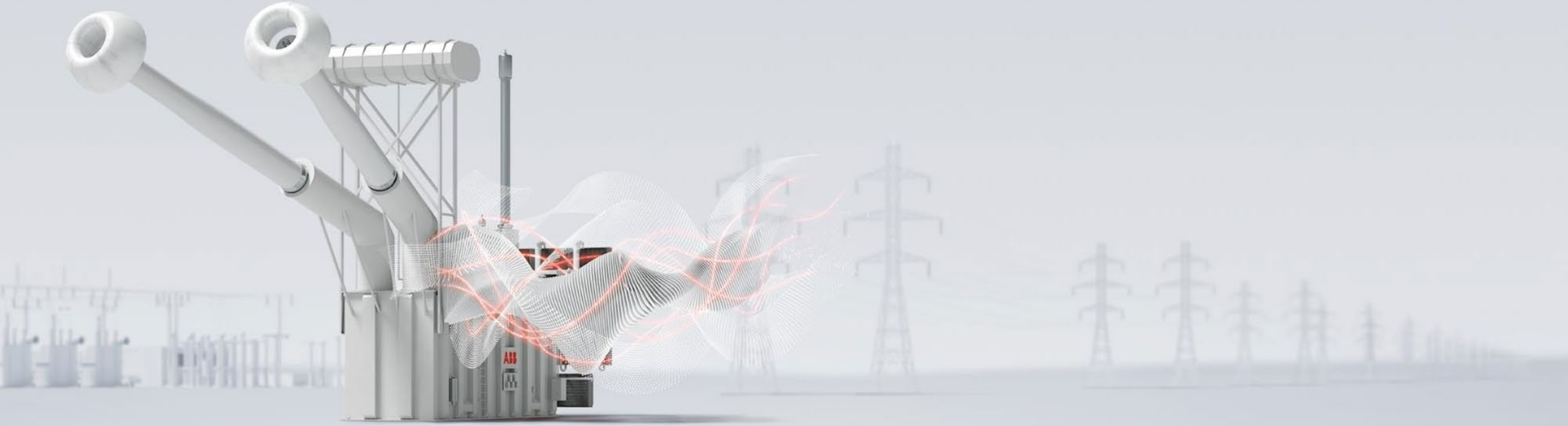

Value Quantification of State-of-the-Art Condition Monitoring in 400 kV Transmission System

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ABB

Value Quantification

Deep dive in asset pre-outage detection within digital substations

Suggested scope and deliverables

Scope

- Determination of asset importance (load flow, reliability analyses, n-1 criterion calculations)
- Priority list for efficient sensor placing
- Asset condition assessment
- Development of an optimal maintenance plan
- Benefit of sensor applications in comparison to conventional substations

Results usage

- Improved grid operation due to higher availability
- Outage reduction and enlargement of MTBF values
- Allocation of optimized maintenance strategies (RCM, TBM, CBM, RBM)

Value Quantification – Digital Substation

Operative risk cost optimization with digital substation

Framework

18,9 GW – 11,7 GW: 10 Electrical load scenarios

400 kV – 110 kV: Transmission system model

21 GW – 17,4 GW: 10 Power generation scenarios

Reliability & availability values for equipment with and without sensor application

Scenario simulations & technical assessment

100.000 – 1.000: Monte Carlo simulation based annual outage combinations

100000 MWh – 1000 MWh:
- Reliability & non-availability determination
- Importance & condition assessment

Cost & benefit calculation

Outage Costs
- Repair & replacement
- Revenue losses
- Penalties (50-300 €/MWh)

Annual risk cost determination with and without sensor application in 12 of 70 substations

Investment Costs
- Replacement
- Refurbishment (retrofit)
- Digitalization of substation

Findings

What's your deal?

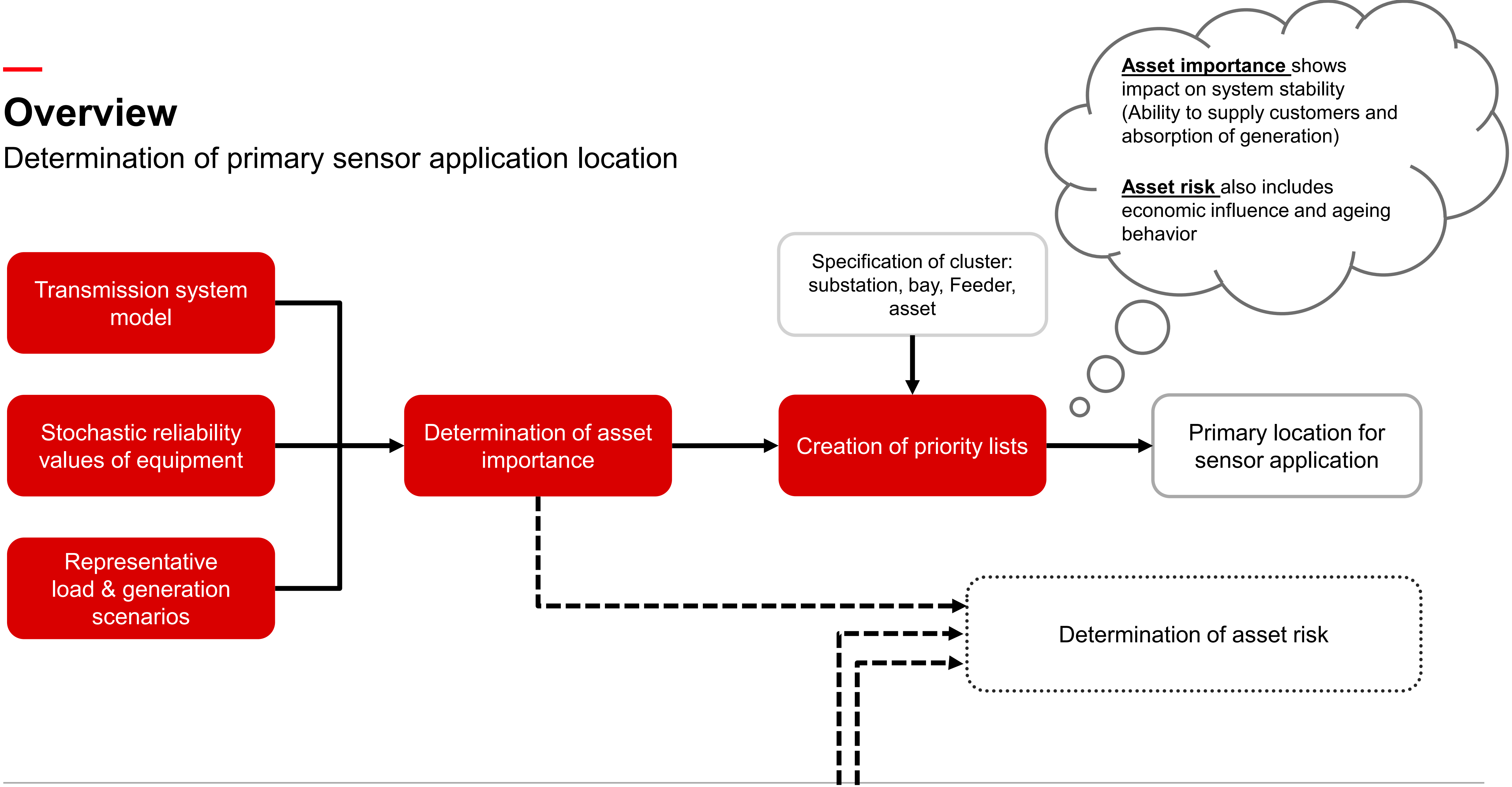
7.400.000 € – 0: NPV calculation for ten years by considering different penalties

1.500.000 € – 300.000 €: Risk cost reduction within one year by considering different penalties

80% – 30%: Reduction of maintenance costs

Overview

Determination of primary sensor application location



Value Quantification – Reduction of operative risk costs

What is risk?

What is the operational risk and what kind of costs are considered?

Equipment-based costs

- Replacement costs for HV-equipment
- Repair costs for HV-equipment

Revenue-based costs

- Loss of profit & penalties from non-fed energy of power plants
- Loss of profit & penalties from undelivered energy to customers
- Loss of profit & penalties for non-transfered energy to neighboring TSO‘s

*

Event probability

- Age-dependent
- Product specific
- Environmental situation
- Etc.

Overview – Value Quantification for Digital Substation

Transmission System Model

- Based on the data of a German TSO
- Maximum detailed considered:
  - Substation: Layouts, switching situations,
  - Power Plants: Generation ramping, priority of auxiliary supply,
  - Vertical Load: Demand of various 110kV network groups

Reliability & Availability Calculation

- Real age distribution of primary equipment
- Age-depended hazard rates and outage duration
- Multi-load scenarios

Operative Asset & Substation Risk Determination

- Repair & replacement costs
- Penalties for non-delivered and non-fed energy
- Lost revenue by non-delivered and non-fed energy
- Loss of profit & penalties for non-transfer energy to neighboring TSO‘s
- Determination of operative risk with a Monte Carlo simulation based on the Value at Risk method

Confrontation of Regular & Digital Substation application

- Comparison of different annual operational risks and costs
- Presentation of investment costs
- Net present value calculation

Overview

Key figures of 400 kV transmission network model

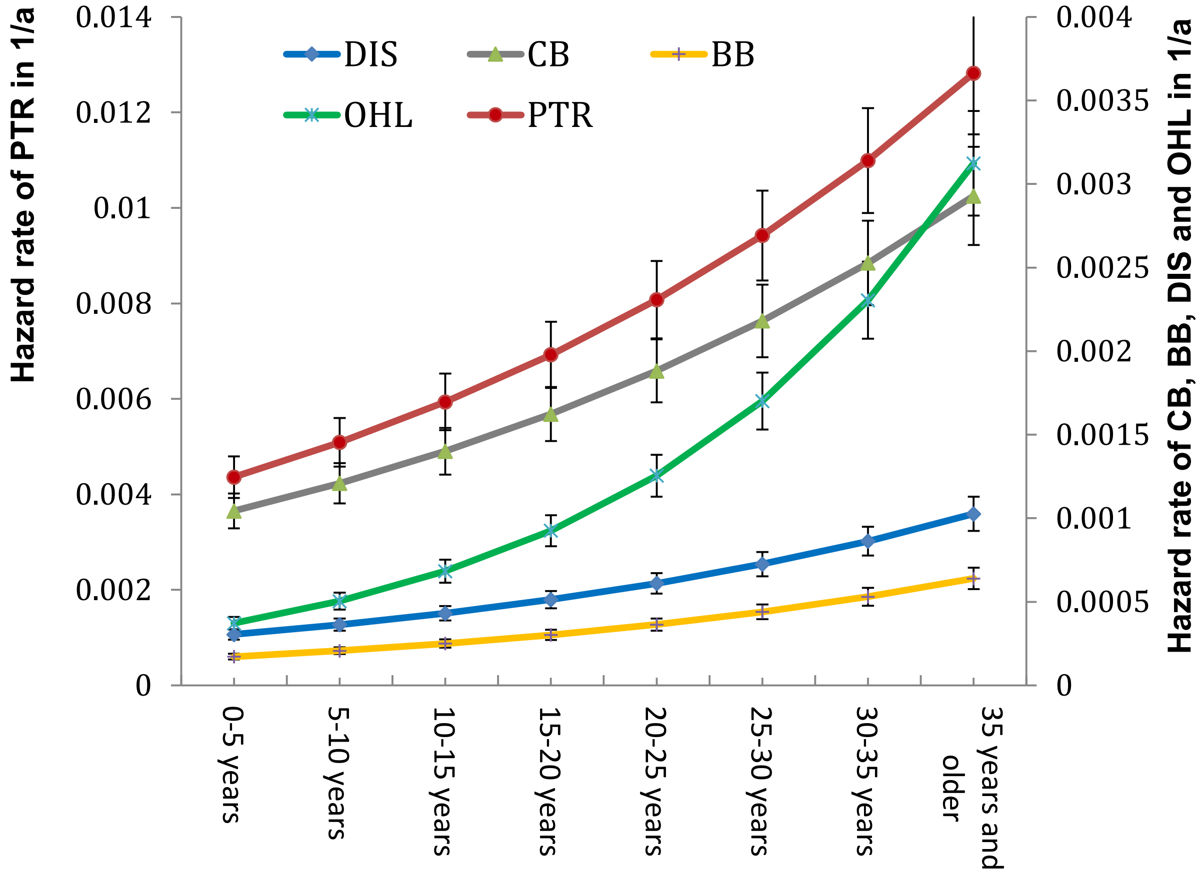
Element	No. of Elements	Hazard rate λ in 1/a	Outage duration T in h	Avarage repair costs in €	Investment costs in €
Bus bar	145	0,00032	6,35	10.000	-
Center break disconnector	302	0,000513	67,63	10.000	40.000
Circuit-breaker	337	0,001473	64,69	25.000	150.000
Generator	30	0	0	-	-
Overhead lines	4453 km	0,001562	5,34	-	-
Pantograph disconnector	952	0	0	-	35.000
Power transformer	103	0,006411	65,99	50.000	3.000.000 – 12.000.000

Assumptions – input data

Age-dependent hazard rate of 400kV equipment

Asset condition assessment

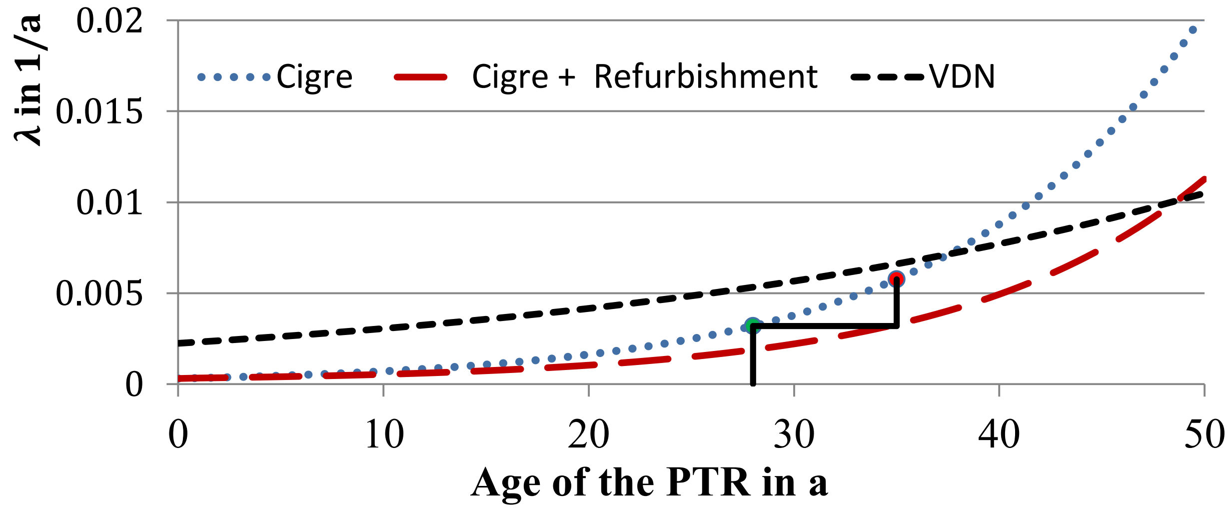
- All asset behavior are considered only with age-dependent increasing hazard rate
- Statistics are taken by CIGRE-, IEEE-publications and are confirmed by the TSO-asset management
- For the further calculations, distribution functions are used within the age groups.



Assumptions – input data

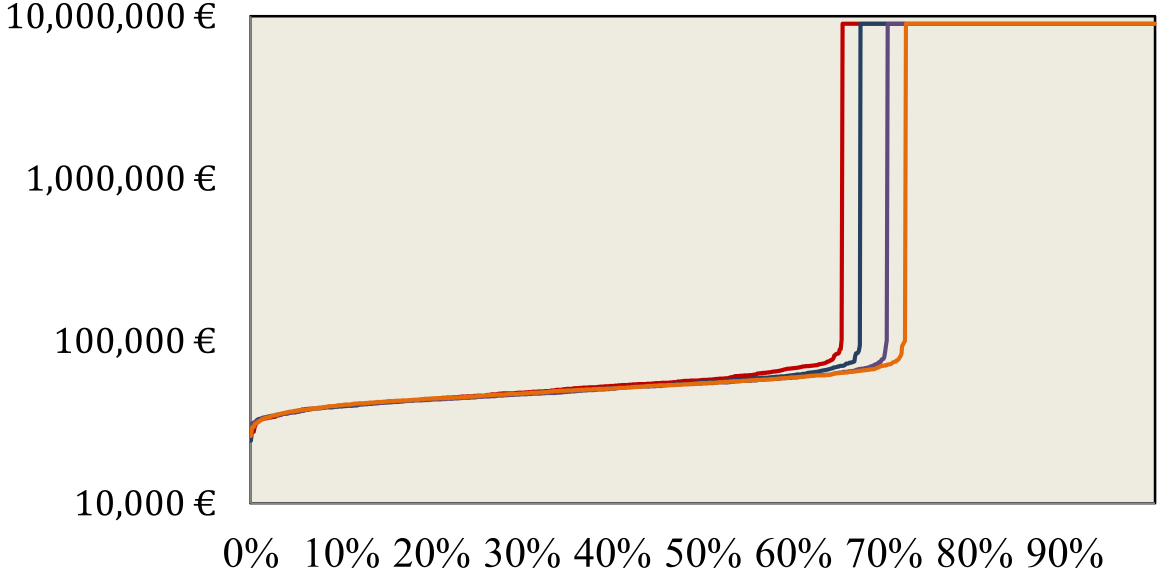
Power transformer in detail

Age-dependent hazard rate of power transformer



t_{PTR} age of the PTR
t_{TAP} age of the tap changer
t_{BH} age of the bushings

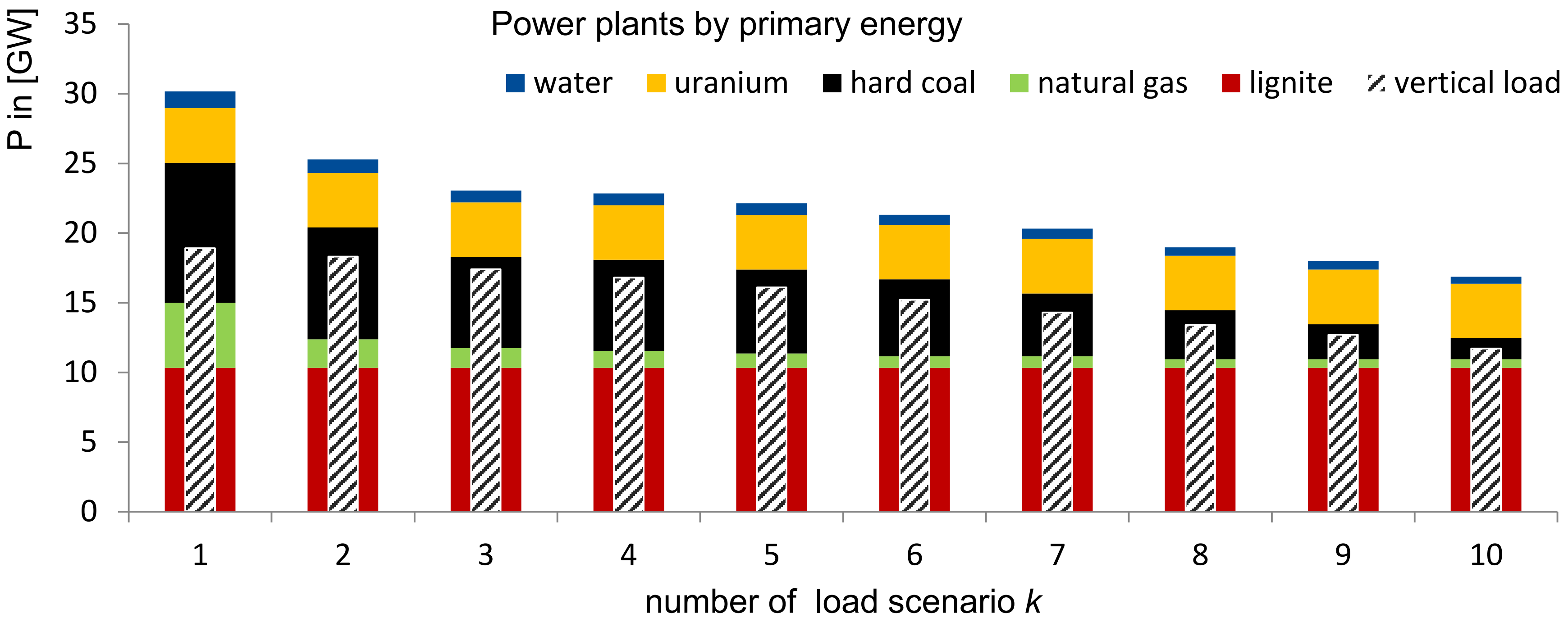
Cumulative histograms of repair costs of power transformer

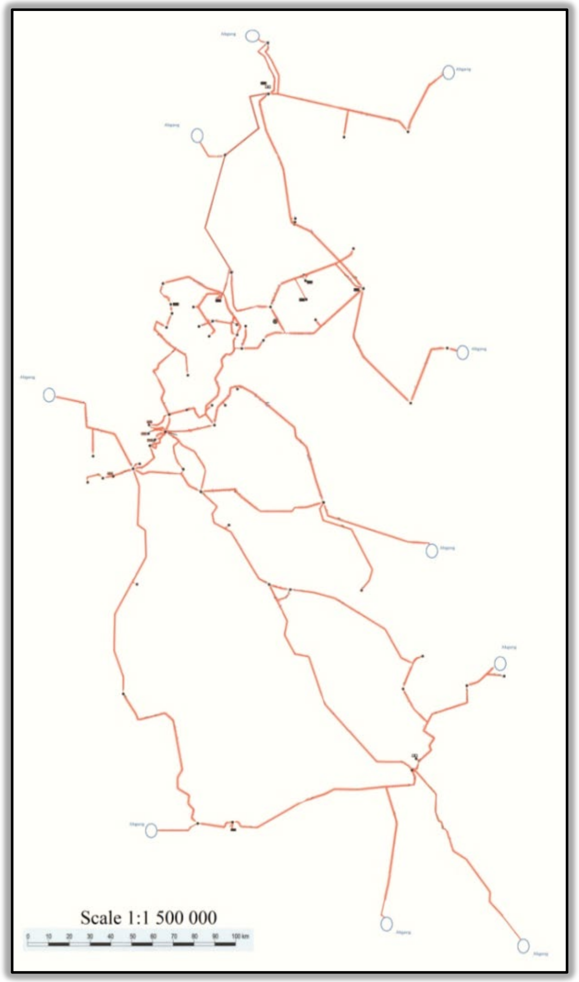


$$\lambda_{\mathrm{PTR}}(t) = 163.5 \cdot 10^{-6} \cdot e^{0.0844 \cdot t_{\mathrm{PTR}}} + 101.7 \cdot 10^{-6} \cdot e^{0.0844 \cdot t_{\mathrm{TAP}}} + 34.8 \cdot 10^{-6} \cdot e^{0.0844 \cdot t_{\mathrm{BH}}}$$

Grid parameters

Framework – 10 load scenarios & overview 400 kV overhead line network





400 kV overhead line network

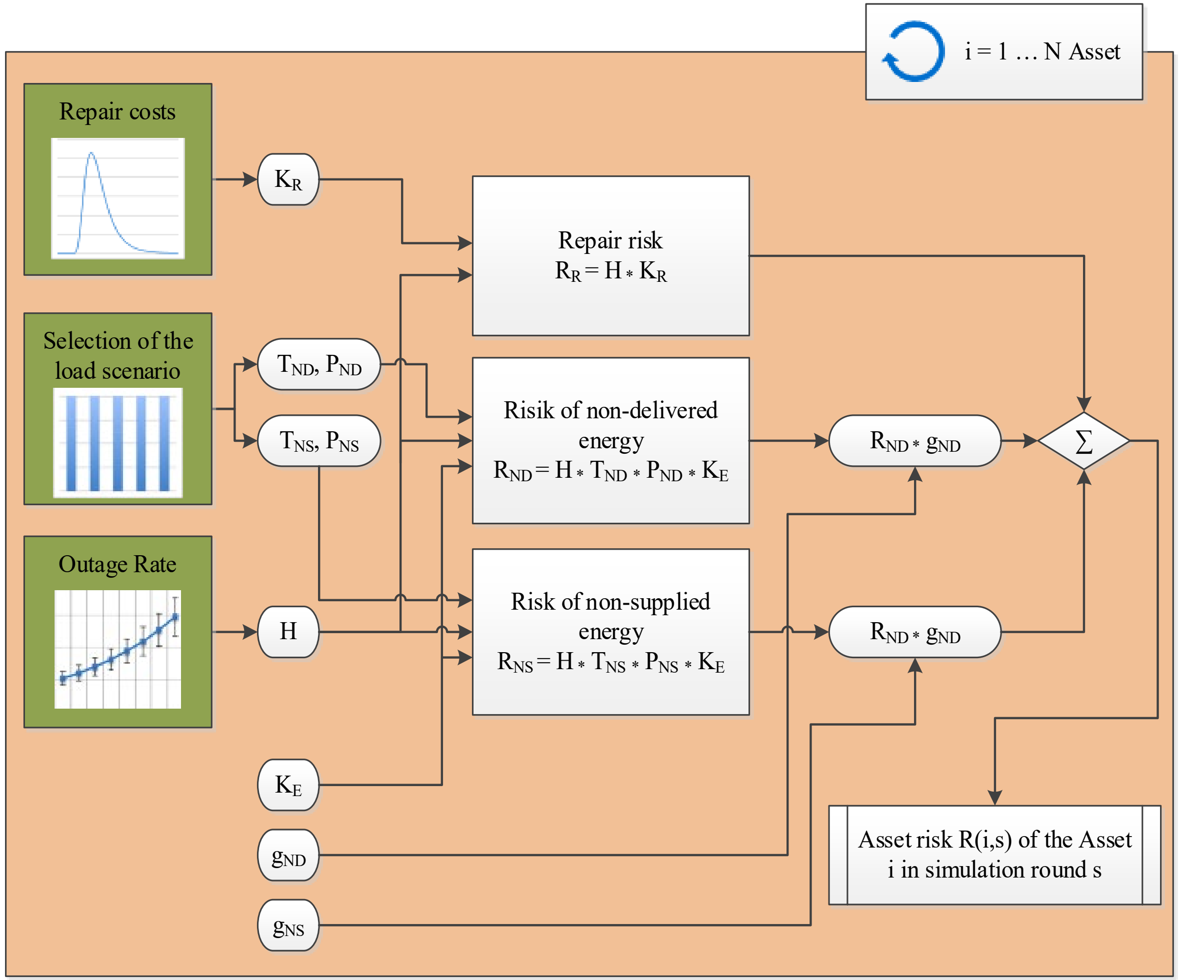
- TSO has only electrical power surplus situations
- Load scenarios are determined out of annual load profile

Assumptions – input data

Asset Risk Determination

Single asset risk determination with

- Distribution function of repair costs
- Age-dependent outage rates with distribution function
- Reliability data of all load & power plant scenarios
- Monte Carlo simulation used for asset risk V(i) and overall risk determination
- Value at risk method used to sort out extraordinary combinations with a confidence interval of 0.95



Assumptions – input data

Excerpt for investigation – 12 substation models

SUBSTATION	LAYOUT	POWER TRANSFORMER	CIRCUIT-BREAKER
BI	H4	2	4
BU	TBT	4	12
DT	H3	1	3
ED	DBT	1	6
KO	DB	1	4
KR	DB	3	7
LB	DBT	3	8
MB	DBT	0	6
SB	ET	1	1
UC	DBT	3	10
UR	DBT	8	3
WT	TBT	3	10

Acronyms for substation layouts

DBT	Double bus bar with Transfer bus bar
TBT	Triple bus bar with Transfer bus bar
H4	H-Connection with 4-Breakers
H3	H-Connection with 3-Breakers
DB	Double bus bar
ET	External Transformer

Scenarios

Substation risk

Regular

Status quo of current equipment

Intensive

Improved behavior of equipment, all assets will be refurbished

New

Replacement of circuit-breakers and power transformers inside of the substation

Online Regular

Retrofit of circuit-breakers and power transformer in the substation with sensors

Online New

Replacement of all circuit-breakers and power transformer in the substation and application of sensors

Method:

Determination of the various substation risks regarding its scenarios and belonging hazard rates

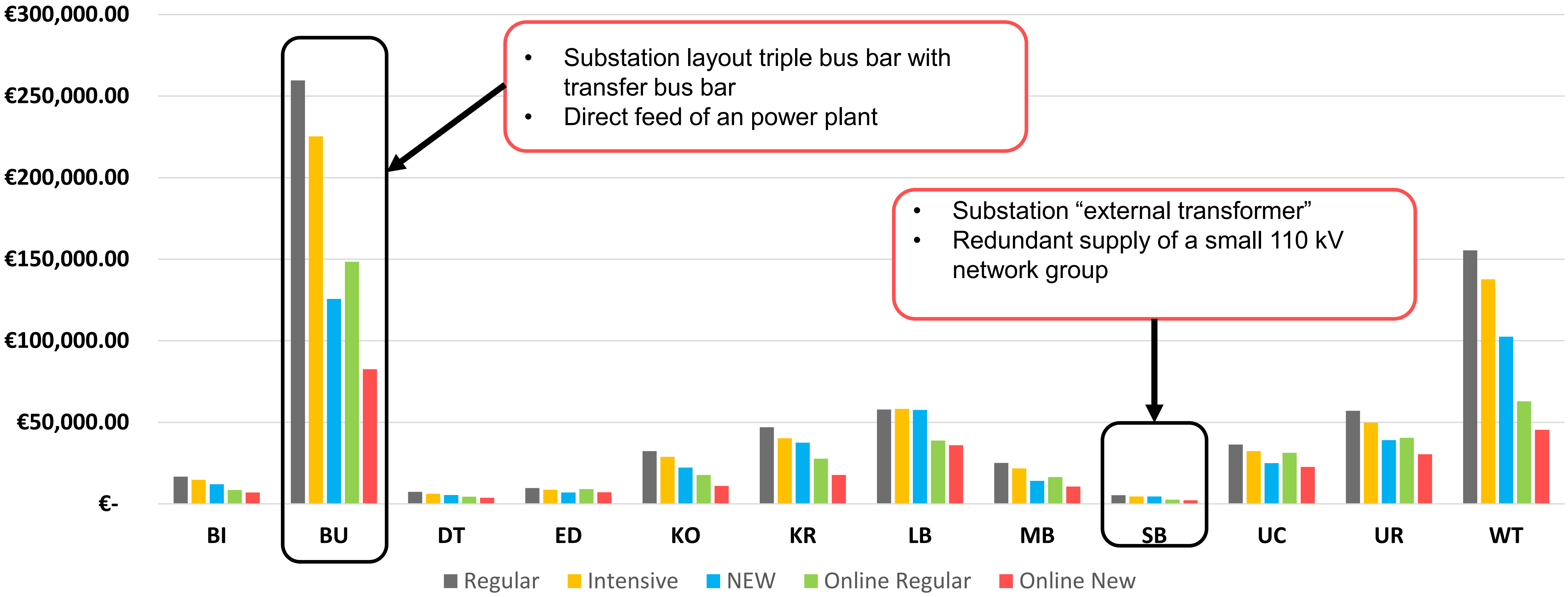
Scenarios

Substation risk – scenarios – what happens?

- **Regular** → **Reliability rates (λ,T) are not adjusted**
- **Intensive** → **Reliability rates (λ,T) will be improved by 25%**
- **New** → **Reliability rates (λ,T) will be set to new asset condition**
- **Online Regular** → **Reliability rates (λ,T) will be adjusted to supervision mode**
- **Online New** → **Reliability rates (λ,T) will be set to new asset condition with supervision mode**

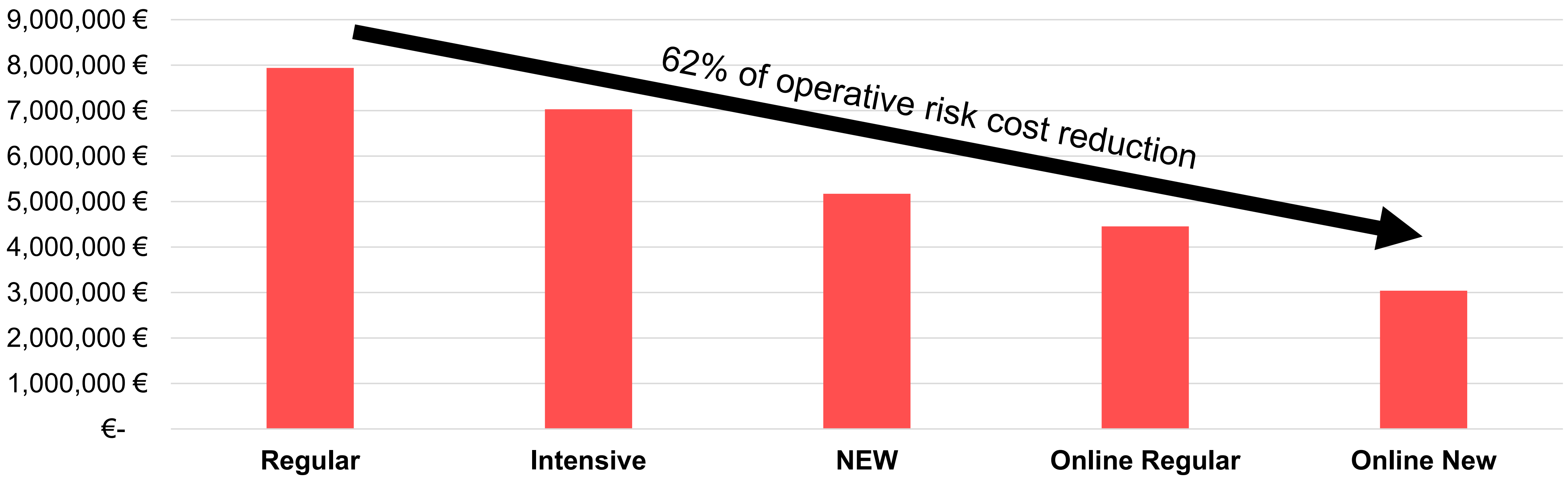
Results

Overview risk of all substation – 1 Year



Results

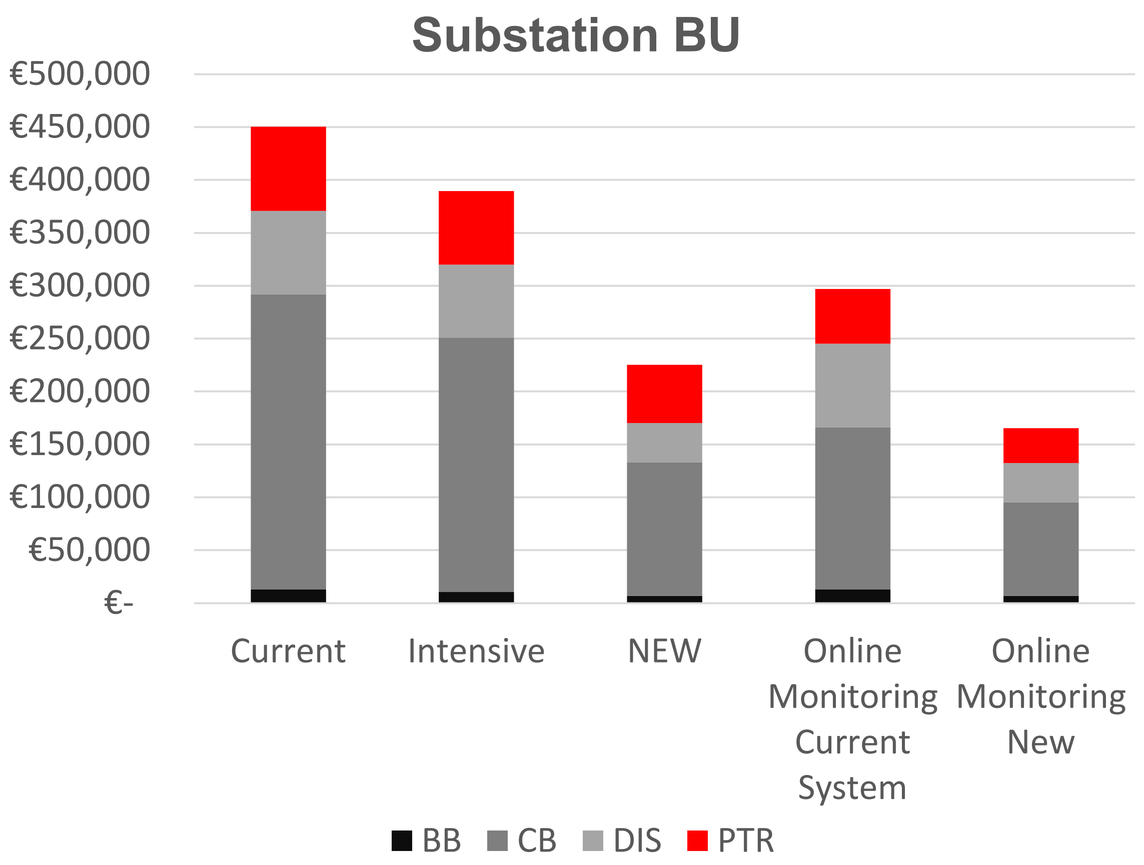
Total operative risk costs of all substation within a period of 15 years

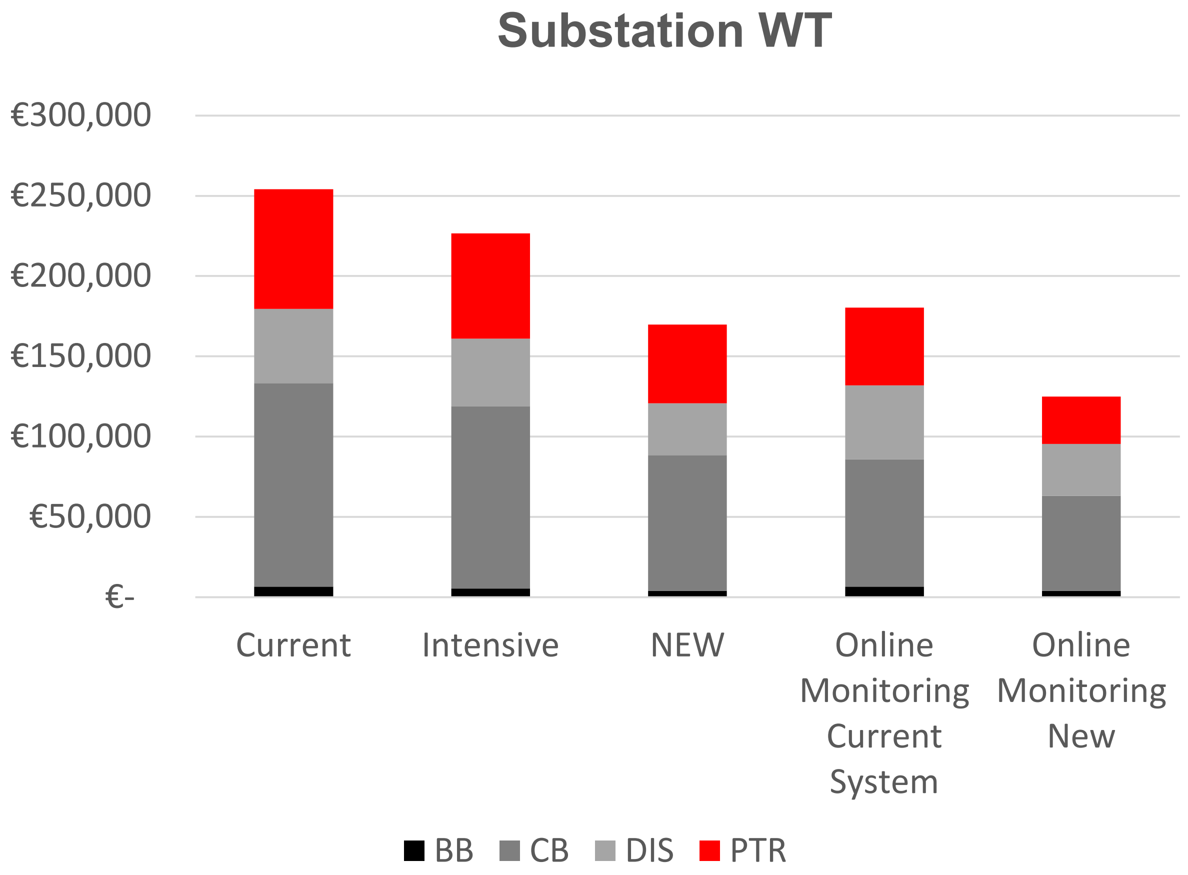


Significant operative risk cost reduction with sensor application!

Detail investigation – Substation BU & WT

Overall results per year





Key Assumptions for NPV - Calculation

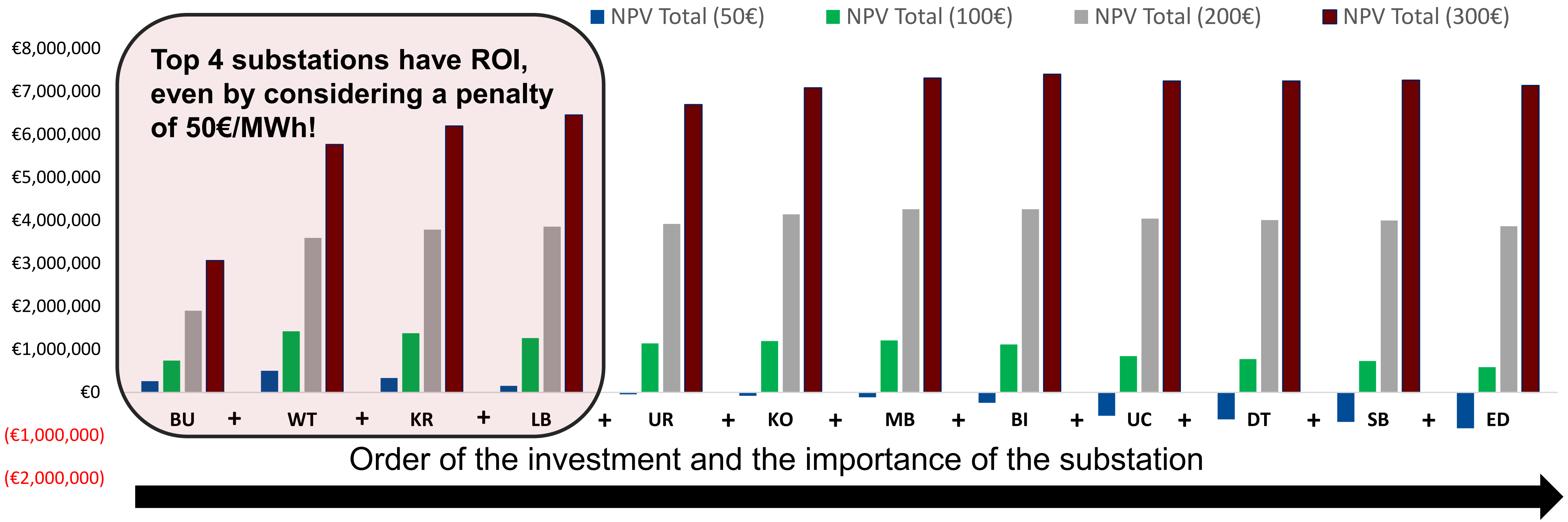
For sensor application in 400 kV transmission network

- **Sensor investment costs (CAPEX)**
  - **Power transformer: 60.000 €**
  - **Circuit-breaker: 15.000 €**

- **Depreciation duration: 10 years**
- **Discount rate: 10 %**

Results

Aggregated total Net Present Value (NPV) for retrofitted equipment



The higher the penalties, the faster the return on investment in the sensor application.
But even with low penalties the sensor application has an short ROI-Duration in important substations.

Conclusion

Operational risk determination & its results

Technical Aspects

- Location, age and configuration are significant indicators for importance of a substation
- Detailed knowledge about equipment and its aging behavior
- Identification of bottlenecks and Investment control application

Financial Aspects

- ROI only with reduction of operative risk costs possible
- Even with low penalties, to monitor power transformer and circuit-breaker is on benefit

Additional Values! - Not considered in this investigation

- Longevity of equipment (postponed investments for asset replacement)
- Further reduction of risk costs by planned switch off before failure
- Reduction of OPEX by improved maintenance