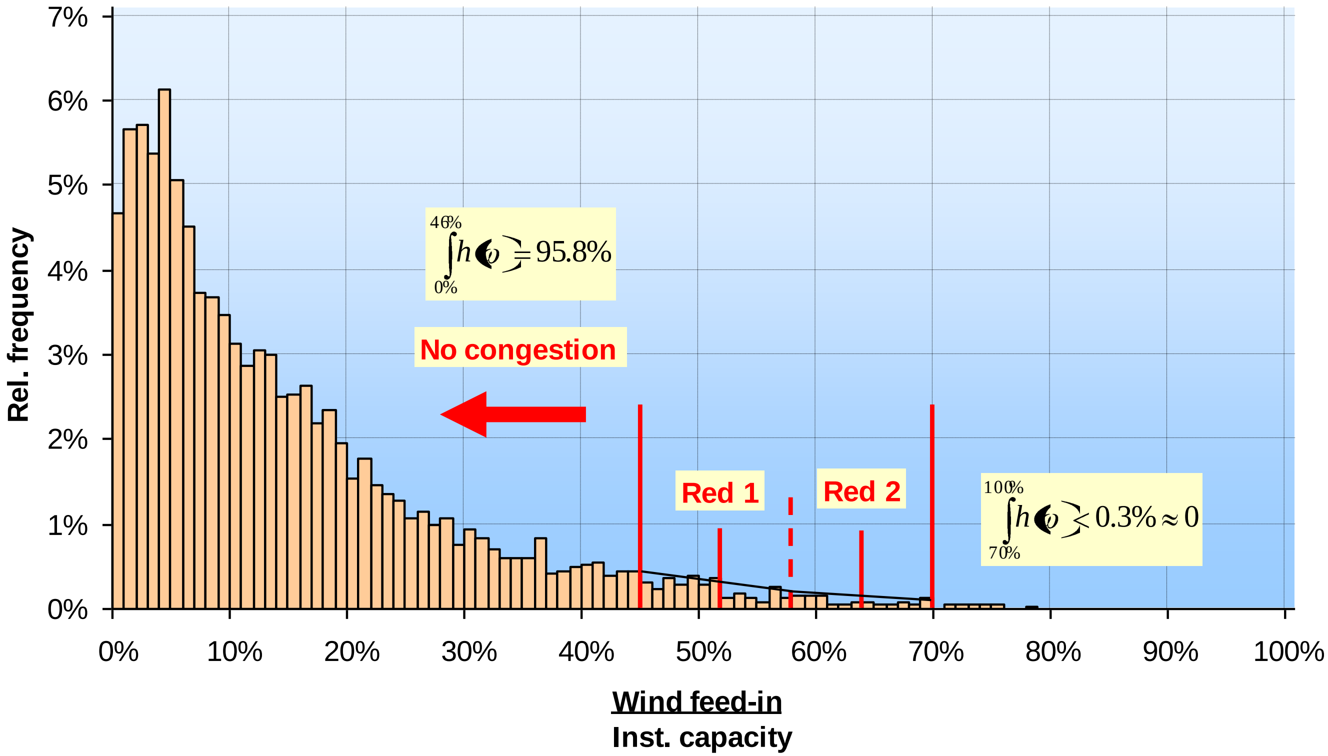
- Free capacity in every node → offer to increase output
- Actual capacity in use → offer to decrease output
- Minimal redispatch costs to comply with the (n-1)-criterion

$$f(\Delta P_{G,i}) = \sum_{i=1}^{n} C_i^{abs}(\Delta P_{G,i}) \overset{!}{=} \min$$



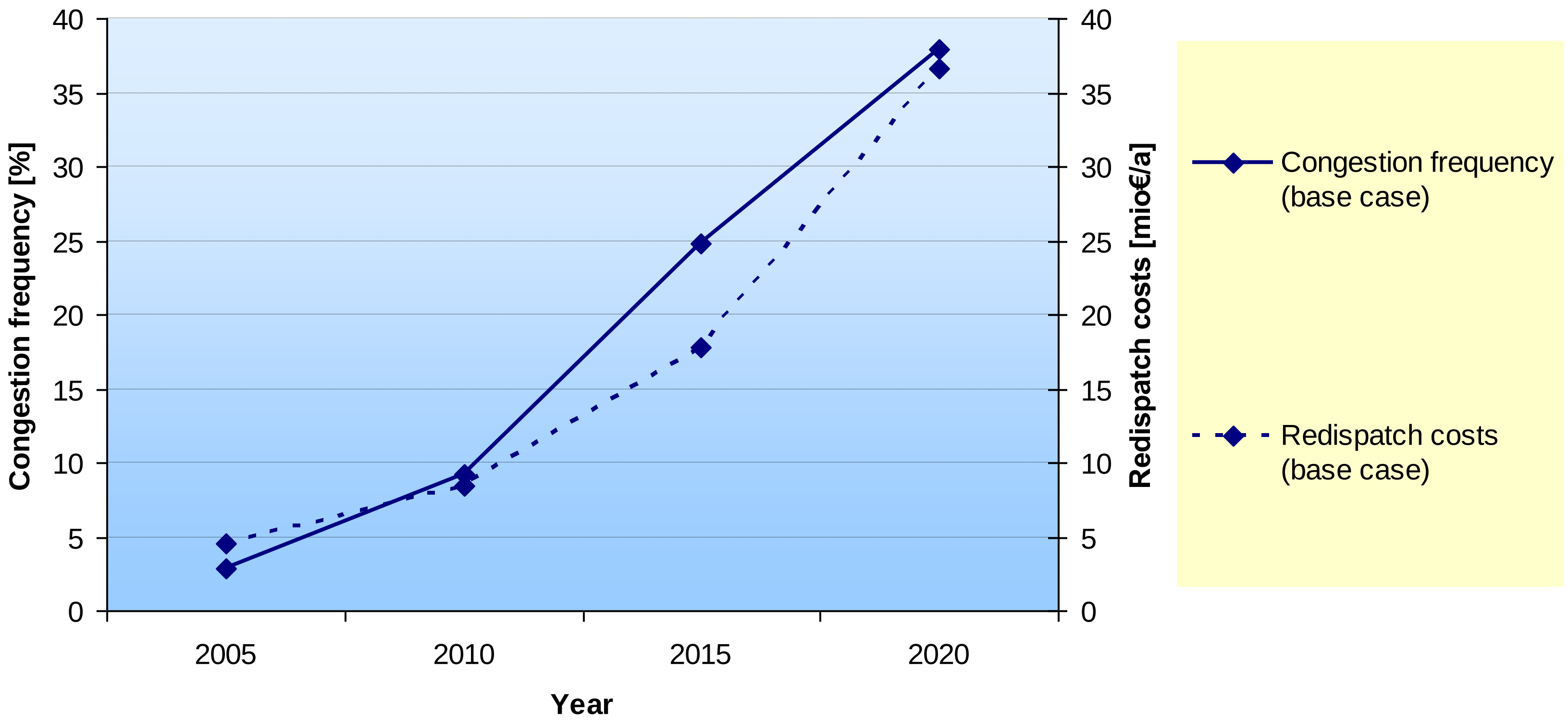
Weighting of the calculated situations

- Wind feed-in is the main influencing factor on the congestion frequency
- Identification of the maximum feed-in to barely guarantee (n-1)-security in different load situations
- Calculation of redispatch costs for higher wind feed-in



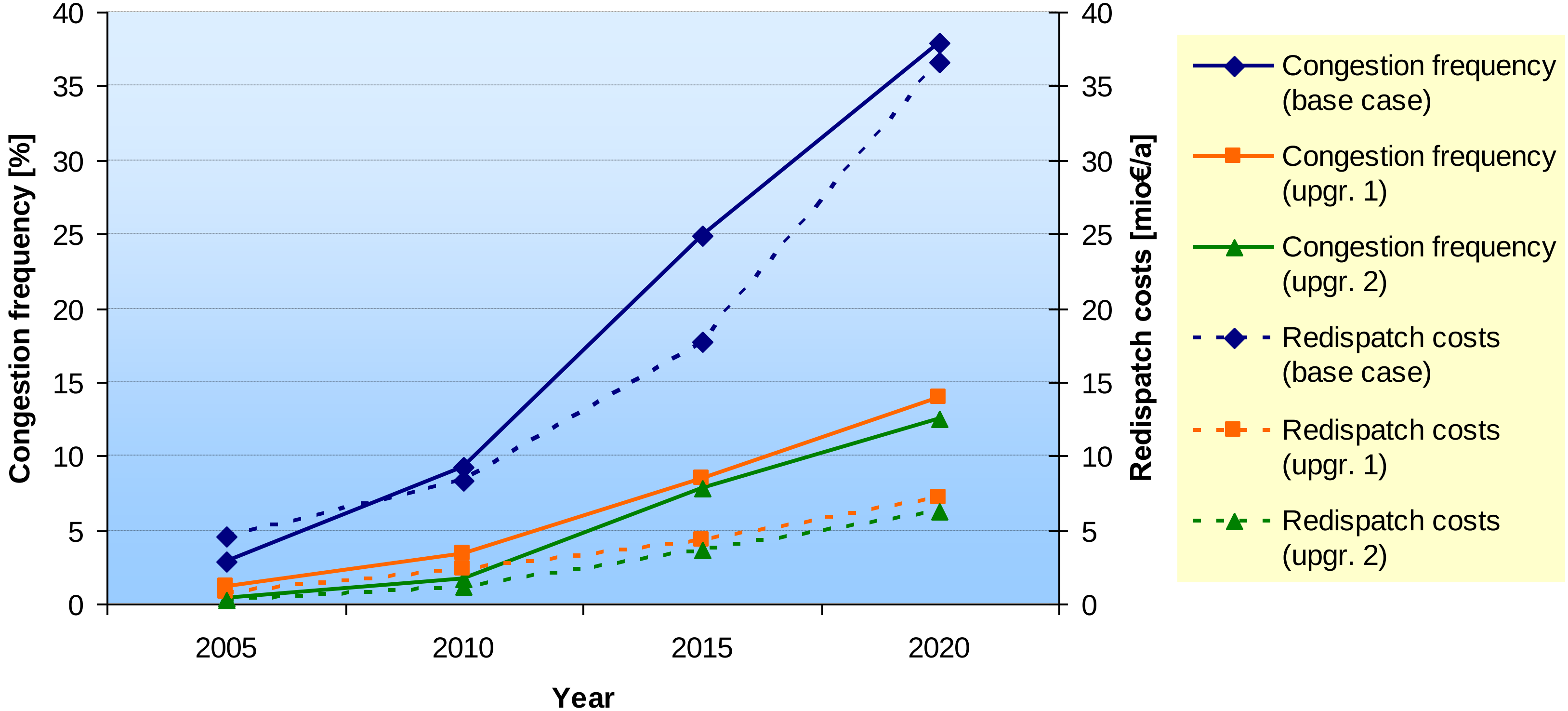
Congestion frequency and redispatch costs (1)

- Frequency of congestions on the north-south-connections
- Annual costs for the required redispatch
- No network upgrades until 2020 regarded to quantify their effect



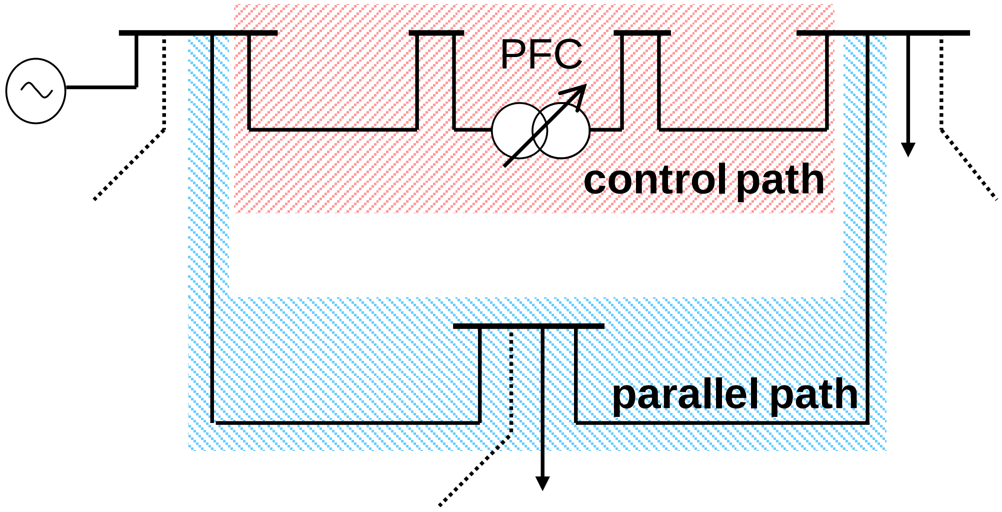
Congestion frequency and redispatch costs (2)

- Calculation of redispatch costs with two different network upgrades
  - Upgrade 1: Replacement of 220 kV with 380 kV on a length of 120 km between nodes 3 and 20
    investment costs: 36 mio€, annual operating costs: 0.36 mio€/a
  - Upgrade 2: Development of a new 380-kV-doublesystem on a length of 60 km between nodes 4 and 20
    investment costs: 42 mio€, annual operating costs: 0.42 mio€/a



Coordination of power flow controlling devices

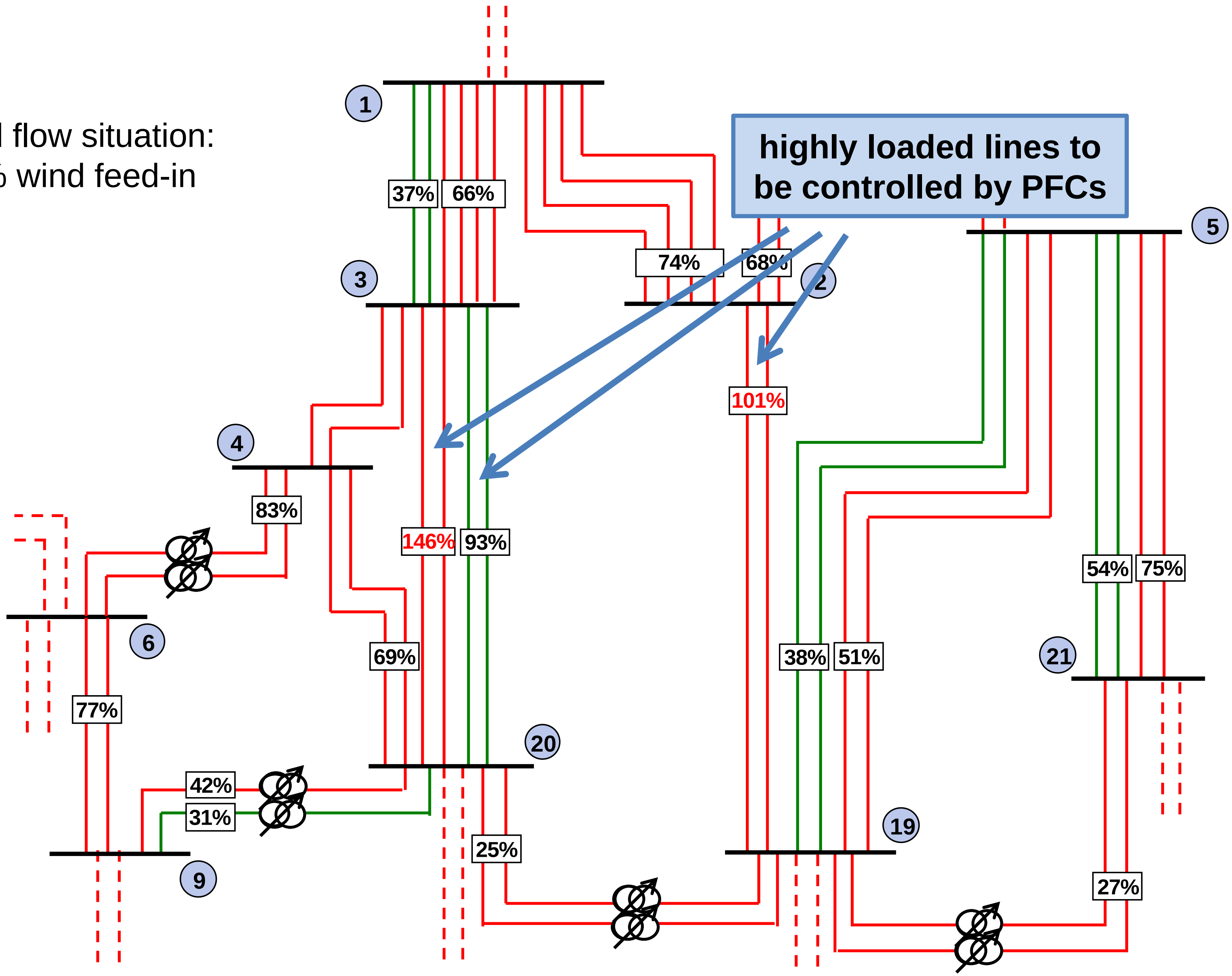
- Installation of fast power flow controlling devices (PFCs) to reduce the frequency of congestion
- Coordination among the PFCs by rule based autonomous wide area control system



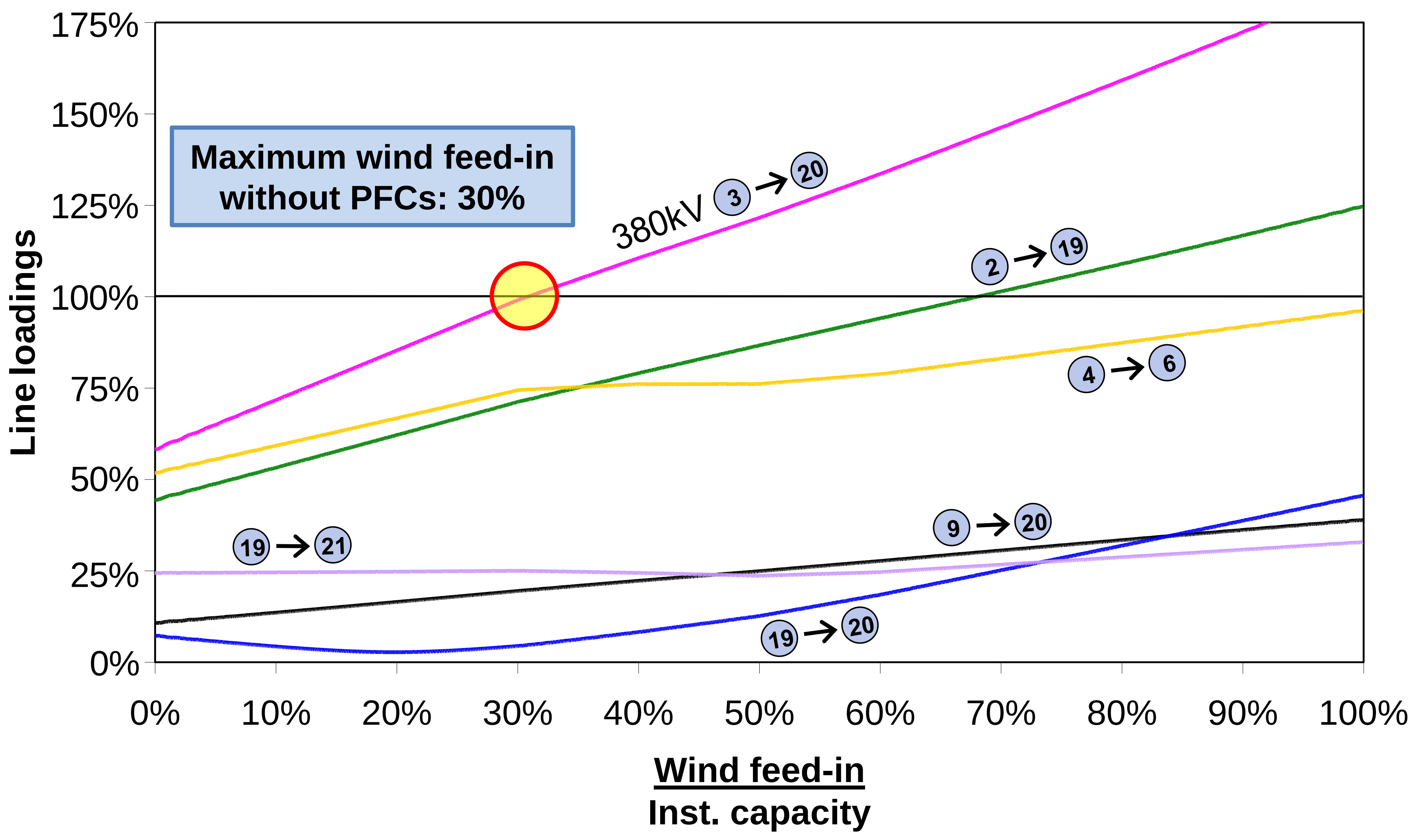
1. IF a device on the control path or on a parallel path of a PFC is overloaded, THEN modify the setpoint-values of the PFC
2. IF there is a failure of a device on a parallel path AND no further path exists for a PFC, THEN deactivate the PFC
3. IF a short circuit happens on a control path or on a parallel path of a PFC, THEN slow down the operating point control of the PFC

Future scenario 2015

load flow situation:
70% wind feed-in



Line loadings without power flow controller



Line loadings with power flow controller

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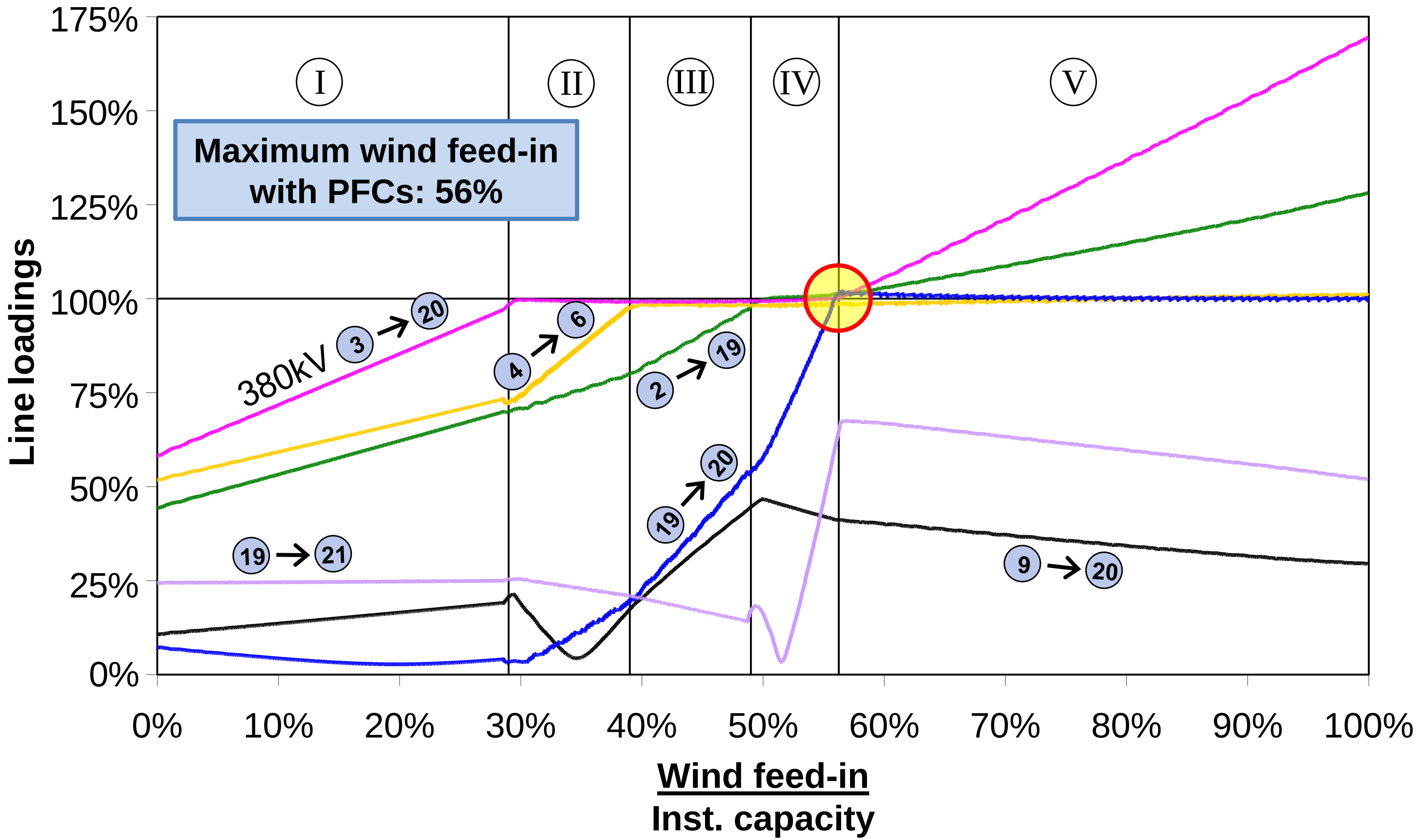
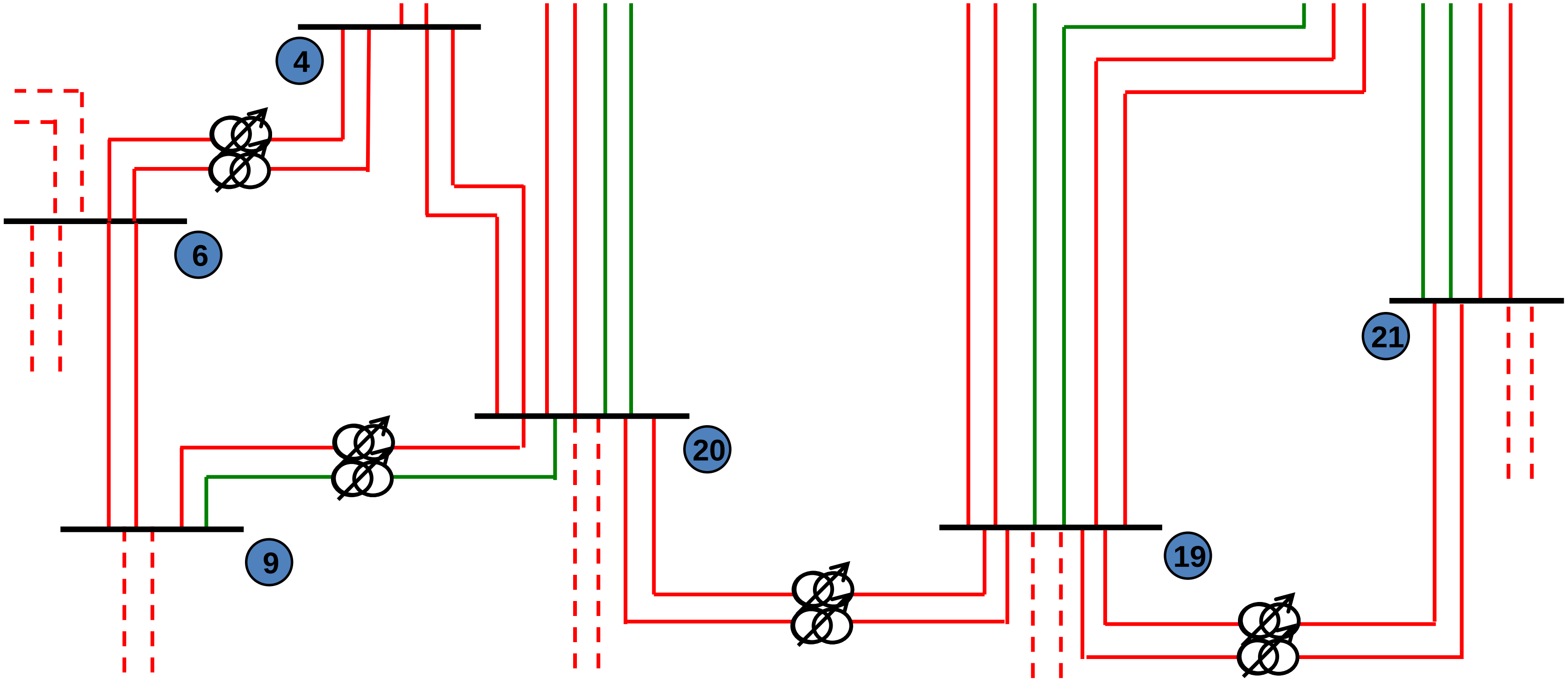


Results of the (n-1)-calculations



PFC installations 04 → 06	09 → 20	19 → 20	19 → 21	Max. wind feed-in
				16%
x				21%
x	x			21%
x		x		35%
x			x	21%
x		x	x	39%
x	x	x	x	39%

Conclusions

- Several bottlenecks expected in the German transmission system
- Raising installed wind capacity in northern Germany is the main influencing factor
- Bottlenecks lead to high redispatch costs and require network upgrades
- Evaluation of cost effectiveness of new lines → cash flow for the system operator depends on regulatory conditions
- Time consuming approval procedure for development of new lines
- Installation of PFCs can increase the transmission capacity before new lines are developed → exact cost calculations required