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Study Committee B2

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Probabilistic safety concept in OHL construction

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Motivation

- The decision to push ahead with the energy transition poses major challenges for transmission grid
- Efficient and safety transmission grid is required
- Construction of DC links, expansion and refurbishment of existing AC grid
- Probabilistic safety concept offers an interesting technical approach for challenge of rehabilitation of existing networks

Figure I: Increasing use of renewable energy

Method/ Approach

- With normative basis from DIN EN 1990 all pylon locations can be assigned to different reliability levels by evaluating possible damage consequences
- With the stochastic models of probabilistic, actions and resistances can be described very accurately
- By comparing the determined and required reliability levels an efficient stability verification of lattice pylons can be carried out
- Risk-considered refurbishment of the energy transmission grid

Objects of investigation

- As part of a case study we calculated the reliability indices for a pylon based on the load case pressure failure
- Two pressure diagonals in the wall perpendicular to the line of a supporting pylon are considered

Experimental setup & test results

- The forces are triggered exclusively by the gust velocity pressure
- The system failure probability is about 1.5 times higher than the highest component failure probability
- A system reliability index of 3.6 was determined, resulting in a reliability level 2 for the pylon.

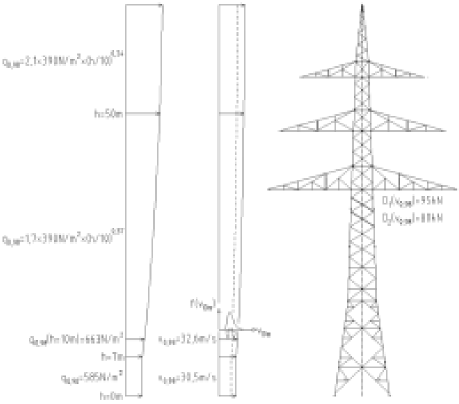

Figure II: Pressure diagonals in the wall perpendicular to a support pylon

Discussion

- If the pylon was located closed to a railway, it would have been assigned reliability level 3
- With reliability index of 3.6 this pylon would be clearly above the requirements and the proof would thus be provided

Conclusion

- Actions and resistances can be described very accurately
- Efficient stability verification of lattice pylons
- Risk-considered refurbishment of the energy transmission grid and effective use of resources
- Great technical potential to ensure electrical supply security for the energy transition and in the long term with a stable power grid

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Method/ Approach

Classification of the safety concepts

- Various safety concepts have been used in the past or are used today

Safety concept	Level	Value for the reliability	Design requirement
Deterministic (empiric)	0	Global safety factor n	existing s ≤ allowable s = critical s / n
Semi-probabilistic	I	Partial safety factors g_R, g_S	existing s (g_S× S) ≤ critical s / g_R
Probabilistic (approximation)	II	Reliability index b	existing b ≥ required b
Probabilistic (exact)	III	Probability of failure P_f	existing P_f ≤ allowable P_f

Table I: Classification of the safety concepts

- In case of recalculations of existing structures a partial safety factor is set too high for simplification reasons, may lead to a replacement of the supposedly undersized cross-sections

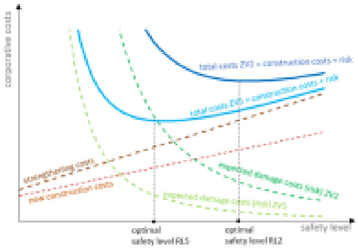

Figure III: Optimal safety level

- Replacement with higher dimensioned components is more expensive then use of same components in new construction (construction site, anchoring work, decommissioning)

Reliability level for towers

Required reliability indices of the pylon system (according to table 7 VDE-AR-N4210-4:2014-08)				
Reliability level	required $\beta_{rel,min}$	permitted $P_{f,rel,max}$	Site-dependent hazard	examples
1	4.3	$8.5 \cdot 10^{-6}$	very high	stadiums
2	3.8	$7.2 \cdot 10^{-5}$	High (reference level)	motorways
3	3.3	$4.8 \cdot 10^{-4}$	Medium	Railway station building
4	3.0	$1.35 \cdot 10^{-3}$	Low	Parking spaces
5	2.6	$4.7 \cdot 10^{-3}$	Very low	Forest area

Table II: Safety levels and target safety indices

- Target reliability index β=3.8 obtained by recalculation of pylons designed according to EN50341-3-4 (1-year extreme)
- Reliability level 1 for higher site-dependent hazards (→ 3-5 times smaller damage consequences)

Verification procedure

- Verification is carried out by comparing the existing reliability index with the required index
- Each component of a steel lattice pylon can lose its function due to several failure mechanisms (components)
- The entire system fails, if a single component fails

Limit state functions

- Difference function between capacity (resistance of a component) and the stress consuming (stress or internal force) caused by external actions

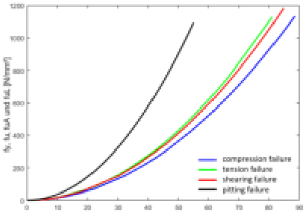

Figure IV: Limit state functions in the original space for four failure modes

Stochastic models

- For probabilistic calculation stochastic models must be set up
- For the stochastic modelling of the gust wind speeds v, an extreme value distribution type III with variation coefficient and a positive curvature parameter is assumed (VDE-AR-N 4210-4)

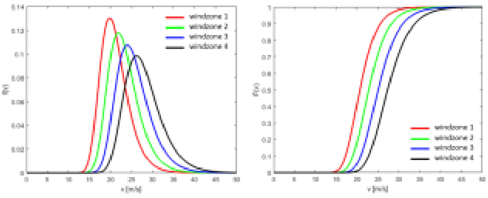

Figure V: Distribution density and cumulative distribution functions Extreme value type III of the gust wind speeds (10m above ground level)

- The stressability of all failure modes is described by means of a lognormal distribution (VDE-AR-N4210-4, 7.3.6)
- With distribution parameters mean value m and standard deviation σ the distribution density and cumulative distribution functions can be created

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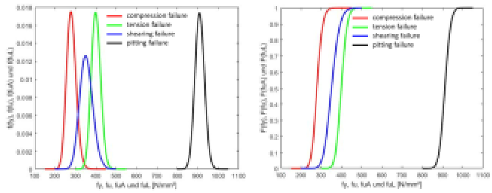

Figure VI: Distribution density and cumulative distribution functions of the lognormal yield strength (S235) and distributed strength

Standardisation

- Limit states are then transformed into the standard space and the design point determined, which is locate on the limit state with the smallest distance to the origin

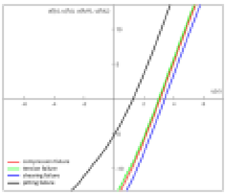

Figure VII: Limit state functions in standard space

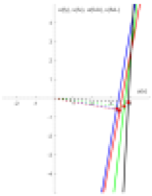

Figure VIII: Reliability index

- Length of this distance is the reliability index β of the component

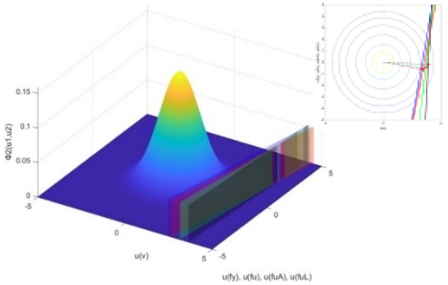

Figure IX: Bivariate standard normal distribution and limit functions in standard space

- The FORM solution is an approximation that can be improved by calculating the curvatures of the limit state in addition to the coordinates of the design point
- The more exact SORM solutions can be calculated

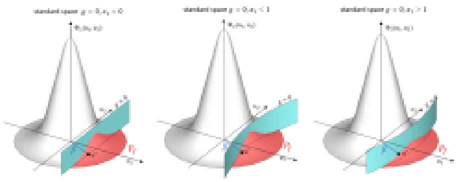

Figure X: Representation of the limit state function in standard space

Reliability index of a system

- Sensitivities are calculated from the design point and the reliability index, the correlation matrix can be created
- Once all component failure probabilities are known, the system failure probability must still be calculated
- A system failure already exists when the first component fails
- The system failure probability of a series system is always higher than the highest component failure probability

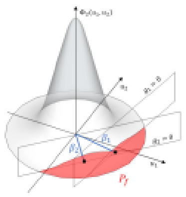

Figure XI: Falure space for two components

- The reliability index is calculated from the failure probability of the overall system which is compared with the required reliability level of the site

Conclusion

- Actions and resistances can be described very accurately
- Efficient stability verification of lattice pylons
- Risk-considered refurbishment of the energy transmission grid and effective use of resources
- Possibilities through more precise considerations on the side of impacts (weather parameters)
- Safety concept for lattice pylons can be applied to other areas of the energy grid
- Great technical potential to ensure electrical supply security for the energy transition and in the long term with a stable power grid