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Residual life concepts applied to HV SF_6-gas insulated switchgear considering tightness

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Content

- Introduction
- Determinant factors for SF_6-tightness in the past and today
- Aged equipment and residual life-time
- SF_6-monitoring
- Characteristics of SF_6-leaks
- Maintenance strategies
- Maintenance activities
- User experience
- SF_6-GIS concepts regarding tightness
- Conclusion

Introduction
More than 40 years of operational life-time experience

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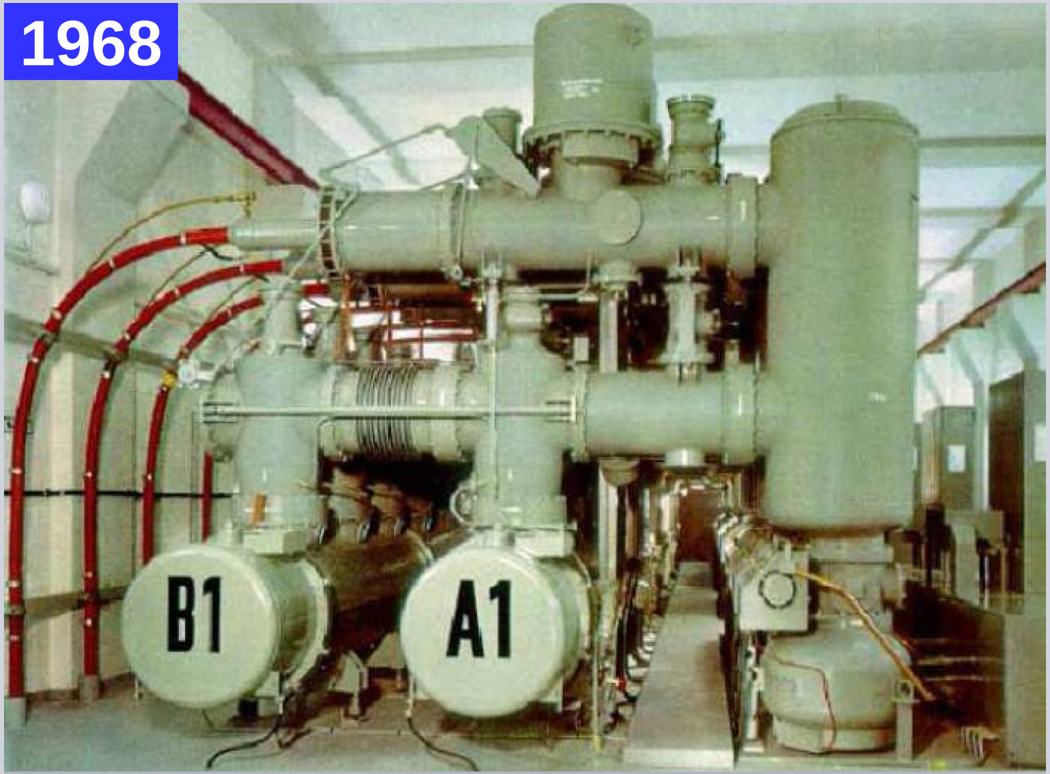

Since more than 40 years in service
Berlin, UW Wittenau, Vattenfall Europe, 123 kV, 31.5 kA

State-of-the-art
145 kV, 40kA GIS

The equipment is gastight

Determinant factors for SF_6-gas tightness and therefore a major factor for residual life of electric power equipment

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- **Design**
- **Material**
- **Type testing**
- **Production and installation/commissioning**
- **Operation, maintenance, service**
- **International standards**

......and trained people for the development of following generation of new equipment as well as experienced people, because of the expected long life-time of the electric power equipment

Equipment design – material
SF_6-Tightness of aluminium vessels

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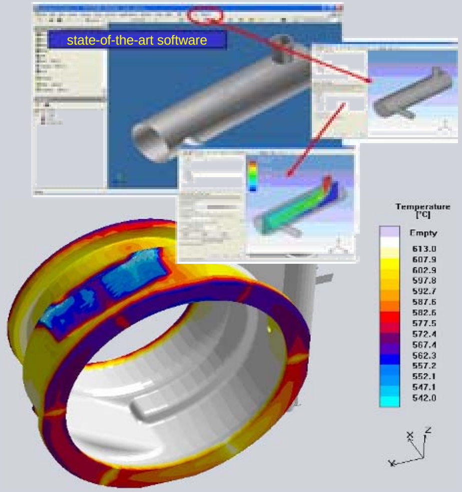
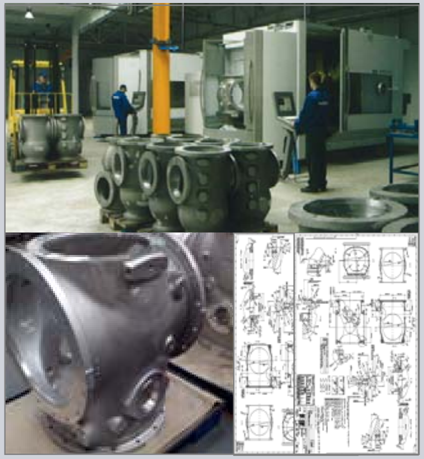


Design

Casting



Machining

Painting

- State-of-the-art production
- Process optimization
- Reliable partner

→

- **Best quality**
- **Decade-long tightness**

Beside requirements on SF_6-tightness, pressure vessel regulations apply as well

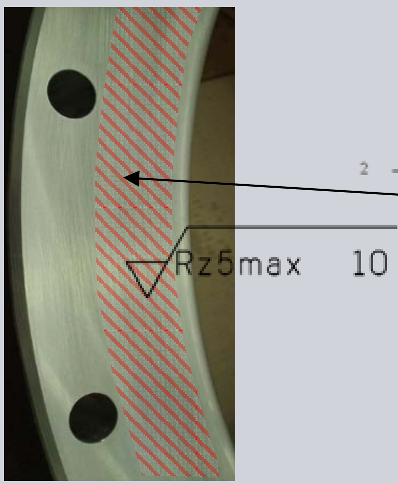
Equipment SF_6-tightness
Routine testing of vessels

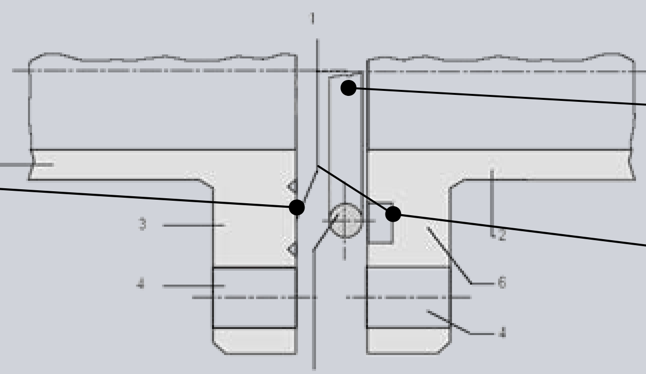
Automatic integral gas tightness routine test of complete switchgear vessels with Helium (instead of SF_6) guarantees the highest tightness

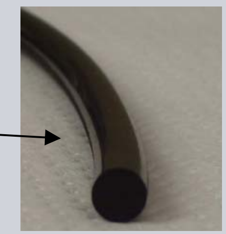
Sealing systems
Design and material

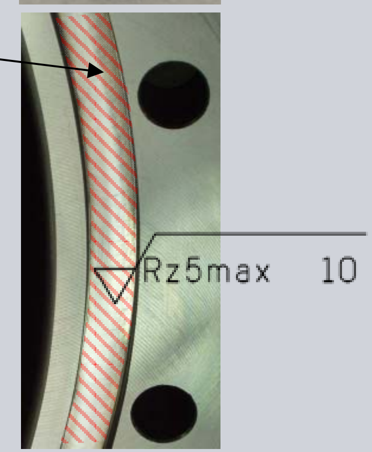
O-ring	→	Material
O-ring	→	Level of filling / pressing
Sealing- / groove surface	→	High quality of the surface
Flange surface	→	Corrosion protection

Static SF_6-sealing systems









1. **Sealing- / groove surface**
2. **Pressure vessel**
3. **Flange with sealing surface**
4. **Bolt hole**
5. **O-ring**
6. **Flange with sealing groove**

Sealing systems like this assure the tightness of the GIS for decades. However, especially for outdoor equipment this must be supported by an effective corrosion protection

Sealing systems
Design and material

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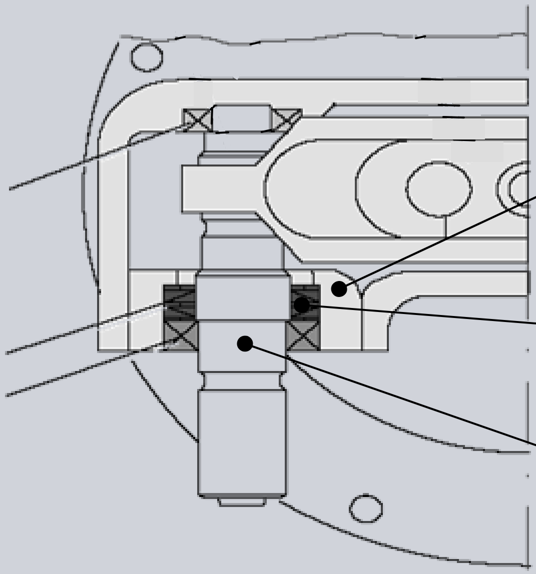
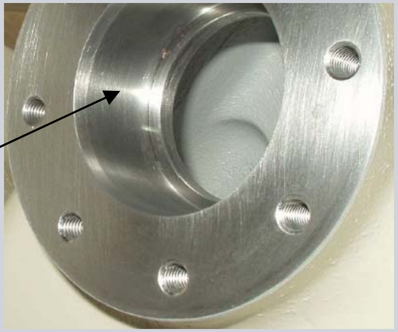
Dynamic SF_6-sealing systems





1 **Bearing**
2 **Bearing**
3 **Radial sealing packages**

Radial sealing packages are an import factor for SF_6-tightness of the GIS

High voltage GIS
Type testing on SF_6-tightness

Tightness tests of complete GIS and also components according to IEC are part of the quality assurance process (closed pressure systems)

The tightness of SF_6-GIS can be confirmed nowadays during type testing (integral measuring process with state-of-the-art measurement devices) in the range of <0,01%/year/gas compartment compared with the required <0,5%/year/gas compartment in the relevant standards

Component design development
Cast-Resin partitions

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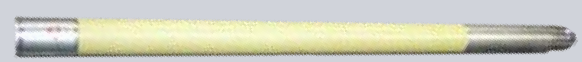
Beside „external“ SF_6-tightness „internal“ SF_6-tightness (between 2 gas compartments) has to be assured as well



Production and testing in the factory (including gas permissible partitions and other insulating parts)

Production, installation & commissioning
SF_6-Leakage detection

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In the factory

- All assembled connections
- Assured leakage rate of <0,5%/a/gas compartment

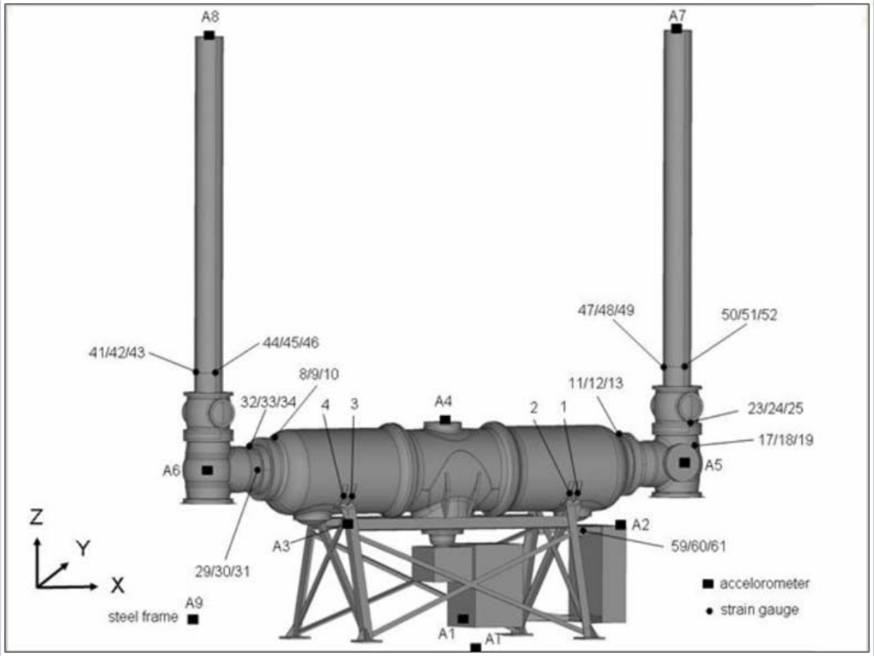
On site

- All made connections
- Assured leakage rate of <0,5%/a/gas compartment

Special care has to be taken during transportation from the factory to the site

SF_6-Tightness – special requirement Seismic qualification

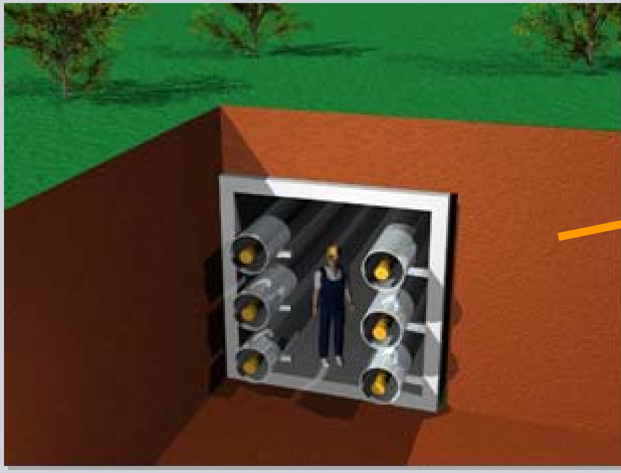
Even under severe conditions like earth quakes the SF_6-tightness has to be assured for functional and environmental reasons

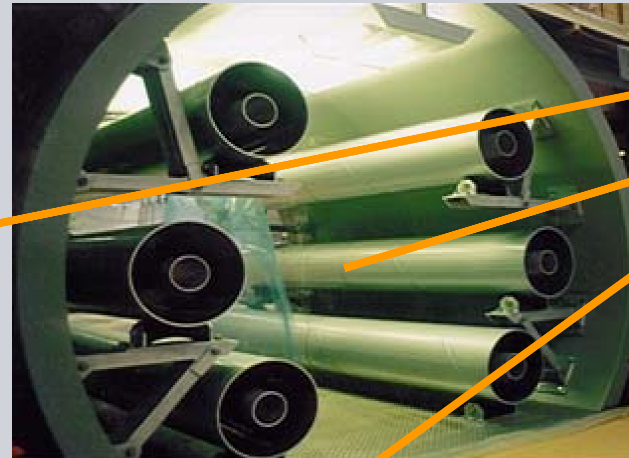


8DQ1-550kV-63kA-5000A-50/60Hz

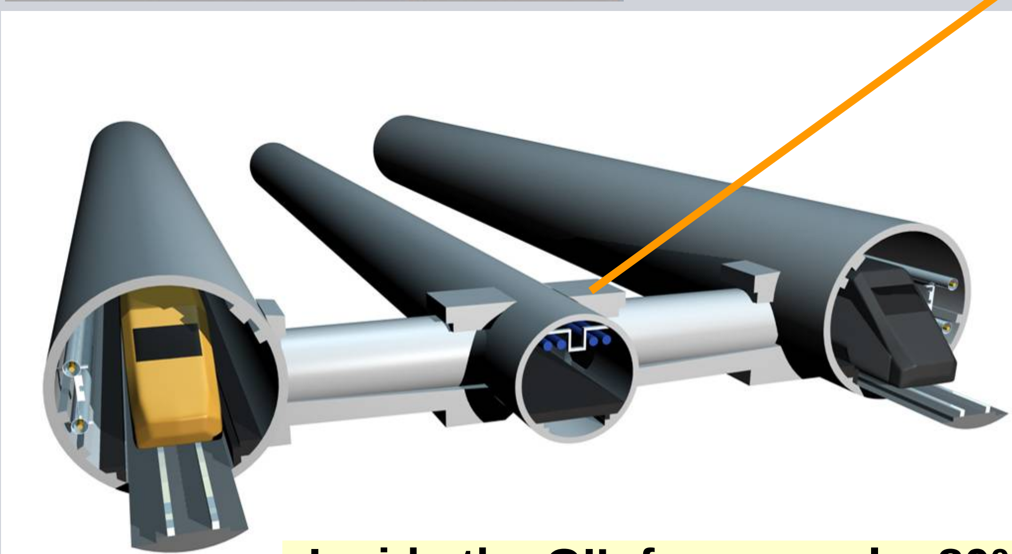
Test lab CESI, Bergamo/Italy

SF_6/N_2 Tightness – special requirement
Gas Insulated Lines





Experience on SF_6-tightness in various solutions for GIL transmission projects



Inside the GIL for example: 80% N_2 & 20% SF_6

Aged equipment
SF_6-Tightness and residual life-time of equipment

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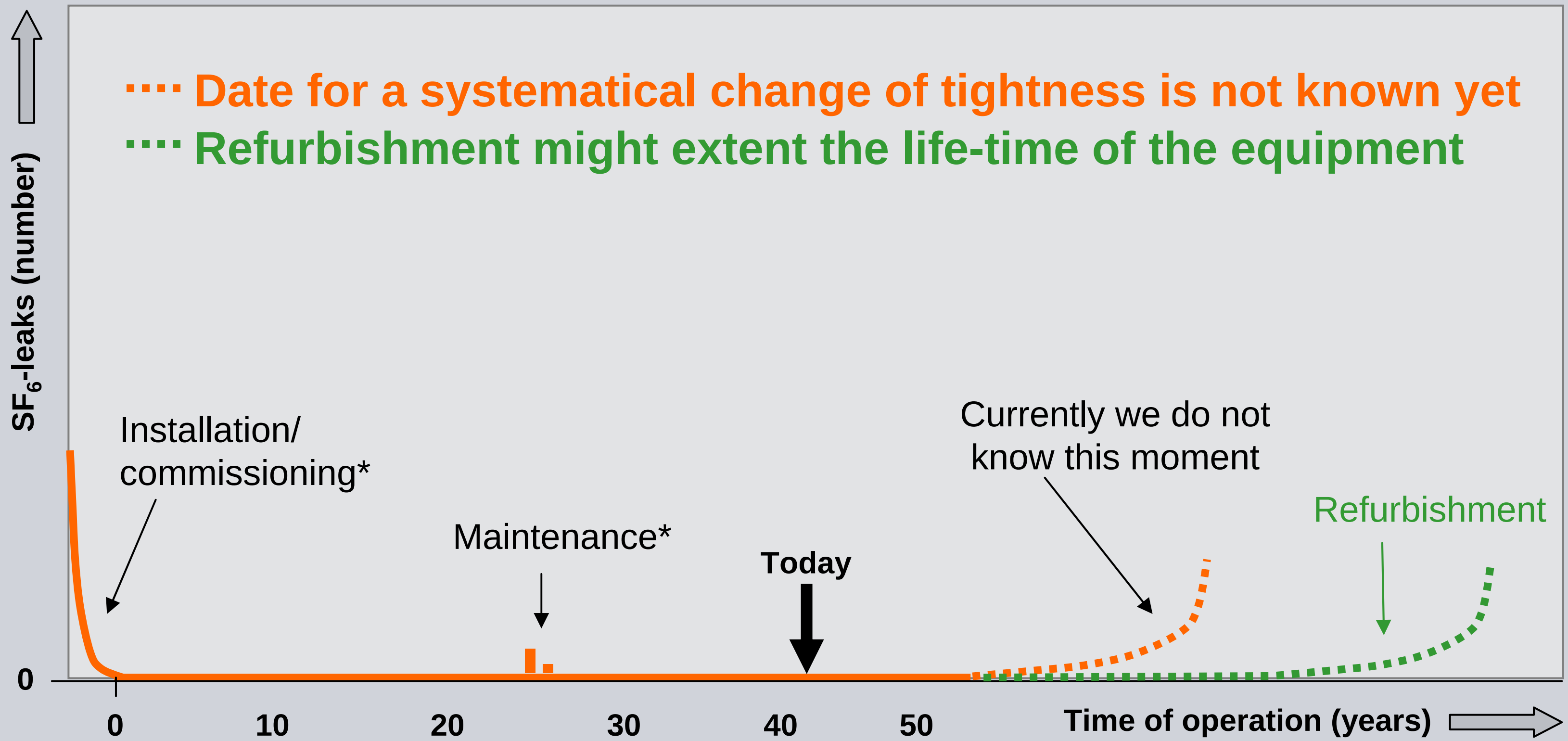

*) Usually transportation issues and handling irregularities on site

Today all installed equipment is still gas tight

SF_6-Monitoring

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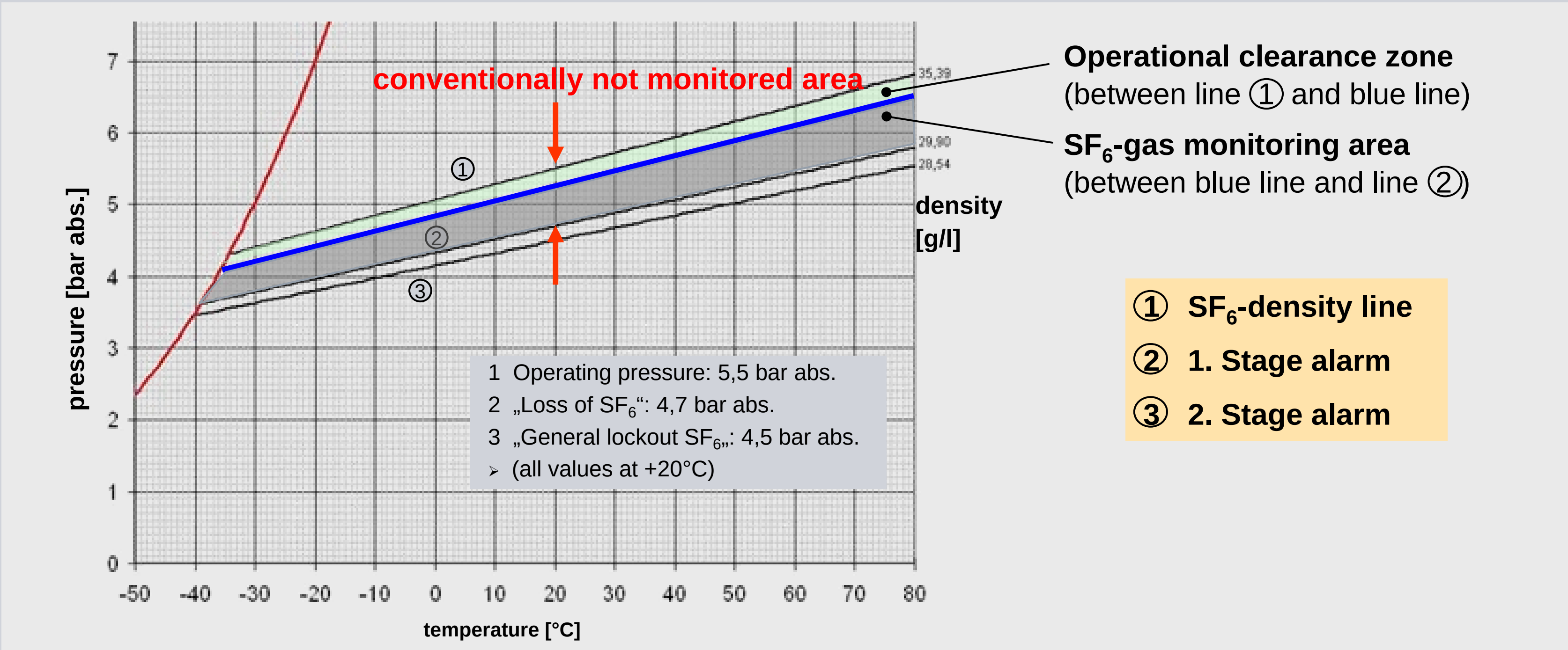

- **The alarm values are based on the electrical functionality of the equipment and used for SF_6-leakage indications as well**

- **A SF_6-gas monitoring system can be used for early leakage detection and trend analysis of leakage size**

SF_6-Gas monitoring system
Density, trend curves, trend forecast

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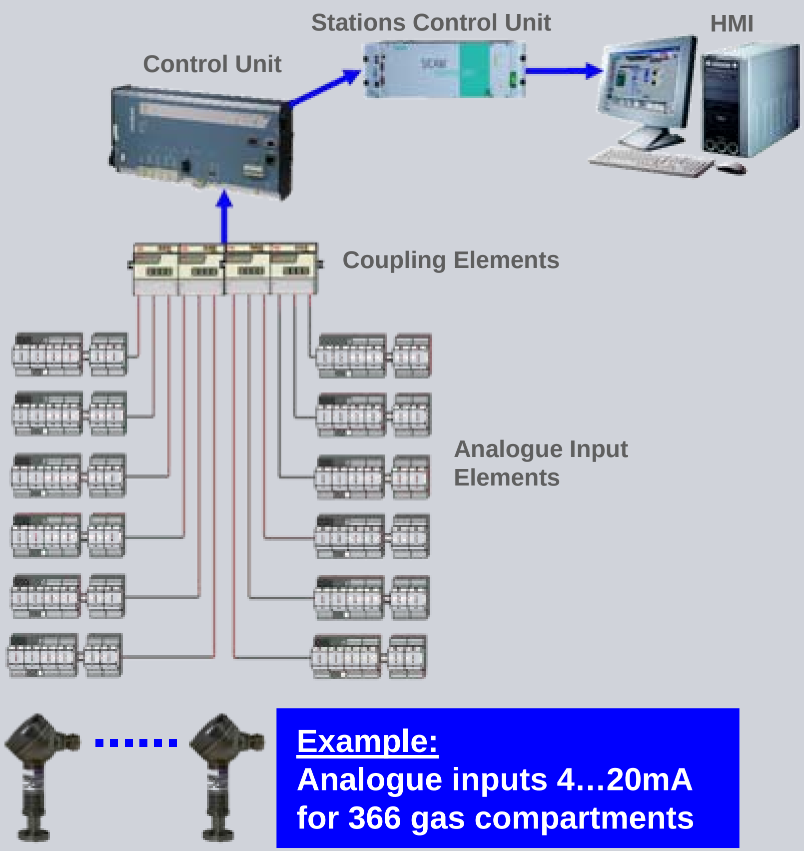
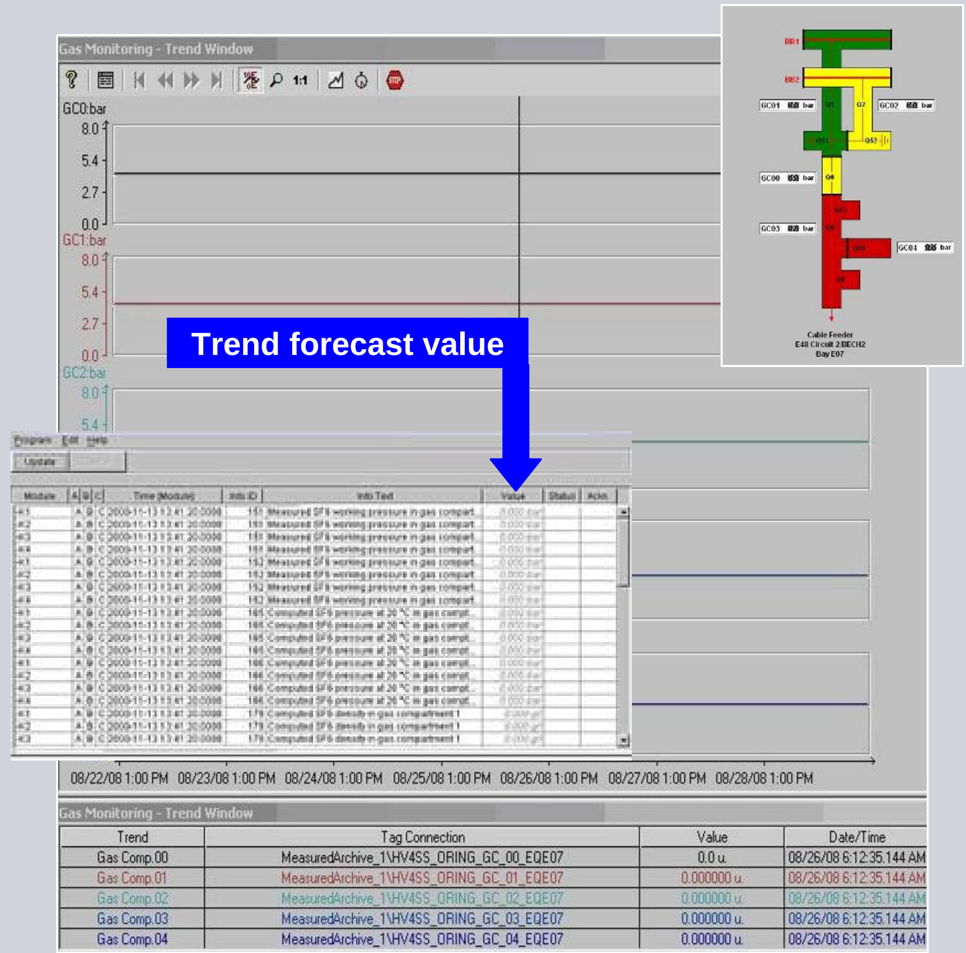
Hardware-structure (example)



(Optional: density calculation of pressure and temperature)

HMI+ trend curves (example)



Characteristics of SF_6-leaks (appear seldom)

- Processing usually very slow (individual cases like wrong mounted O-ring, cast aluminium vessel)
  ➔ ***Enough time to react before 1st stage or 2nd stage alarm appears***

- Processing very fast (individual case) as component failure, ambient circumstances, malicious damage
  ➔ ***Pressure inside gas compartment drops to ambient pressure level***

- Due to corrosion in case of insufficient protective measures during installation (outdoor)
  ➔ ***Can process as a little or big leak***

- Due to „ageing“
  ➔ ***At this moment in time not reached***

Regardless the type of SF_6-leak, it has to be repaired as soon as possible after detection

Maintenance strategies in general for SF_6-HV switch gear

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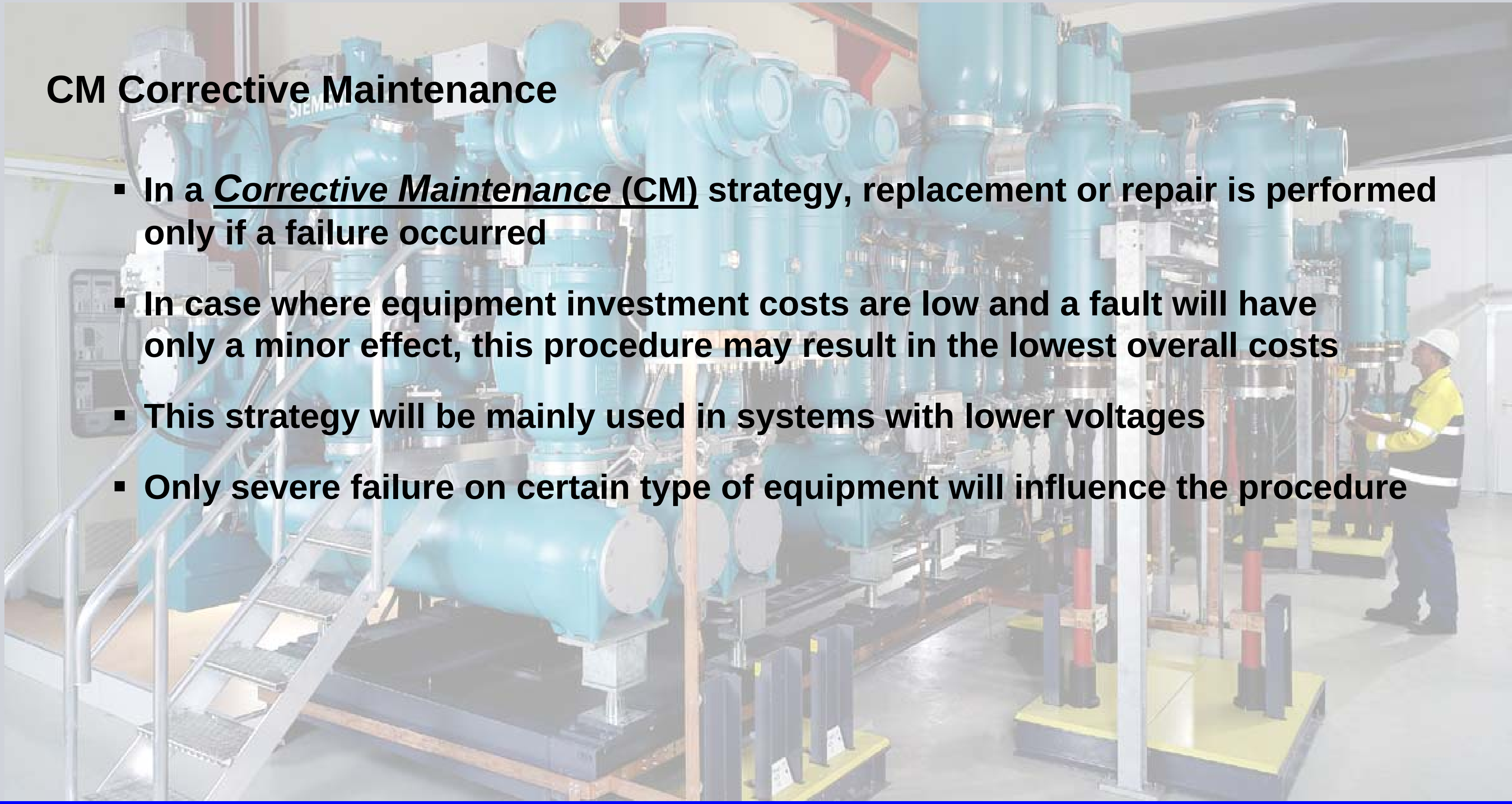
Aim of all maintenance activities: maintenance costs should be minimized, the intervals between maintenance enlarged, the availability of the equipment increased, environmental issues considered → SF_6

- **Maintenance steps:**
  - Inspection: determining and assessing the actual condition
  - Servicing: preserving the desired condition
  - Repair: restoring the desired condition
  - Replacement: replacing equipment or systems which are no longer usable

- **Several maintenance strategies are used in electrical systems:**
  - Corrective
  - Time-based
  - Condition-based
  - Reliability-centered
  - Risk-based

Maintenance strategies



CM Corrective Maintenance

- In a ***Corrective Maintenance* (CM)** strategy, replacement or repair is performed only if a failure occurred
- In case where equipment investment costs are low and a fault will have only a minor effect, this procedure may result in the lowest overall costs
- This strategy will be mainly used in systems with lower voltages
- Only severe failure on certain type of equipment will influence the procedure

Not recommended for maintaining of SF_6-tightness

Maintenance strategies

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CM Corrective Maintenance

TBM Time Based Maintenance

- **A *Time Based Maintenance* (TBM) strategy featuring predefined intervals rooted in empirical feedback, where components are replaced after a specified period of use, has been practiced as the usual maintenance strategy in electrical power systems for many years**
- **This approach generally produces satisfactory results**
- **It will not, however, be the most cost-effective option in all cases, since the components will usually not remain in operation up to the end of the life-time which is possible**

Partly recommended for maintaining of SF_6-tightness

Maintenance strategies

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CM Corrective Maintenance

TBM Time Based Maintenance

CBM Condition Based Maintenance

- **Since some years, however, there has been a developing shift away from TBM and towards *Condition Based Maintenance* (CBM)**
- **CBM is driven by the technical condition of the components**
- **Under this approach, all major parameters are considered in order to determine the technical condition with maximized accuracy**
- **For this reason detailed information via diagnostic methods or monitoring systems should be available**

Recommended for maintaining of SF_6-tightness

Maintenance strategies

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CM Corrective Maintenance

TBM Time Based Maintenance

CBM Condition Based Maintenance

RCM Reliability-Centered Maintenance

- **A fourth strategy, which additionally include a reliability-based component, is in use**
- **The aim of this approach is to include the influence on the importance of the equipment in the network and the actual condition of the equipment**
- **A maintenance strategy is referred to as *Reliability-Centered Maintenance* (RCM) and it has to be noticed that this RCM-method is different considering other RCM applications which consider equipment only**

Partly recommended for maintaining of SF_6-tightness

Maintenance strategies

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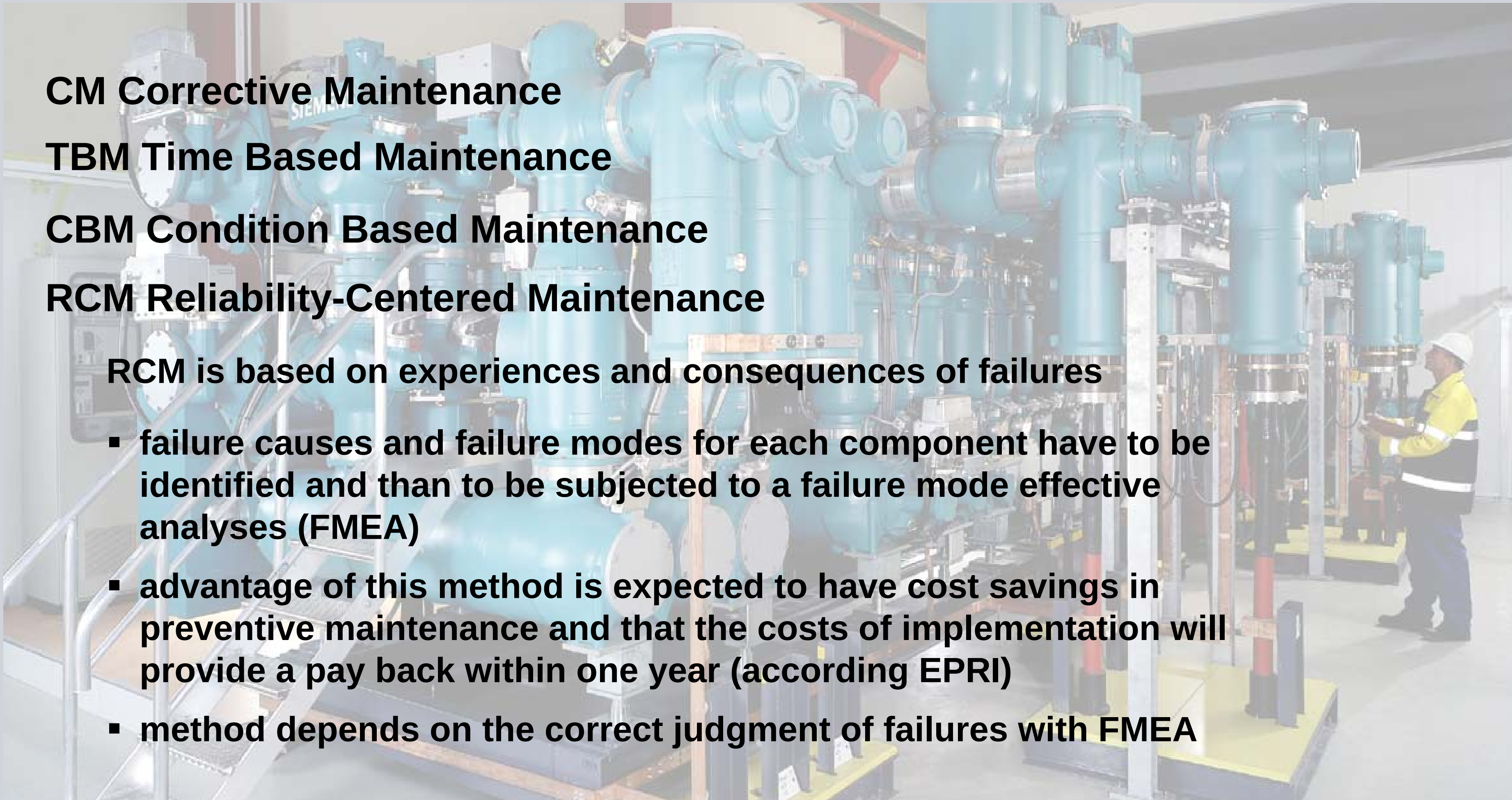

CM Corrective Maintenance

TBM Time Based Maintenance

CBM Condition Based Maintenance

RCM Reliability-Centered Maintenance

RCM is based on experiences and consequences of failures

- **failure causes and failure modes for each component have to be identified and than to be subjected to a failure mode effective analyses (FMEA)**
- **advantage of this method is expected to have cost savings in preventive maintenance and that the costs of implementation will provide a pay back within one year (according EPRI)**
- **method depends on the correct judgment of failures with FMEA**

Partly recommended for maintaining of SF_6-tightness

Maintenance strategies

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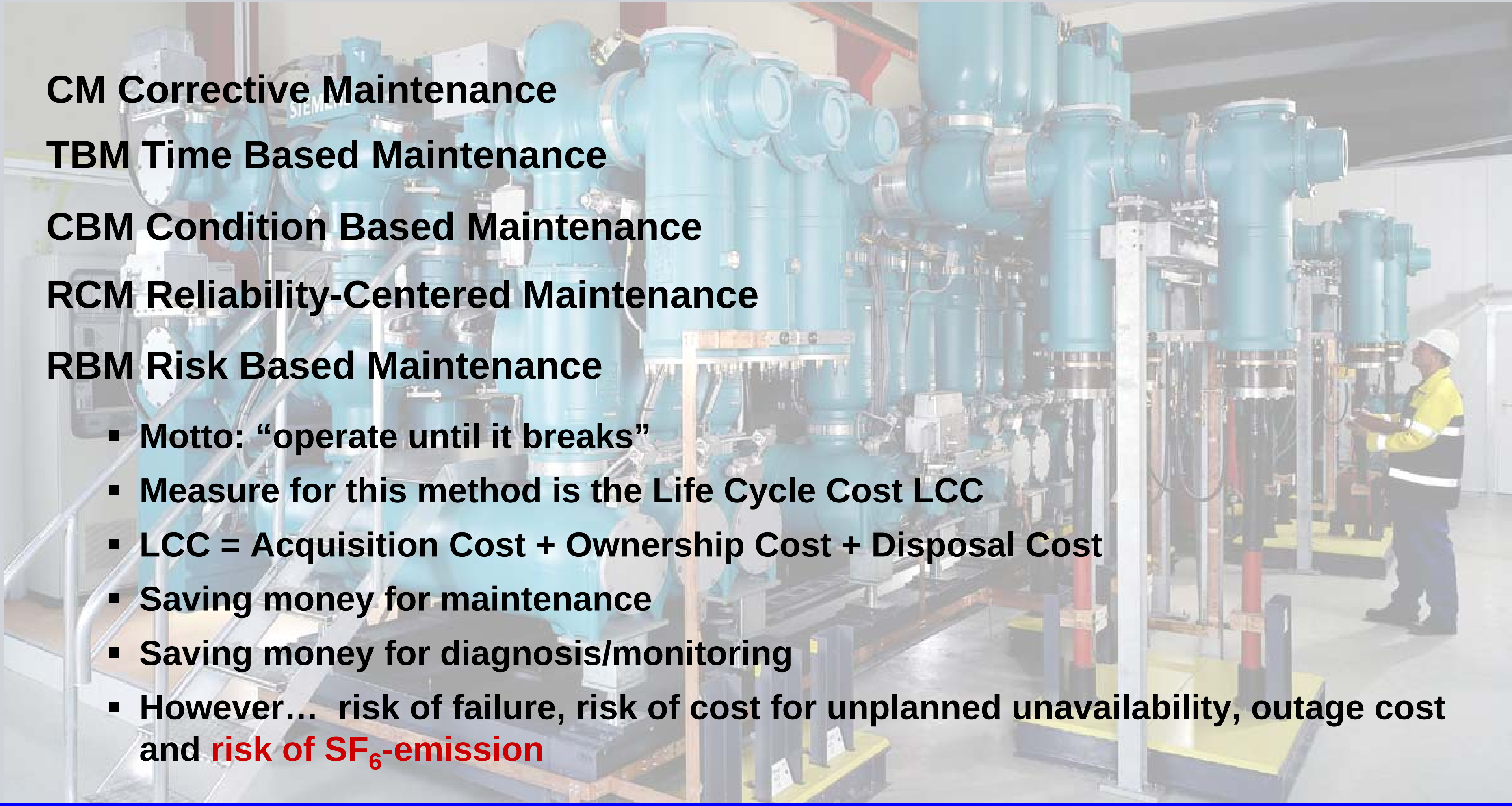

CM Corrective Maintenance

TBM Time Based Maintenance

CBM Condition Based Maintenance

RCM Reliability-Centered Maintenance

RBM Risk Based Maintenance

- **Motto: “operate until it breaks”**
- **Measure for this method is the Life Cycle Cost LCC**
- **LCC = Acquisition Cost + Ownership Cost + Disposal Cost**
- **Saving money for maintenance**
- **Saving money for diagnosis/monitoring**
- **However… risk of failure, risk of cost for unplanned unavailability, outage cost and risk of SF_6-emission**

Not recommended for maintaining of SF_6-tightness

Maintenance strategy to assure SF_6-tightness and to extend the life-time of the equipment

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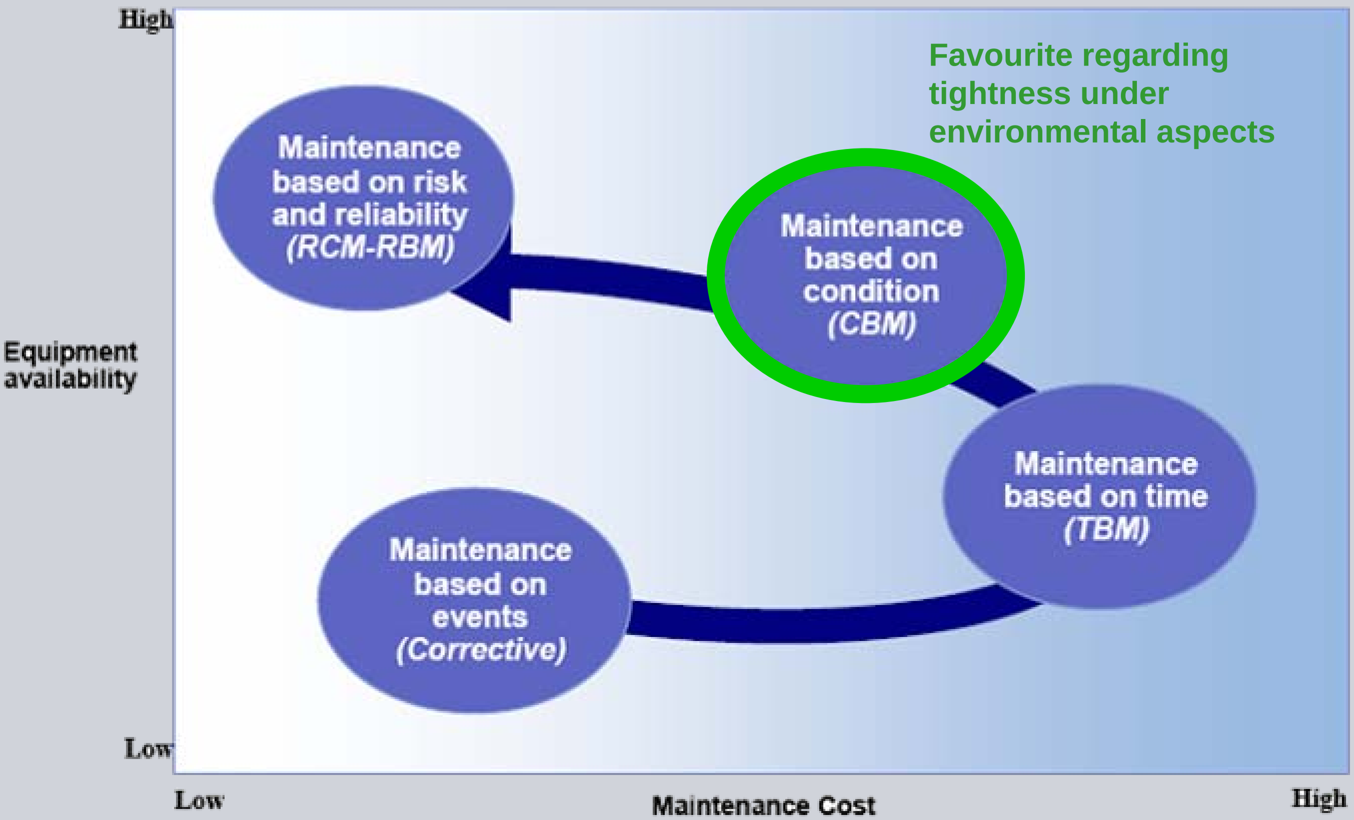

Implementation of maintenance strategy for the equipment -in general- and tightness in particular

➔ **Gives guidance to end of life decision and has a significant impact on the life cycle cost of the assets**

Maintenance activities to assure SF_6-tightness

- **To be checked <u>quantitatively</u>: SF_6-pressure gauge, SF_6-dew point, SF_6-acidity, SF_6-density/pressure switch settings, SF_6-trend analysis monitoring**
- **To be checked <u>visually</u>: bursting disks, any type of SF_6-gas piping, corrosion at bolted flange enclosure joints and other SF_6-related components, particularly on outdoor equipment, damaged or degraded seals, adherence of dust or other foreign material to seals, porosity in enclosure castings or welds, painting**
- **Avoid openings, take care when opening measuring connections or gas compartments (e.g. for filter material change)**
- **Use original spare parts only**
- **Contact OEM for further information/clarification**

User experience

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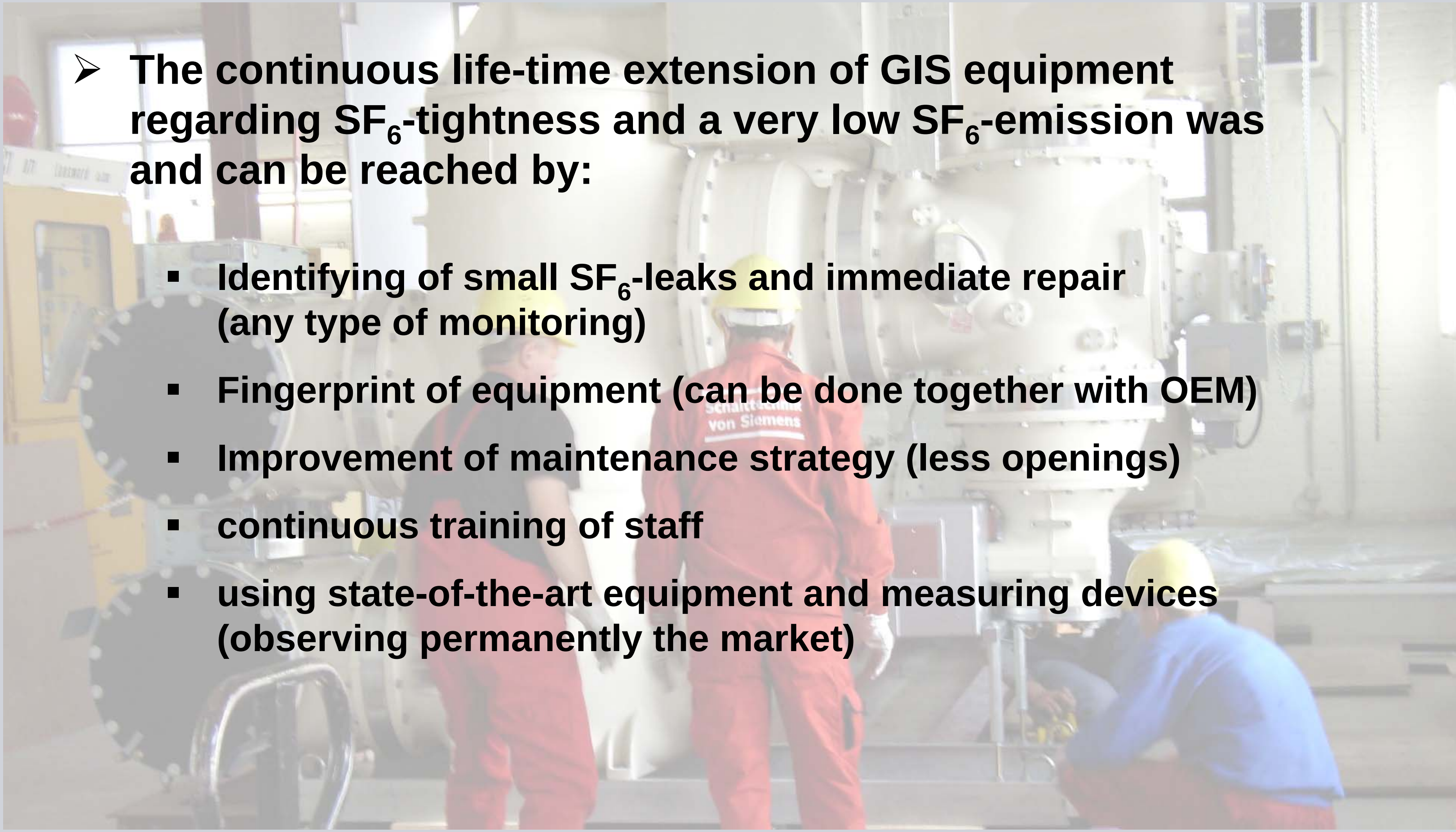

- **The continuous life-time extension of GIS equipment regarding SF_6-tightness and a very low SF_6-emission was and can be reached by:**
  - **Identifying of small SF_6-leaks and immediate repair (any type of monitoring)**
  - **Fingerprint of equipment (can be done together with OEM)**
  - **Improvement of maintenance strategy (less openings)**
  - **continuous training of staff**
  - **using state-of-the-art equipment and measuring devices (observing permanently the market)**

SF_6-GIS-concepts for life-time extension regarding tightness and low SF_6-emission

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In the past	State-of-the-art GIS technology
Large gas compartments	Optimized gas compartments
Short maintenance intervals (frequent opening of gas compartments)	2 openings during expected life-time: once after 25 years of service, once during end-of-life procedure after approximately 50 years
Limited SF_6-handling instruction	Detailed explained SF_6-handling instruction and regulations
SF_6-maintenance units with a minimum SF_6-recovering pressure of 50-100 mbar	High power SF_6-maintenance units with SF_6-recovering pressure till 1 mbar
Insensitive SF_6-leakage detectors	Sensitive SF_6-leakage detectors to find smallest leaks
SF_6-measuring instruments without collecting the used gas	SF_6-measuring instruments collecting the gas are now offered
Fundamental tests and implementation of new production processes	Using Helium for leakage detection where possible (e.g. housing leakage test)

Since the implementation of the GIS-technology almost 5 decades ago, manufactures have supported the extension of the life time of installed equipment and continuously improve the design of the GIS

Conclusion

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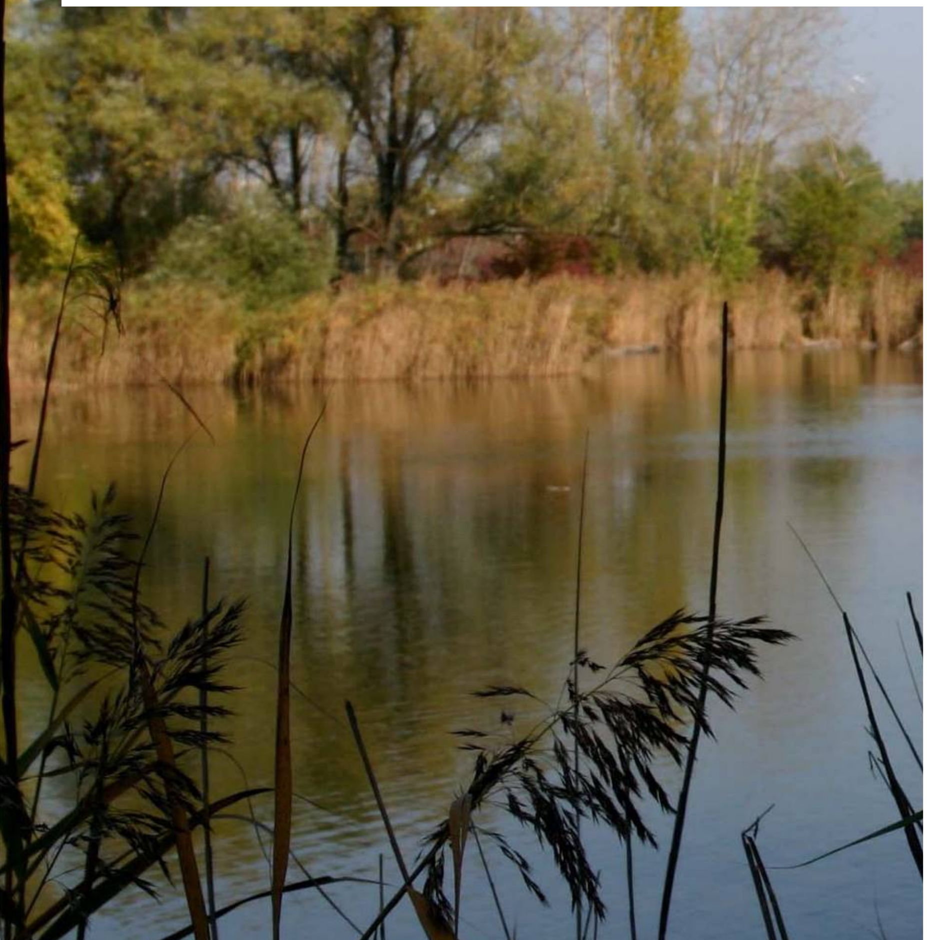
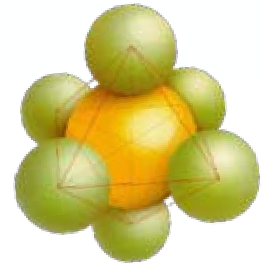
- Implementation of adequate maintenance strategy for aged equipment
- Evaluation of each SF_6-leakage for systematical or individual failure
- Gas tight equipment and low SF_6-emission reduce life-cycle costs
- Residual Life of equipment goes in line with low SF_6-emission
- For end-of-life procedures, SF_6 has to be kept in a closed cycle

Thank you for your attention!





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