Methods to Establish Turbo-Generator Outage Intervals

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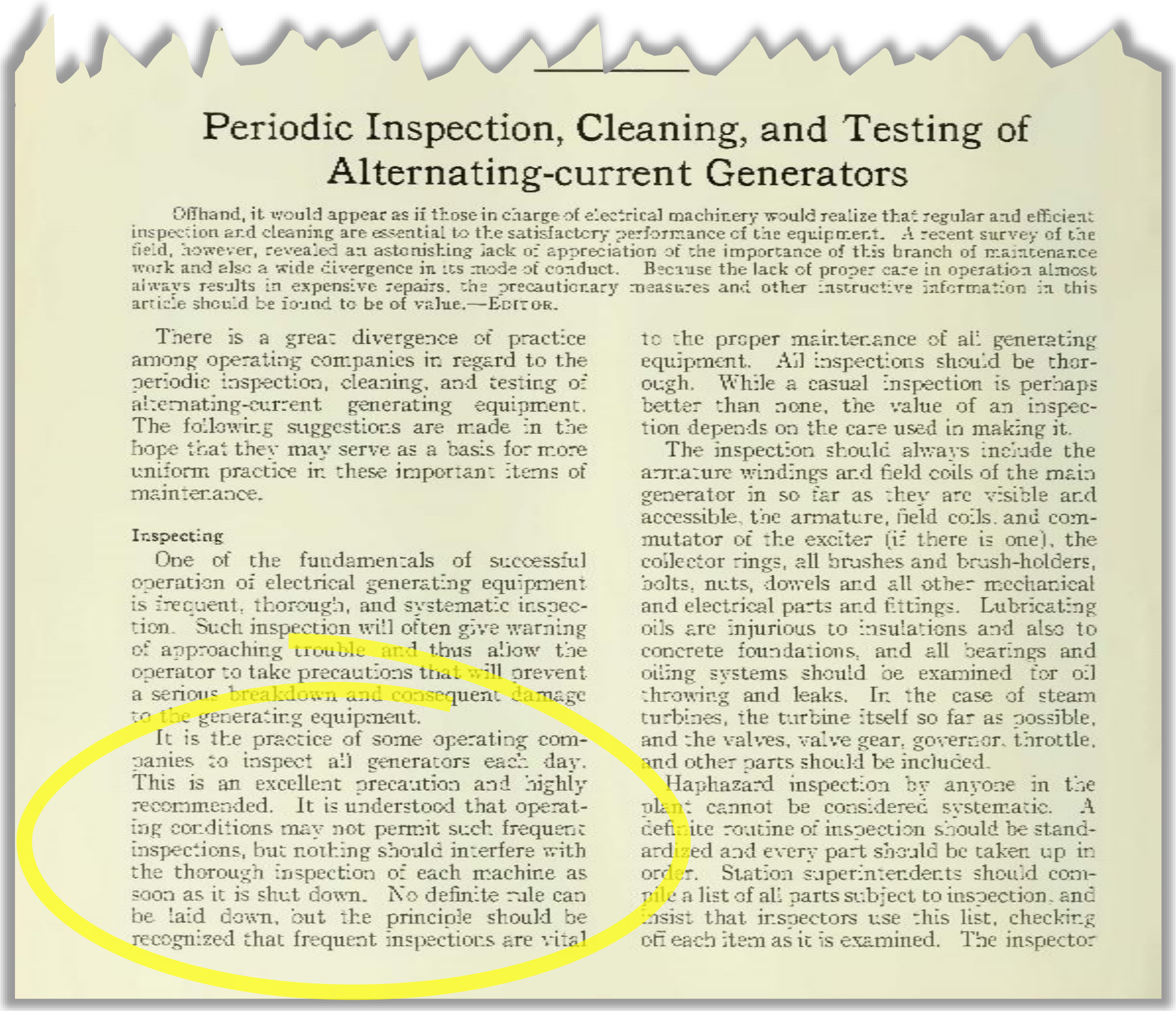
Once upon a time…

- Literature survey about outage intervals: most information in OEMs' documents, very few generic papers
- General Electric Review, 09/1923 suggested periodic inspection:
  - each day highly recommended
  - as soon as machine shut down
  - frequent inspections are vital
  - include armature winding and field coils if they are accessible



Periodic Inspection, Cleaning, and Testing of Alternating-current Generators

Offhand, it would appear as if those in charge of electrical machinery would realize that regular and efficient inspection and cleaning are essential to the satisfactory performance of the equipment. A recent survey of the field, however, revealed an astonishing lack of appreciation of the importance of this branch of maintenance work and also a wide divergence in its mode of conduct. Because the lack of proper care in operation almost always results in expensive repairs, the precautionary measures and other instructive information in this article should be found to be of value.—EDITOR.

There is a great divergence of practice among operating companies in regard to the periodic inspection, cleaning, and testing of alternating-current generating equipment. The following suggestions are made in the hope that they may serve as a basis for more uniform practice in these important items of maintenance.

Inspecting

One of the fundamentals of successful operation of electrical generating equipment is frequent, thorough, and systematic inspection. Such inspection will often give warning of approaching trouble and thus allow the operator to take precautions that will prevent a serious breakdown and consequent damage to the generating equipment.

It is the practice of some operating companies to inspect all generators each day. This is an excellent precaution and highly recommended. It is understood that operating conditions may not permit such frequent inspections, but nothing should interfere with the thorough inspection of each machine as soon as it is shut down. No definite rule can be laid down, but the principle should be recognized that frequent inspections are vital to the proper maintenance of all generating equipment. All inspections should be thorough. While a casual inspection is perhaps better than none, the value of an inspection depends on the care used in making it.

The inspection should always include the armature windings and field coils of the main generator in so far as they are visible and accessible, the armature, field coils, and commutator of the exciter (if there is one), the collector rings, all brushes and brush-holders, bolts, nuts, dowels and all other mechanical and electrical parts and fittings. Lubricating oils are injurious to insulations and also to concrete foundations, and all bearings and oiling systems should be examined for oil throwing and leaks. In the case of steam turbines, the turbine itself so far as possible, and the valves, valve gear, governor, throttle, and other parts should be included.

Haphazard inspection by anyone in the plant cannot be considered systematic. A definite routine of inspection should be standardized and every part should be taken up in order. Station superintendents should compile a list of all parts subject to inspection, and insist that inspectors use this list, checking off each item as it is examined. The inspector

Outage schedule considerations

- OEM’s instruction manual and other documents (TILs, bulletins, etc.)
- User’s internal procedures, experience with generator series
- Typical faults of certain models, revealed by technical forums / conferences
- Operating mode and abnormal operational events experienced in the past
- Records from previous maintenance, online monitoring and offline tests
- Turbine maintenance or main plant statutory inspection schedule
- Importance of the unit in the grid and electrical system situation
- Utility’s economical restrictions and available personnel
- Maintenance contractor availability (personnel, materials, tools)
- Other restrictions, such as imposed by insurance company or LTSA contract

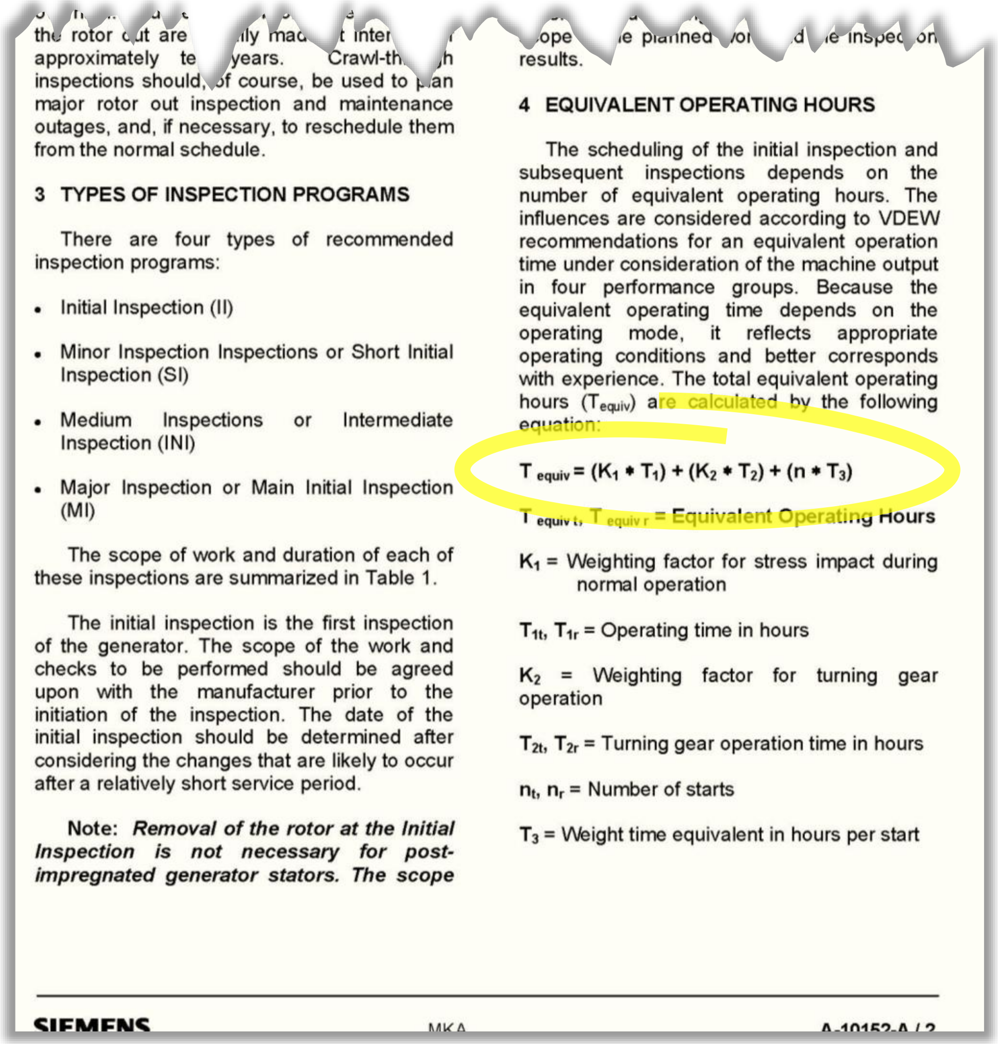
OEM's recommendations

- By the simple traditional method, the interval between two successive major (rotor-out) outages was specified as a fixed number of years
- Newer calculated methods take in consideration the operational regime, for instance major outages being performed:
  - After a certain number of operating hours or starts, whichever comes first
  - After a certain number of equivalent hours or years, whichever comes first. The equivalent hours may be calculated from actual operating time, number of starts, time on turning-gear (with certain weighting factors)
- In the last years, OEMs accept major outages performed by robotic inspection
- The OEM's instructions may be cumbersome or inconsistent

User's procedures

- Our first internal procedure required major outages at fixed time intervals. By experience, the OEMs' 3-5 years intervals gradually increased to 6-9 years
- In early 2010s changes occurred in our fleet: new combined cycle plants, adaptation of old plants to burn natural gas, entrance of private power plants
- The service mode switched from base load to flexible operation, consequently requiring flexible maintenance. In 2012 we updated our internal procedure
- It includes common rules for outage intervals applicable to any machine / any flexible operating regime, by methods based on VGB international standard
- VGB organization published during the last 30 years overhaul guidelines for turbo-generators. IEC or IEEE do not issue such documents
- Siemens' generator manuals also specify outage intervals based on VGB

Presentation purpose


the rotor out are ... lly made ... t inter... approximately te... years. Crawl-th... h inspections should, of course, be used to plan major rotor out inspection and maintenance outages, and, if necessary, to reschedule them from the normal schedule.

3 TYPES OF INSPECTION PROGRAMS

There are four types of recommended inspection programs:

- Initial Inspection (II)
- Minor Inspection Inspections or Short Initial Inspection (SI)
- Medium Inspections or Intermediate Inspection (INI)
- Major Inspection or Main Initial Inspection (MI)

The scope of work and duration of each of these inspections are summarized in Table 1.

The initial inspection is the first inspection of the generator. The scope of the work and checks to be performed should be agreed upon with the manufacturer prior to the initiation of the inspection. The date of the initial inspection should be determined after considering the changes that are likely to occur after a relatively short service period.

Note: *Removal of the rotor at the Initial Inspection is not necessary for post-impregnated generator stators. The scope*

...ope ... e planned ... d ... e inspection results.

4 EQUIVALENT OPERATING HOURS

The scheduling of the initial inspection and subsequent inspections depends on the number of equivalent operating hours. The influences are considered according to VDEW recommendations for an equivalent operation time under consideration of the machine output in four performance groups. Because the equivalent operating time depends on the operating mode, it reflects appropriate operating conditions and better corresponds with experience. The total equivalent operating hours (T_{equiv}) are calculated by the following equation:

$$T_{equiv} = (K_1 * T_1) + (K_2 * T_2) + (n * T_3)$$

$T_{equiv\,t}$, $T_{equiv\,r}$ = Equivalent Operating Hours

K_1 = Weighting factor for stress impact during normal operation

T_{1t}, T_{1r} = Operating time in hours

K_2 = Weighting factor for turning gear operation

T_{2t}, T_{2r} = Turning gear operation time in hours

n_t, n_r = Number of starts

T_3 = Weight time equivalent in hours per start

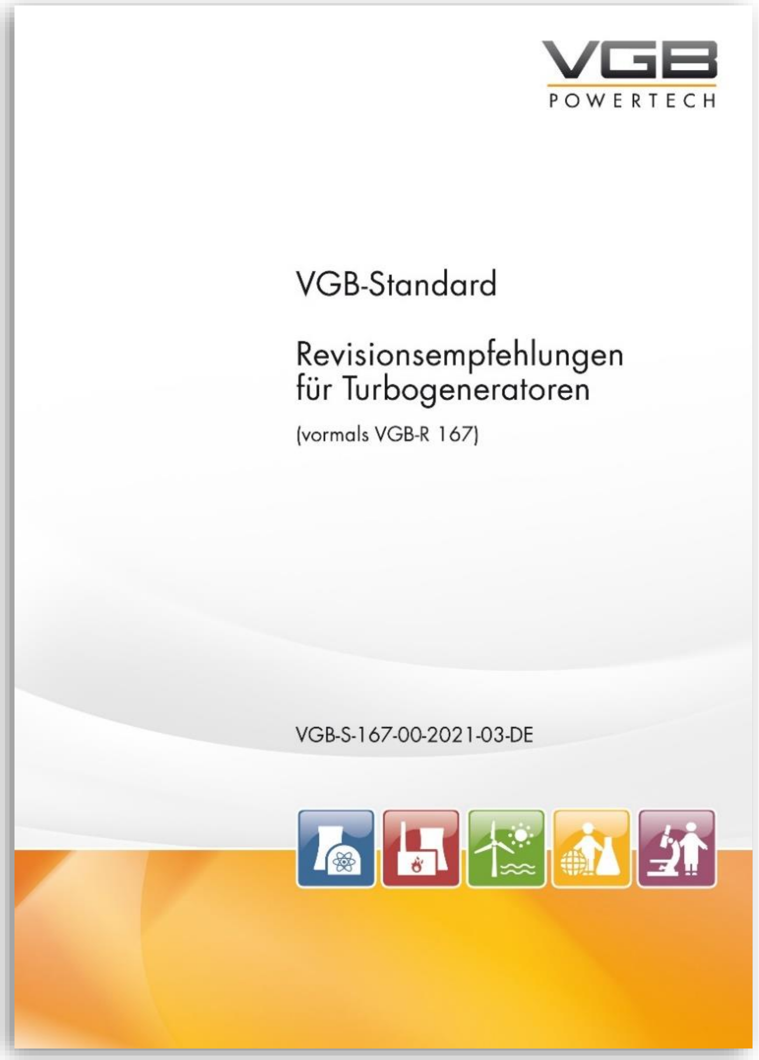
SIEMENS MKA A-10152-A / 2

- Exemplifies our experience and introduces the VGB method to users who may not be aware of such documents
- *Author's company is not a member of VGB and does not represent it in any way*
- VGB is an independent association active in the generation and storage of electricity
- Founded in 1920, has today 436 members from 34 countries (mostly from European Union), 300 GW installed capacity
- Most members operate or own power plants

VGB standards

- VGB provides standards, journals, conferences
- 1991: VDEW guideline "Recommendation for the overhaul intervals of turbo-generators“ (in German)
- 2010: R-167 guideline "Overhaul recommendations for turbo-generators“ (in German), 2011 in English
- 2021: S-167 *standard* “Overhaul recommendations for turbo-generators“ (so far in German only)
- The project group included OEMs, users, experts
- VGB standard can be procured from:

  https://www.vgb.org/shop/technicalrules/vgb-standards/s167eb.html



VGB method

- VGB method relies on equivalent operating hours Te since the previous outage, calculated from plant recorded data and empiric stress weighting factors

$$Te = \underbrace{T1 \cdot K1}_{\text{in-service}} + \underbrace{T2 \cdot K2}_{\text{turning-gear}} + \underbrace{n \cdot T3}_{\text{starts}}$$

- By VGB, the typical types of significant planned outages are:
  - Medium outage with partial dismantling but without rotor removal (the term traditionally used by GE is Minor outage)
  - Major outage with rotor removed or by robotic inspection (as accepted by recent GE and Siemens documents)
- The first outage extent correspond to medium or major outage

In-service operation

- Continuous operation of generators produces wear (depending by in-service time) and requires adequate maintenance measures

$$Te = \underbrace{T1 \cdot K1}_{\text{in-service}} + \underbrace{T2 \cdot K2}_{\text{turning-gear}} + \underbrace{n \cdot T3}_{\text{starts}}$$

T1 = service hours

K1 = stress weighting factor for in-service status

- In the first edition K1 was a generator power-dependent influence factor
- In the 2010 edition K1 = 1. For a generator already designed for a particular rated power continuous operation, its size does not influence the outage intervals. In the 2021 edition K1 is not mentioned anymore

Turning-gear regime

- At turning-gear speeds, the rotor winding moves relative to the rotor body as a result of the force of gravity and may lead to increased wear and to copper dust

$$Te = T1 \cdot K1 + T2 \cdot K2 + n \cdot T3$$

in-service turning-gear starts

T2 = turning-gear hours

K2 = stress weighting factor for turning-gear status

- K2 is a generator power-dependent influence factor. At higher rated power more stress is assumed (longer rotors are more susceptible to self-weight bending). Longer rotors are also more sensitive because their complex structure
- If there are no turning-gear records, 50 hours per shutdown is assumed

Number of starts

- During start and load increase, different expansion coefficients of copper and iron cause relative movements, or / and mechanical copper deformation

$$Te = \underbrace{T1 \bullet K1}_{\text{in-service}} + \underbrace{T2 \bullet K2}_{\text{turning-gear}} + \underbrace{n \bullet T3}_{\text{starts}}$$

n = number of starts

T3 = operating hours charged per start

- The stresses due to starts are length-dependent so T3 was MVA-dependent
- The last edition introduced a cooling type factor KTyp as a family of curves per cooling medium (air / hydrogen / water), cooling type (direct / indirect) and MVA. KTyp indicates how the temperature varies between copper and cooling medium

Load changes

- Frequent, large and rapid load changes cause transient temperature differences between different components, may lead to relative displacements and stresses

$$Te = \underbrace{T1 \cdot K1}_{\text{in-service}} + \underbrace{T2 \cdot K2}_{\text{turning-gear}} + \underbrace{n \cdot T3}_{\text{starts}} + \underbrace{\Sigma LCh}_{\text{load changes}}$$

- In 2010 edition, the load-change influence appeared for the first time as an experimental and optional Appendix. The stress due to sudden load changes was considered similar to additional starts, but with a weaker weighting factor
- In 2021 standard, the load-change influence is considered through a load cycle index LK (sum of all load changes evaluated with weighting factors K). 4 load change classes (operating scenarios): small / moderate / increased / large

Sequence of outages

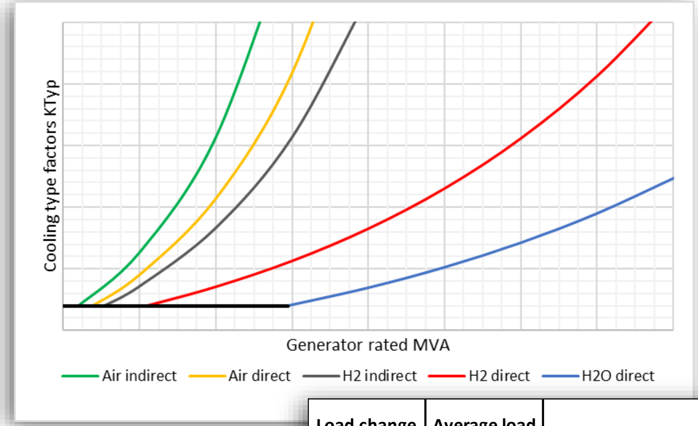
- The equivalent operating hours are used to establish the outage intervals. The sequence of outages is flexible, and the intervals do not have to be identical
- In the 1991 VGB edition, the interval between major outages was:
  - 40,000-60,000 equivalent operating hours,

  but maximum every 10-12 years (depending by generator MVA)
- In the 2010 and 2021 editions, the interval between major outages is:
  - for existing generators 50,000-70,000 hours, dependent on actual condition
  - for new machines up to 80,000 hours (up to 100,000 if contractually agreed)

  but maximum every 12 years
- First outage of new machines: preferably before the warranty expires

VGB editions compared

- Comparison made between 2010 guideline (without load change consideration) vs. 2021 standard (with load change contribution)
- The equivalent hours have been calculated for 12 real sample turbo-generators, during a period of 10 years (2012-2021)
- Sample generators have various rated powers, different cooling types for stator and rotor, and diverse load change classes (load cycle index)
- Real operational data used: service hours, turning-gear time and number of starts



Load change class	Average load cycle index	Power plant operation scenario
1	LK=45	Small load changes e.g. nuclear plants
2	LK=120	Moderate load changes e.g. coal plants, combined cycle plants **This is the most common class**
3	LK=240	Increased load changes e.g. fossil plants, combined cycle plants
4	LK=350	Large load changes, e.g. e.g. peak load plants

VGB editions compared

Nr	Unit name	Generator manufacturer	Gen rated MVA	Operation scenario Load change class	Stator cooling	Rotor cooling	Service T1 hours	Turn-gear T2 hours	Starts n	Load index LK cycles/year	VGB 2010 Equivalent Te hours	VGB 2021 Equivalent Te hours	VGB 2021/ /VGB 2010 Te/Te ratio %
1	RT4	ABB	650.0	Moderate load changes	H_2O dir	H_2 dir	68440	3700	74	120	71021	82317	**116%**
2	OR5	GE	647.0	Moderate load changes	H_2O dir	H_2 dir	64547	3600	72	120	67052	77675	**116%**
3	RT2	Westinghouse	647.0	Moderate load changes	H_2O dir	H_2 dir	66203	5650	113	120	70134	81145	**116%**
4	HA3	Siemens	550.0	Moderate load changes	H_2O dir	H_2 dir	68937	16064	437	120	81022	92063	**114%**
5	ES3	Siemens	320.0	Moderate load changes	Air indir	Air dir	49854	19700	394	120	60019	73483	**122%**
6	ES1	GE	294.0	Moderate load changes	H_2 indir	H_2 indir	64967	20033	447	120	75546	88540	**117%**
7	ES8	Parsons	269.0	Increased load changes	H_2O dir	H_2 dir	28268	47050	941	240	51226	59047	**115%**
8	ES2	Alstom	175.0	Moderate load changes	Air indir	Air dir	64967	20033	447	120	74153	85235	**115%**
9	GZ12	Siemens	173.0	Large load changes	Air indir	Air dir	12442	72558	2072	350	49973	67079	**134%**
10	ES4	Brush	164.7	Moderate load changes	Air indir	Air indir	49854	19700	394	120	58337	68968	**118%**
11	HG6	GE	148.5	Increased load changes	H_2 indir	H_2 indir	37780	47220	5628	240	100910	132668	**131%**
12	ZF2	GE	133.8	Large load changes	H_2 indir	H_2 indir	3665	46200	924	350	22771	27568	**121%**

- The equivalent hours calculated by VGB 2021 are consistently higher (by 14%-34%) than those by VGB 2010, leading to more frequent outages
- The change is mostly a result of considering now the influence of load-changes

Conclusions

- In today situation of flexible operation and cyclic duty it may be very difficult to implement the outage intervals originally recommended by OEMs
- It is suggested to consider the use of common outage interval rules, applicable to any generator / operating regime, preferably based on published standard
- 10 years experience accumulated with VGB equivalent hours method
- VGB standard is not flawless, it may need additional aspects to be addressed
- The 2021 edition of VGB standard includes a new term for load-changing influence - may lead to increased equivalent hours, decreased outage intervals
- It is necessary to check the harmonization of generator outage with turbine outages and other restrictions (like insurance company or LTSA contract)

Thank you!

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