RELIABILITY AND LONG TIME BEHAVIOUR OF MV-DISTRIBUTION SWITCHGEAR IN SEVERE ENVIRONMENTAL CONDITIONS - EXAMINATION OF SF\textsubscript{6}-INSULATED RING MAIN UNITS (RMU) UP TO 20 YEARS IN SERVICE.

B. I. Oftedal, Siemens AS Norway - Email: Bjoern.Oftedal@siemens.com
H. Späck, Siemens AG Germany - Email: Helmut.Spaecck@siemens.com

Summary

SF\textsubscript{6} insulated RMUs are designed and tested for operation in severe environmental conditions and have proven its reliability on thousands of units in service since 1983. International standards give only limited recommendations of how to test switchgears for special and severe environmental conditions and which risks have to be considered for an expected life time of more than 30 years.

To accumulate field experience, tests are carried out on switchgears which were operated up to 20 years in different regions in the world. Such tests include e.g. dielectric tests, mechanical tests or dew point measurements inside the SF\textsubscript{6} compartments.

One of the examined 24kV-RMU was in service continuously from 1985 to 2000 on the south west coast of Norway with salty atmosphere and has been used since 2000 also in sandy and traffic atmosphere after moving in a substation for temporary installation.

The investigations were performed in July/August 2004 in the Testing Laboratory Medium Voltage Frankfurt am Main, Germany.

In detail, the following tests were carried out:
- Checking the condition of the gas.
- Checking the condition of the electrical contacts.
- Dielectric tests including partial discharge measurement.
- Mechanical tests.
- Visual inspection on the SF\textsubscript{6}-vessel and mechanical parts, e.g. for corrosion.

The examination showed a good condition of the primary circuit, the SF\textsubscript{6}-tank and the other materials. The insulating-gas itself has got minimal humidity with a dew point of less than -30°C.

Out of this examination we can derive a conclusion that the RMU will have an expected life time which is much longer than 30 years. It also shows that the chosen design and the intensive aging tests, e.g. according to IEC 60932 are suitable to prove the long time behaviour for switchgear in severe environmental conditions.

Introduction

Gas-insulated medium-voltage switchgear is a long-life capital good and an integral part of modern power distribution systems.

This type of switchgear is an environmentally compatible product in comparison with conventional switchgear, mainly because of:
- small switchgear design,
- no maintenance is required,
- long life time and
- minimal requirements for the installation room.

RMUs [1] came into the market in 1983 and have been in service under severe environmental conditions in many countries e.g. in Indonesia, the Middle East or in Norway since then.

RMUs for long time operation in severe environmental conditions have to be specially designed and tested. International standards give only limited recommendations of how to test the switchgear for special and severe environmental conditions and which risk have to be considered.

Therefore it is necessary
- to have a proper design with less inherent risks,
- to use excellent and proven materials and manufacturing techniques, even though it is partly more expensive,
- to perform additional tests to verify the long time behaviour of switchgear and to compare the results with field experience,
- to control and improve the design and manufacturing as a continuous process.

Some of the additional tests are:
- Measurement of permeation of water vapour through insulating and tightening materials.
- Dew point measurements at switchgears after years of operation in severe environmental conditions.
- Temperature cycle test on bushings and other insulating parts for investigation of internal mechanical stresses.
- Ageing tests according to IEC 60932 [6] for complete switchgear panels.
- Intensified temperature/humidity cycle tests for corrosion investigation on mechanical parts.
Classification of environmental conditions and environmental tests in the standards

Basically different degrees of environmental conditions are described in IEC 60721 [4]. On the other hand environmental tests are defined in IEC 60068 series [5]. But at the moment there is no standard to recommend environmental and climatic tests to evaluate the usability of medium voltage switchgears in severe environmental conditions.

Gas insulated RMUs are designed in accordance with IEC 62271-200 [3] (former IEC60298).
This includes the common requirements of IEC 60694 [2], especially normal “indoor service conditions” with occasional dewing inside the switchgear.

For severe environmental conditions, exceeding the limits of IEC 60694, these conditions have to be agreed between the manufacturer and the user. Such severe conditions which are typical for RMUs in transformer substations could be
- tropical climate with high humidity,
- high temperatures, small animals,
- frequent dewing or
- salt fog at coastal areas.

The main effect of these severe environmental conditions is an accelerated ageing of the installed switchgear.

IEC 60932 [6] describes two procedures for testing the ageing behaviour of medium voltage switchgear used in severe climatic conditions: penetration test and ageing test. Depending on the test result, the switchgear is classified according to "design classes". The highest level is "design class 2".

During the temperature/humidity cycles the test object is energized by the rated voltage and the leakage current is measured. The standard stipulates that no breakdown should occur. Before and after the temperature/humidity cycles characteristic mechanical values are measured to evaluate the functional performance of driving mechanisms of switching devices.

If the switchgear has passed the ageing or penetration test level 2 and is classified as "design class 2", the switchgear is assumed to operate satisfactorily in severe environmental conditions.

Because of the difficulties to design switchgear for "design class 2" and the limited necessity of such switchgear in the past, IEC 60932 was not applied very often.

According to the customer requirements, different manufacturers have carried out their own additional environmental tests which simulate single or combined environmental duties. The problem to be solved is to transfer the test results of the accelerated climatic or ageing tests to real life time expectation. A good method to do this is to compare the test results with observed real ageing processes.

Risks of operation for medium voltage switchgear in severe environmental conditions

Deterioration of insulation
From the past the most important risk is the deterioration of the insulation which can be caused by
- ageing of the insulating materials due to high humidity and pollution,
- appearance of cracks in insulating parts,
- changes in conductive screening layers or
- permeation of water vapour into the gas compartment through sealing materials.

These phenomena have not only to be considered in severe environmental conditions, they have to be considered in normal operating conditions, too. Long time partial discharges and leakage currents destroy the insulation and have to be avoided.

Reliability of driving mechanisms
The reliability of driving mechanisms of the switching devices is mainly affected by corrosion effects and by wear of mechanical parts, e.g. fatigue of springs. Statistics show that mechanical defects are one of the most important reasons for outages of switching devices. Avoiding this corrosion shall be considered as an essential requirement in order to apply medium voltage switchgear in severe environmental conditions.

Tightness of gas insulated switchgear
The tightness of gas insulated switchgear is characterized by leakage rates and diffusion effects. The leakage rate of the switchgear should be as small as possible.

If the switchgear has gaskets, the interaction of the different materials in the tightening system needs special consideration. Corrosion in very small slits must be avoided. If gaskets are used for tightening of moving parts it has to be ensured that no untightness appears when moving these parts after years of no operation.

All polymeric insulating or tightening materials have certain permeation behaviour for different gases, like water vapour. This permeation is driven by the relative high water vapour pressure outside the gas compartment and the low water vapour pressure inside the compartment. To avoid inadmissible dewing inside the gas compartment, resulting in deterioration of insulating properties, the permeation of water should be minimized.

Therefore it is important to minimize the number and length and the permeation area of the gasket arrangements and to use material with very low permeation coefficients for water vapour for all components of the SF6 enclosure.

Experience shows that this problem was not known during introduction of the first medium voltage gas insulated switchgear. The gas compartment was tight for SF6 but a continuous increase of humidity inside the gas compartment had been observed.
Activities to eliminate risks of operation of switchgear in severe environmental conditions

Some of the general activities are:
- Designing and testing of the switchgear with experienced engineers and approved processes.
- Use of proven material and manufacturing methods.
- Periodically repeated tests on switchgear panels or components besides the routine tests, to ensure the high quality level.
- The analysis of faults is used to improve the switchgear design and to derive means to avoid faults in the future.
- Accumulating field experience by inspection or testing of switchgear which was in service for many years in different regions of the world either in the test lab or on site, e.g. mechanical tests or partial discharge measurements. One unit of RMU type 8DJ10 has been operated in an outdoor installation inside the test lab area in Frankfurt for nearly 15 years and has been checked periodically for electrical and mechanical behaviour.
- Continuous improvement of design and manufacturing methods according to technical advances.

Basic design

Fig. 1 shows the sectional view of a typical 8DJ RMU with the main components.

The heart of the switchgear is the gas-filled “sealed-for-life” compartment with the switching devices, bars, electrical and mechanical bushings. To avoid any tightness problems, the vessel is made of stainless-steel and completely welded without any sealed openings.

Metal bellows are used as mechanical bushings for operating the three-position switch as well as the SF₆ ready-for-service indicator, which is moved by a magnetic system at both sides of the vessel wall. The electrical bushings for cable connections are made of epoxy cast resin and completely welded into the vessel.

The pressure relief device is also welded into the vessel. Even the pipe for evacuating and filling the gas compartment with SF₆ is welded after the tightness test and the filling procedure.

Securing the insulation properties

Besides securing the tightness of the gas compartment and avoiding of inadmissible permeation of water vapour into it, one important task is to minimize internal mechanical stresses within the components of the gasinsulated enclosure. If internal mechanical stresses are superimposed with normal service stresses and ageing, cracks can occur in the insulating components, partly after years. Consequently, partial discharges, break downs and leakage may occur.
Therefore the gas compartment is made of tough stainless steel with bushings containing a minimum of cast resin. The selected special composition of cast resin, the automatic mixing process and several routine tests after manufacturing ensure that components have very low internal mechanical stresses.

Some of the routine tests are
- X-ray test for cracks and shrinking holes,
- partial discharge measurement,
- temperature cycle test from −40°C up to +80°C on a certain amount of bushings.

Partial discharge measurements
Partial discharges within polymeric materials and on surfaces can cause electrical treeing and deterioration of insulating properties (electrical ageing). The current knowledge about the effects of partial discharges is not sufficient for standardizing common technical limits.

Therefore there has been set up an own standard with the basic requirement that during normal service no partial discharge should occur.

<table>
<thead>
<tr>
<th>Limits for partial discharge rates:</th>
<th>Components</th>
<th>Complete switchgear</th>
</tr>
</thead>
<tbody>
<tr>
<td>at 1.1 (U_r)</td>
<td>(\leq 5)pC</td>
<td>(\leq 20)pC</td>
</tr>
<tr>
<td>at 1.1 (U_r/\sqrt{3})</td>
<td>partial discharge free</td>
<td>(lower than the ground level)</td>
</tr>
</tbody>
</table>

The test procedure is in accordance with IEC 62271-200.

The experience of more than 20 years of gas-insulated MV-switchgear in service confirms that these limits are well chosen from the practical point of view. Compared with standards of other high voltage equipment, e.g. power transformers or instrument transformers, this standard is very demanding.

Ageing test according to IEC 60932
The RMUs have passed this ageing test and are classified as “design class 2”, applicable for severe climatic conditions. At the driving mechanisms of the switching devices no significant corrosion occurred. The moving characteristics of the mechanisms were not changed.

Securing the reliability of the driving mechanism
Since the relevant switchgear standards give no requirements concerning the long time behaviour in severe environmental conditions, these capabilities are verified by
- condensation tests according to DIN 50017,
- condensation tests with \(SO_2\) acc. to DIN EN ISO 6988,
- salt fog test according to DIN 50021,
- intensified temperature/humidity cycle tests similar to IEC 60068-2-30.

The purpose of these tests is to find out the most suitable materials and surfaces for mechanical parts.

On the other hand, the transfer of test results of high duty short time corrosion tests to the long time behaviour of the switchgear cannot be made easily because of special conditions at the different switchgear locations.

RMUs which came back to the factory after years of service at tropical and coastal areas, in substations with water in the cable duct or in open air installation were investigated with regard to corrosion effects.

The results were compared to the above mentioned corrosion tests showing that the most severe climatic duty results from frequent dewing in the switchgear at high ambient temperatures. A common rule of chemistry says that an increase of temperature of about \(10^K\) makes the corrosion speed double.

Derived from experience, there has been defined an intensified temperature/humidity cycle test similar to IEC 60068 series for further improving of the switchgear with
- temperature cycle from -5°C up to +80°C,
- at a relative humidity of 93%
- 12 cycles with a cycle time of 24 hours.

This test was carried out on “normal” and “improved” driving mechanisms with test results as follows:
- Corrosion effects as known from the practical experience of operation in very severe environmental conditions appear after 3 to 5 temperature/humidity cycles.
- After having performed about 12 cycles the corrosion is much stronger than known from real switchgear observation.
- The improved type of driving mechanism at which all parts are zinc-coated and have a special surface treatment do not show any significant corrosion effects after 12 cycles.
- After the temperature/humidity cycle test all investigated improved drives operate without any objections from the test engineers.

Securing the tightness of the gas compartment minimizing the permeation of water vapour
Especially the concept of the “hermetically sealed enclosure” with the completely welded stainless-steel vessels prevents inadmissible diffusion of insulating gas to the outside and ingress of water vapour to the inside.

To ensure the high quality, the following tests are used:
- 100% leakage test with helium of all components before welded in with a permissible leakage rate of \(10^{-7}\)mbarl/s
- Integral leakage measurement with 1 bar helium of the complete gas compartments with a permissible leakage rate of \(10^{-7}\)mbarl/s; this means a pressure reduction of the insulating gas is far less than 0.1 % per year.
- To ensure the stability of the gas vessel due to the daily pressure fluctuations, pressure changing tests with 10 000 load cycles have been carried out on typical arrangements
with a leakage test at the end of the tests.

- Measurements of permeation rates were made with components, e.g. bushings. In order to accelerate the permeation velocity, the test objects were stored in a climatic chamber at a temperature of 80°C and a relative humidity of 85%. This corresponds to a partial pressure of water vapour of about 400 mbar. The permeation coefficient was determined by measuring the pressure rise in the small compartments of the test objects. By means of these test results, the water vapour permeation for e.g. tropical climate can be calculated.

- Dew point measurements were carried out on several panels of 8DJ load break switchgear which came back to the switchgear factory after years of operation. The measured dew points were all below -30°C. The measurements confirm the above mentioned test and calculation results of water vapour permeation.

Examination of a RMU after 19 years of service in Norway

Transformer Substation with RMU

A typical substation used in Norway in 1985 is shown in Fig. 2, which also was used for the examined RMU.

Fig. 2: Transformer substation with RMU

The typical features of this type of substation are
- sheet steel structure with wooden planking,
- doors of sheet steel without thermal insulation,
- condensation can occur inside the substation frequently,
- small oil-filled transformer with low load,
- ventilation via natural openings; salt fog and dust can enter the substation,
- ingress of moisture via not sealed cable entry points of the substation.

Ring Main Unit

The 24kV RMU type 8DJ10 selected for examination was in service continuously from 1985 to 2000 on the south west coast of Norway with salty atmosphere and has been used since 2000 also in a sandy and traffic atmosphere after moving in a substation for temporary installation.

The substation was installed in a normal distribution network. During its lifetime the three-position switch of the 8DJ10 was operated only a few times. The ring-main feeders normally will be operated after faults in the network, e.g. for selection of earth faults. The trans-former feeder will be operated for maintenance of the transformer or for works on the LV compartment of the substation.

The switchgear was manufactured at the Switchgear Factory in Frankfurt am Main, the Siemens Centre of Competence for gas-insulated medium-voltage switchgears.

Test results

The investigations were carried out in July/August 2004 in the Testing Laboratory Medium Voltage Frankfurt am Main, Germany which is independent and has been accredited by DATech (German Accreditation Body Technology) and PEHLA according to the standard ISO/IEC 17025.

Dielectric tests including partial discharge measurement

High-voltage tests were performed with the uncleaned RMU according to DIN EN 60271-200 [3] with 80% of the test voltages for factory new switchgears:

- Power frequency voltage test 50 Hz, 40 kV / 1 min. between phases and to earth and across the contact gap of the three-position switch-disconnector.
- Lightning impulse voltage test 1,2 / 50 µs, 100 kV between phases and to earth and across the contact gap of the three-position switch-disconnector.
- Then additionally rated power-frequency voltage test 50 Hz, 50 kV / 1 min. between phases and to earth and across the contact gap of the three-position switch-disconnector.

All tests were passed successfully.

The partial discharge test was done with the polluted RMU: Start and stop of partial discharge at >18kV phase-to-earth voltage; i.e. the switchgear was free of partial discharges during normal service.

Mechanical function tests

In order to check the correct mechanical functions the following tests were carried out:

- Switching functions of operating mechanism
- Easy latch movement in all operating mechanisms
- Tripping of transformer switch with test fuse
- Interlocking of fuse compartment cover
- Interlocking of cable compartment covers
The measurement of the switching time/speed of all operating mechanisms meets the requirements of the normal routine tests.

The a.m. tests were passed successfully

Fig. 3 shows an impression of the operating mechanism of a ring main feeder.

Fig. 3: Driving mechanism of a ring-main feeder

Checking the condition of the insulating gas

The gas pressure was 0.5 bar (gauge), which corresponds to rated filling pressure of a new switchgear panel. The dew-point of the gas was less than – 30 °C, comparable to a new switchgear.

Checking the conditions of the electrical contacts

The electrical contacts were inspected visually and showed no sign of erosion. The three-position switch-disconnectors and the connecting bars showed no ageing; see fig. 4.

Inspection of the SF₆-vessel and mechanical parts

The visual inspection showed traces of corrosion on the external part of the vessel in the welding area. This is only superficial corrosion. The corrosion is completely removable by polishing the surface.

Conclusion

As a result of this examination we can derive the conclusion that the RMU from Siemens will have an expected life time which is much longer than 30 years. It also shows that the chosen design and the intensive ageing tests, e.g. according to IEC 60932 are suitable to prove the long time behaviour for switchgear in severe environmental conditions.

The know-how obtained from the accumulated field experience and the tests described in this paper are an integral part of the continuous improvement of the product development process and the life cycle management for medium-voltage switchgear.

References

[2] IEC 60694 Common clauses for high-voltages switchgear and controlgear standards
[3] IEC 62271-200 AC metal-enclosed switchgear and controlgear for rated voltages above 1 kV and up to and including 52 kV
[4] IEC 60721 Series Classification of environmental conditions
[5] IEC 60068 Basic environmental testing procedures
[6] IEC 60932 (Report) Additional requirements for enclosed switchgear and controlgear from 1 kV to 72.5 kV to be used in severe climatic conditions