SAFETY AND RELIABILITY OF MEDIUM VOLTAGE SWITCHGEAR WITH SOLID INSULATION

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SUMMARY

In The Netherlands and many other countries, extensive experience has been gained over a period of more than thirty years with the application of insulation-enclosed M.V. switchgear (12 kV). This experience covers both switches and switch-fuse combinations of compact Ring Main Units, as well as circuit-breakers and metering transformers for switchgear in primary substations.
The insulation enclosures concerned are made of cast resin, consisting of a solid bisphenol A-type epoxy resin, together with phtalic anhydride as a curing agent, with silica flour as filler. This insulation material can simultaneously serve as construction material and insulation material.
Considerable experience over a long period has proved that epoxy resin is an excellent insulation material, which provided it has been correctly designed, can be applied to produce safe and reliable switchgear.

The paper gives a review of the design philosophy of insulation-enclosed switchgear. Attention is paid to specific requirements for the insulation enclosure as laid down in IEC standards, in order to guarantee safety and reliability during its lifetime.
Experience with this system, acquired over many years of service, is described.
Laboratory tests on the insulation material and also an extensive field investigation on 137 transformer stations are described.
The paper also gives the opportunity to give some general comments on switchgear and the environment.

DESIGN PHILOSOPHY OF INSULATION-ENCLOSED SWITCHGEAR

In order to offer the operator of M.V. switchgear and controlgear (12 to 24 kV) optimal protection against hazardous approach to live parts, the switchgear has to be fully enclosed. If this enclosure is made of metal that is intended to be earthed, the gear is called metal-enclosed. If it is made entirely of an insulating material, it is defined as insulation-enclosed switchgear.
The relevant IEC publication for the metal-enclosed type of switchgear is no. 298.
Insulation-enclosed switchgear is based upon IEC publication no. 466. It is defined as switchgear with an external insulation enclosure covering all components except for external connections.
This group of switchgear is insulated in such a way that it fulfils the requirements regarding safety of the operator when touching the accessible insulation surface of the gear.

Both metal-enclosed and insulation-enclosed switchgear offer protection for the operator against hazardous approach, but each has its own special characteristics. The safety of a metal enclosure is dependent on:
- the effectiveness of the earth connection;
- the potential difference that occurs during earth-faults;
- the integrity of the earthing circuit connections.

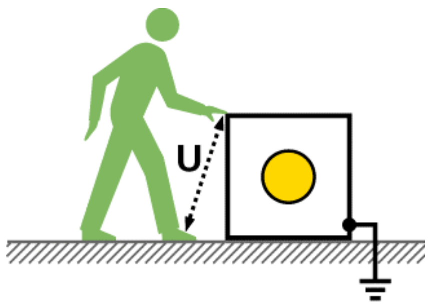


Figure 1

On the other hand, the safety of an insulation enclosure is dependent on:
- the effectiveness of the insulation;
- the level of leakage currents when a person touches the switchgear surface;
- the quality of the insulation surfaces.

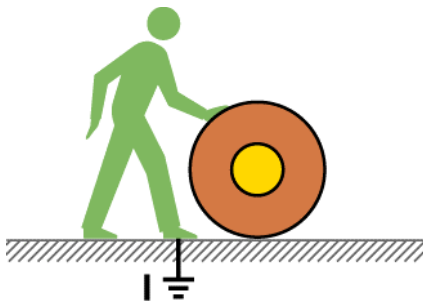


Figure 2

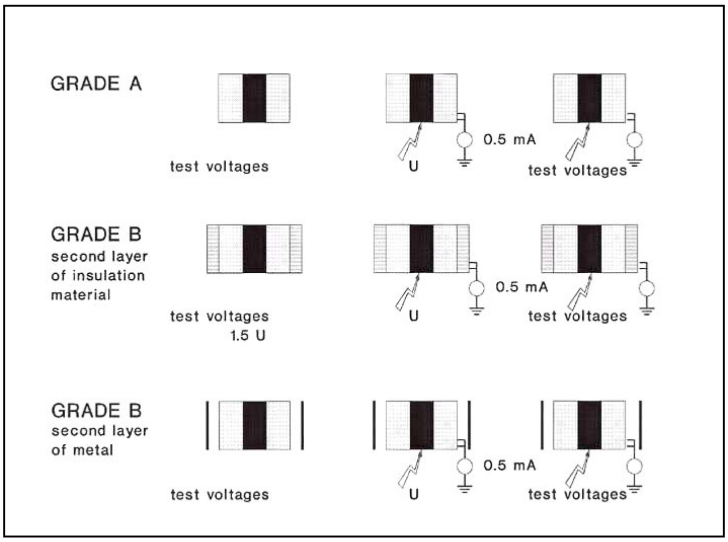
There is, therefore, a fundamental difference between metal-enclosed and insulation-enclosed equipment in that a single metal enclosure does not provide complete protection without a reliable earthing system, which must be effectively tested, and which is not a part of the switchgear.
On the other hand, an insulation enclosure provides intrinsic protection, which is checked during the design and production process.

In order to fulfil the requirements of IEC-466, the primary parts of insulation-enclosed switchgear have to be "fully insulated".
This means that the insulation has to fulfil three criteria :
- it must be "total";
- it must be of "full quality";
- it must be "safe to touch".

"Total" insulation means that the insulation material (mostly epoxy resin) completely surrounds all primary parts. The connections between the components must also be fully insulated. For connections that have to be opened regularly, this has to be achieved by adequate air clearances between live parts and accessible outer surfaces.
For connections that are not regularly separated, full insulation can be achieved with the aid of rubber sleeves.
Insulation is referred to as "full quality" if it is able to withstand the basic impulse level that has to be withstood between the primary conductors and all external insulation surfaces, including those at the connections.
To be "safe to touch" under live conditions, the leakage currents during touching of the accessible outer insulation surfaces must not exceed 0.5 mA.

IEC-publication 466 describes two protection grades for the safety of operation viz. grade A and grade B.
Protection grade A refers to an insulation which fully meets the rated insulation level. This means firstly that the thickness of the insulation enclosure has to be sufficient to withstand the relevant test voltages; secondly that the leakage currents must not exceed 0.5 mA; and lastly that the appropriate test voltages can be withstood between the main circuits and the accessible outer surfaces.
Protection grade B requires an insulation in addition to insulation grade A as a safeguard, should the grade A insulation be damaged.
Grade B insulation therefore consists of two layers; one layer which complies with the requirements of grade A above, and a second layer, if made of insulation material, that is capable of withstanding a 1 minute power-frequency test voltage of 150 percent of the rated voltage.
An earthed metal cover may obtain protection equivalent to grade B. For such equipment, the requirements of IEC publication 298 apply.
Protection to grade A is generally sufficient for those parts of the enclosure that can only be touched accidentally or inadvertently. Grade B is considered suitable for parts that are liable to be touched when operating and carrying out maintenance work.
Figure 3 shows a diagrammatic representation of protection grades A and B.

fig. 3 protection grades A and B



Test voltages	U = 12 kV	U = 24 kV
$U_{1\,min}$	28 kV	50 kV
U_w	75 kV	125 kV

With full insulation there is nowhere a direct path of air between phases, even at the existing internal connections. As a result, breakdown due to flashover between phases and between phases and earth is prevented.
Furthermore, there are no opportunities for the occurrence of open arcs, thus fulfilling the appropriate recommendations in which the avoidance of such arcs is emphasised.
The choice for insulation enclosures leads to a switchgear of small dimensions and modular, flexible design.

Specific requirements of insulation-enclosed switchgear

Besides the common type tests prescribed in IEC 298 and IEC 466, for metal-enclosed and insulation-enclosed material respectively, in IEC 466 four other important type tests are prescribed to test the safety aspects of the insulation enclosure:
- measurement of partial discharges;
- a thermal stability test;
- verification of the degree of protection;
- a humidity test.

The measurement of partial discharges has to be carried out on all components with the maximum permissible values being 20 pC at 1.1 times the highest system voltage.
The thermal stability test is a 100 h test at 180 percent of the rated voltage at a temperature of 90-100°C. The test provides an accelerated ageing test for solid insulation.
Verification of the degrees of protection involves examination of the degree of personnel protection against hazardous approach to live parts and moving parts, and examination of the protection for persons against dangerous electrical effects. These effects involve the ability of the insulation to withstand test voltages, and the examination of leakage current levels.
Although it is not laid down in IEC publications 298 and 466 as a routine test, Holec carries out partial discharge tests on each completely assembled product.
The objective of the IEC humidity test is to prove that insulation-enclosed switchgear is also safe when touched in the presence of condensation and dust deposits.
Even under wet conditions the leakage current must not exceed 0.5 mA.

EXPERIENCE WITH INSULATION ENCLOSED SWITCHGEAR

Holec started experimenting with epoxy resin around 1950, in an era when solid insulation consisted of materials such as porcelain, bakelised paper, phenol-formaldehyde mouldings or even marble.
It was then discovered that the combined advantages of very high insulating qualities, very good mechanical properties and ease of forming intricate shapes, made epoxy resin an ideal material for M.V. switchgear. The insulating material serves both as construction material and insulation enclosure.
Now, about 40 years later, application of epoxy resin for M.V. switchgear is taken for granted; even the most advanced concepts seem inconceivable without it.
The first commercial series of insulation-enclosed switchgear was developed in 1955.
Substituting free air for cast resin insulation lead to a drastic reduction in the dimensions of the switchgear used up to that time.
The basic concept and shape of Magnefix -modular built, double insulation, extreme compactness, and magnetic fixation of the moving contacts- was well received by the market and has been maintained for the designs of later years (fig. 4).

fig. 4 Magnefix type MD4 Ring Main Unit (RMU)

Application of these compact, prefabricated, insulation enclosed Ring Main Units, with their favourable price-performance ratio, has considerably reduced the cost of distribution substations, hence providing lower operation costs.

Service experience

The experience with the cast-resin used in "Magnefix" switchgear is excellent. Since 1955, a large number of Ring Main Units have been in operation worldwide under varying conditions.
Over half-a-million panels are now in operation. Expressed in "years of operation" this experience totals about 1.2 million years. No failure cause could be traced back to the mere use of epoxy resin.
Having had such large numbers of units in operation for so many years, failures of course have occurred, but the problems have always been able to be traced back to fuse links, cable terminations, manufacturing faults and mechanical malfunctioning due to pollution as a result of bad service conditions.

With respect to Magnefix switchboards that had been in service for many years it was important to be able to give users answers on questions such as:
- what is the technical life span of such switchboards?
- what maintenance is required and how frequent ?
- which factors influence the life span?

In an attempt to give well-founded answers to these questions, Holec has carried out an investigation in three stages:
- laboratory tests on installations;
- laboratory tests on insulation material;
- field investigation.

Laboratory tests on installations. The investigation in the laboratory concentrated on tests regarding the condition of five Magnefix switchboards that had been in service for 20 - 27 years.

In order to investigate the dielectric strength of some old units, it was fortunately possible to withdraw some from service.
The investigation of these units covered two aspects:
- the condition of the complete installation;
- qualities of the insulation material itself.

The check on the complete installation comprised:
- a visual inspection;
- a dielectric investigation.

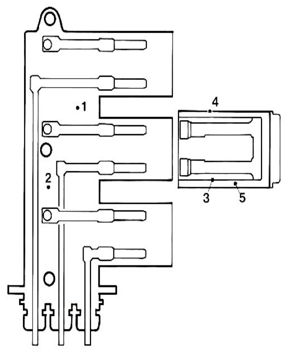
For these tests the units were kept in the same condition as when they were withdrawn from the substation.
All five stations, which had been in service for 20-27 years under poor service conditions with no maintenance, still fulfilled the dielectric requirements for both the power frequency voltage and impulse voltage tests.
For the power frequency test, values that were valid before 1974 were applied (35 kV instead of 28 kV and 45 kV instead of 32 kV).
The measured leakage currents were well below the limit of 0.5 mA.

Laboratory tests on insulation material. To study ageing effects in the insulation material, epoxy-resin samples were investigated on possible changes in mechanical and dielectrical properties.
Some of those samples were taken from Ring Main Units type Magnefix, which have been in operation for many years.
During service life the quartz-filled epoxy-resin was exposed to a multi-stress environment (mechanical, thermal, electrical and chemical). For example mechanical stresses are caused by thermal cycles and by the difference in thermal expansion coefficients between the resin and the copper conductors.
The electric stresses are quite low in most areas, however, in the fixed part a field strength of approximately 1 kV/mm is present between crossing copper conductors (120° phase difference). Due to deposition of dust and moisture electrical tracking on the outside of the caps may occur.

The investigated samples were taken from the fixed part and from the switch caps as well. For comparison, other samples were taken from units which had not been in service, or from newer castings. In one case, a sample taken from a cylindrical casting (diam. = 40 mm) produced in the laboratory, was studied. (case 6).
Details of the cases studied are given in table 1, on page 6. The cap in case 4 had the most surface contamination. For all cases separate samples were prepared for each of the analyses.

Table 1 DATA OF INVESTIGATED CASES

Case number	years in operation	Service condition	location of sample
1	22	M	fixed part, out of bulk
2	22	M, E	fixed part, out of bulk, between two phases
3	22	M, S	switch cap, near inner surface
4	15	M, S	switch cap,near outer surface
5	10	none	switch cap
6	3	none	cylinder
7	0	M	fixed part, out of bulk
8	0	M	fixed part, out of bulk, between two phases



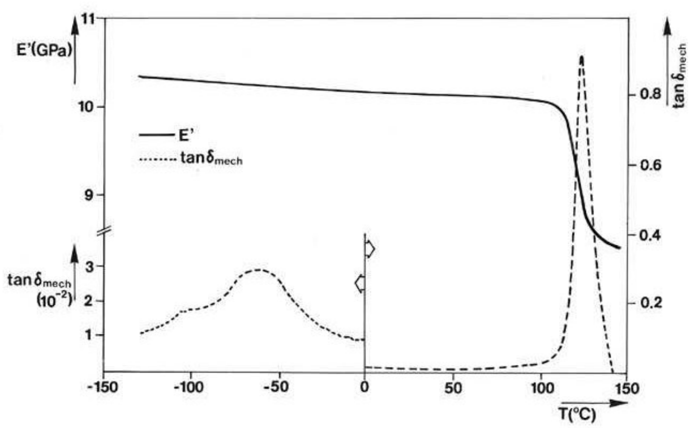
M = mechanically stressed
E = electrically stressed
S = environmental : influences on surface

Experiments
Three analyses were carried out, i.e.:
- Dynamic Mechanical Thermal Analysis (DMTA)
- Dielectric Thermal Analysis (DETA)
- Thermal Mechanical Analysis (TMA)

In the DMTA a weak driving force at 1 Hz is applied to a flat sample, sized 35 x 10 x 1 mm. The samples for the DETA were discs of diam. 40 mm, 1 mm thick.
The dielectric permittivity and loss tangent (e', $\tan d_{el}$) were measured using a General Radio Bridge type 1621 at 1 kHz and 50 Hz resp. TMA expansion curves were measured using a Dupont apparatus type 943. Sample sizes were 3 x 3 x 3 mm. Samples were obtained using a very low-speed diamond saw, to avoid any damage (especially heating) to the sample. For TMA in each case three samples were sawn with 3 mutually perpendicular orientations.

DMTA
In fig. 5 a DMTA scan for case 2, which was stressed electrically during 22 years, is shown.
The Youngs modulus (E') decreases at the glass transition at T_a = 124°C, while the mechanical loss factor shows a maximum $\tan d_{mech}$ = 0.9.

Fig. 5
DMTA (1 Hz) for case 2.
The youngs moduli E' (solid line) and the mechanical loss factor $\tan \delta_{mech}$ (dotted line) are shown versus temperature.
Rate of rise is :
4 K/min below 0 °C
2 K/min above 0 °C



At low temperatures a secondary transition occurs at T_b =-61 °C. At table 2 the DMTA-results of all samples are compared. The accuracy of the transition temperatures is +/- 1K for T_b. From a high number of experiments it is known that T_b fluctuates +/- 2.5K for samples of the same batch. Furthermore, the values of the E-moduli and the loss factors at 20 and 80 °C are listed, where the latter is the maximum operating temperature. Cases nr. 3 and 4 show a T_a-value that is abt. 5 degrees lower with respect to case 6. Case 4 also deviates by possessing a slightly higher mechanical loss tangent at 80 °C.

Table 2 COMPARISON OF DYNAMIC MECHANICAL THERMAL ANALYSIS (1HZ)(DMTA) FOR DIFFERENT AGEING TIMES AND CONDITIONS

Case nr.	$T_á$	$T_ß$	E' (20°C)	E' (80°C)	tan $ä_{mech}$ (20°C)	tan $ä_{mech}$ (80°C)
	°C	°C	GPa	GPa	10^{-3}	10^{-3}
1	124	-61	14	12	6	18
2	124	-61	14	12	9	18
3	120	-60	14	12	8	18
4	118	-61	14	12	8	22
5	123	-61	13	12	7	16
6	124	-62	14	13	8	17

DETA

Likewise dielectric thermal analyses were performed. The higher measuring frequency of 1 kHz, shifts the characteristic transition temperatures approximately 20K upwards. Fig. 6 shows the dielectric permittivity and the loss tangent tan d_{el} for case 2, having transitions at T_a = 149 °C and T_b = -38 °C. Table 3 summarises the results.
In addition at 20 °C also the e' and tan d values at 50 Hz are shown. T_b is approximately 10K higher for cases nr. 2 and 4. Cases 4, 7 and 8 show lower T_a-values.
For case 4 the loss tangents at 1 kHz and 50 Hz are enlarged, however not seriously.

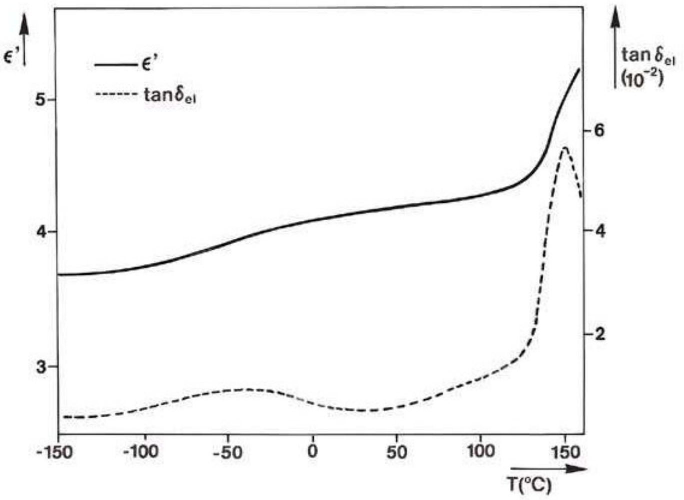


Fig. 6
DETA (1 kHz; rate of rise 5 K/min) for case 2.
The dielectric permittivity ª ' (solid line) and the dielectric loss factor tan $ä_{el}$ (dotted line) are shown versus temperature.

Table 3 COMPARISON OF DIELECTRIC THERMAL ANALYSIS (DETA)
FOR DIFFERENT AGEING TIMES AND CONDITIONS

DETA at 1 kHz							At 50 Hz	
Case nr.	T	T	ª ' (20°C)	ª ' (80°C)	tan Ö$_{el}$ (20°C)	tan Ö$_{el}$ (80°C)	ª ' (20°C)	tan Ö$_{el}$ (20°C)
	°C	°C	1	1	10^{-3}	10^{-3}	1	10^{-3}
1	151	-45	4.1	4.2	5	9	4.1	6
2	149	-38*	4.1	4.2	5	9	4.1	7
3	146	-47	4.0	4.2	5	10	4.1	7
4	142	-38	4.1	4.2	5	13	4.1	9
5	150	-47	4.1	4.2	4	9	4.1	6
6	148	-51	4.1	4.2	4	10	4.1	5
7	144	-58	4.1	4.2	4	7	4.1	8
8	143	-45**	4.1	4.2	5	8	4.1	7

* 2nd. run -45°C
** 2nd. run -58°C

TMA
TMA has been carried out at a temperature increase of 5K/min; for each sample two sequential thermal runs have been done. In this way the thermal history that is "frozen in" in the epoxy-matrix can be distinguished as the difference between the first and the second run. Fig. 7 shows a typical example for case nr. 2. The expansion curve (1) bends at 113 °C because of the glass transition and at 123 °C a contraction of dL/L = 0.04% follows.
(L = length of the sample in the orientational direction). In the second curve (2) a pure glass transition remains. Table 4, on page 9, summarises the main results. The slope of the curve below T_g (glass-temperature) is denoted as the thermal expansion coefficient a_g.
(T_g and a_g values are averaged over 3 orientations). Furthermore the stress-releases dLi/Li (i=t,a,r) for each orientation are listed.
Except for cases 2 and 8, contractions (minus sign) were always measured.

Although large elongation effects are seen in cases 2 and 8, the net volume change is about zero, which is characteristic for a Hookean deformation.
Although the net volume change of all other cases is not equal to zero, this does not necessarily mean non-Hookean deformations.

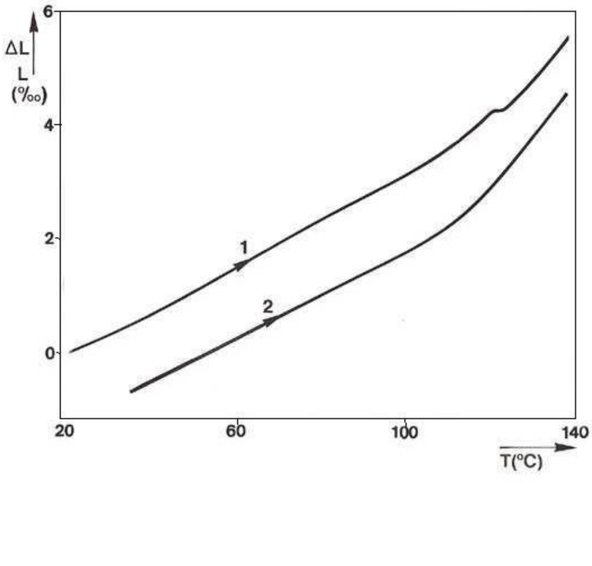


Fig. 7
TMA (rate of rise 5 K/min) for case 2.
Two sequential runs for one tangentially oriented sample of case 2.
Relative length change dL/L versus temperature is shown.

Table 4 COMPARISON OF THERMAL MECHANICAL ANALYSIS
TMA FOR DIFFERENT AGEING TIMES AND CONDITIONS

Case nr.	α_g	T_g	dL_t/L_t	dL_a/L_a	dL_r/L_r
	$10^{-6}K^{-1}$	(°C)	°/oo	°/oo	°/oo
1	42	113	-0.5	-0.3	-0.1
2	38	115	-0.4	-1.8	+2.2
3	38	108	-0.4	-0.2	-0.2
4	37	103	-1.3	-0.1	-0.5
5	36	112	-0.3	-0.3	-0.2
6	34	110	-0.7	-0.1	-0.2
7	33	107	-0.4	-0.3	-0.4
8	35	108	+0.2	-2.4	+2.0

Surface condition of the caps

The properties of a new cap and one which had been in use for over 20 years were compared with respect to surface resistance and tracking resistance.

The surface resistance of both the new and the old cap was of the order of 10E6 - 10E7 MW.

The tracking resistance, measured on the unclean surface at 600 V was the same for both caps.

Discussion

It is interesting to compare the corresponding cases 1 and 2 with cases 7 and 8 respectively, which pairwise belong to the same castings. As pointed out (3), frozen in mechanical stresses in the epoxy-matrix increase the T_α- temperature. For case 2 a second DMTA-scan was carried out, however compared to the first scan a marginal 3K decrease in T_α occurred.

On the other hand, DETA measurements for cases 2 and 8 show that T_b shifts 10K downwards indeed, approaching the T_α values of cases 1 and 7 resp.

This indicates that stresses have been released in the first scan. This is confirmed by TMA, showing a frozen in compression of 2 o/oo for cases 2 and 8 only, mainly radially oriented with respect to the copper conductors. Shrinkage during the curing of the epoxy resin might explain the effect observed, whilst electrical ageing (1 kV/mm) cannot be distinguished. Furthermore case 4 shows lower T_α and T_g-values but still within the normal production tolerances, so it is not considered important to look for other causes (for instance an incomplete hardening might result in higher losses).

In conclusion it is seen that the reported mechanical, dielectrical, thermal and surface characteristics of the investigated samples show no significant changes purely due to ageing under service conditions.

Of course since the measured properties are material properties, they are not uniquely correlated to functional properties (except for the surface and tracking resistance) like thermal, mechanical or electrical endurance.

Field investigation

Switchgear involved. The field investigation relates to 12 kV Ring Main Units of the well known design "Magnefix" type MD4. (Figure 4)
Of this concept -insulation enclosed, modular built, extreme compactness, magnetic fixation of the moving contacts, single pole operated- over 160.000 RMU' s are worldwide in operation by now.
The field investigation was carried out on 137 RMU' s in total, which are in service in the distribution networks of the Electricity Boards of the IJsselmij N.V., the PLEM N.V.
and the PEN N.V. In general, the quality of the service condition is affected by the type and quality of the accommodation and by environmental factors, such as air pollution, motor traffic, vicinity of the seashore, humidity and condition of the soil, etc. Most of these factors were, in one form or the other, also valid for the investigated substations.

Enclosures accommodating the equipment under investigation could be divided into the following categories :
a) Walk-in, indoor substations, forming part of a larger building.
b) Walk-in, free standing substations, made of sheet metal.
c) Walk-in, free standing substations, made of brick.
d) Compact substations, made of concrete or sheet metal, which cannot be entered.
e) Cabins, in which only the M.V. and L.V. switchgear is installed without the relevant transformer.

The investigated switchboards were in service from some years up to 23 years. Hardly any maintenance had been carried out.

Test program. The investigation was based upon the experience that the condition of the switchboard in service is highly dependent on the service conditions.
The relevant IEC-standards prescribe reasonable requirements for the normal service conditions, however, in practice the conditions for most RMU' s in question are worse.
Naturally, the dependability of the switchboards is of great importance, but the main criterion for the assessment concerned the safety for operation of the switchgear.
The 137 substations were all investigated by one and the same laboratory engineer, to obtain a judgement as objective as possible.
For each installation, with the aid of a checklist, observations were obtained by :
- determination of the service conditions,
- visual inspections,
- measurements.

The determination of the service conditions included :
- data of the relevant climate conditions,
- data of the switchboard,
- type and situations of the enclosure, etc.

The visual inspections included:
- condition of the switchboard,
- audible or visible discharges,
- corrosion of metal parts, etc.

The measurements included:
- values of leakage currents.

Besides the judgement of the exterior condition of the switchboard, - pollution, discharges, corrosion -, for the assessment of whether an installation is safe to operate after many years of service, the values of the leakage currents are very important. These are determined as described in IEC-publication 466 and shall not exceed 0.5 mA.

All recorded results were stored in a database. The database was processed with the aid of a commercially available computer program (dBase III plus).

Results of the investigation. It was determined that, of the 137 installations, 85% still could be operated safely, without special measures in the near future. For 15%, only limited maintenance work was recommended to be sure of optimum safety during operation and for instance cable replacement.
These results can be related to the number of years in operation and to the type of the accommodation. The relations are given in the diagrams of figures 8 and 9.
Figure 8 shows that no installations installed after 1977, require maintenance in the near future

Figure 8

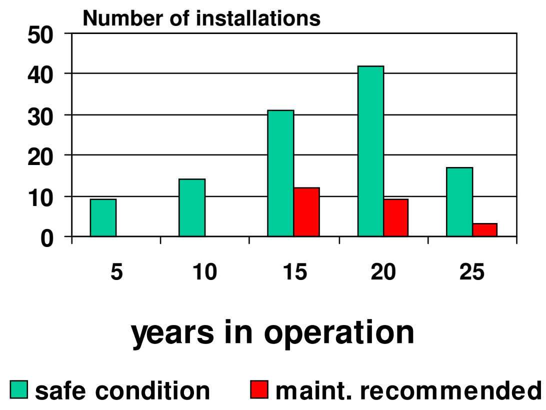
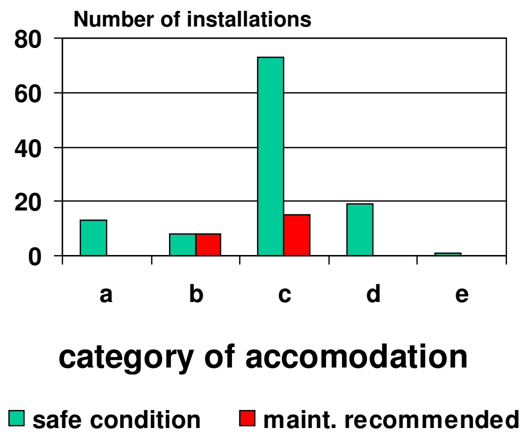


Figure 9 shows that the installations in the accommodation of the categories a, d and e are in an excellent condition, and that the accommodation of type d, made of brick, offers better service conditions for the switchgear than accommodation type c, made of metal.

Figure 9



Together with the results of earlier investigations (1) it can be concluded that:
- Irrespective of the severity of the recorded service conditions and in respect of the use of epoxy resin, Magnefix switchgear type MD4 is completely safe to operate for the first ten years after installation without any maintenance.
- If the service conditions are reasonable and in accordance with those as prescribed in IEC-publication 466 for normal service conditions, the switchgear is even completely safe to operate without any maintenance, for at least 20 years after installation.
- In general a maintenance frequency of ten years is sufficient for the switchgear in question. A further recommendation is to improve more severe service conditions by preventive measures on the accommodation.

Preventive measures and maintenance. Preventive measures in the accommodation and some maintenance of the installation, can, if necessary, improve the situation considerately.

Preventive measures encompass such factors as:
- limitation of ventilation,
- prevention of air streams passing the installation,
- prevention of circulation and diffusion of water vapour by sealing of the cable entrance.

Maintenance encompasses such factors as:
- cleaning of the installation by removal of dust, and if any,
- removal of dirt, chemical pollution and discharge traces.

SWITCHGEAR AND THE ENVIRONMENT

In The Netherlands, there is a tendency to treat SF6 gas filled switchgear with caution.
It will be clear that SF6 is generally accepted in high voltage switchgear for 50 kV and above. These installations are under close scrutiny. Skilled operators are available for maintenance and repair. But there is considerable apprehension in The Netherlands about the use of SF6 in simple, unattended switchboards and ring-main units. These units could be located on any street corner as well as indoors in large buildings. It may be true that "sealed for life" gives adequate protection against pollution, but one should realise that the internal situation of simple installations cannot be determined visually or audibly. Especially if the quenching and insulating functions are combined, some internal deterioration may occur after some years, resulting in internal arcs.
In the relatively small tanks, fault currents that can cause arcs to penetrate the wall, or even cause explosions, cannot always be prevented.
Also external influences, for instance failures with cable boxes and fuses, as well as mechanical and other damage (e.g. fire) cannot always be avoided. These failures with SF6 give aggressive and toxic by-products. It is not easy in all cases to rely on the existing safety specifications.
The national environmental organisations in The Netherlands are asking the government at the present time to pay attention to the danger of poisonous matter to the environment and the surrounding neighbourhood of the transformer station.
In addition, the escape of poisonous materials during the maintenance or destruction of the installation is giving cause for concern.
The materials applied in our epoxy-resin insulated systems have been carefully selected so that no harm will come to the operating personnel and the environment. This is not only valid for during service, but also at the end of the technical life cycle of the switchgear, since with our present day knowledge, the materials used cause no pollution in the environment.

CONCLUSION

Cast resin has been widely used as insulation material for a period of approximately 30 years, first mainly as a material for insulators and bushing in air insulated or oil insulated switchgear and as insulating and construction material for insulation enclosed switchgear. Over the past decade epoxy resin has frequently been used in gas (SF6) insulated switchgear. So it can be concluded that a wealth of experience has been gained in the application of this insulation material.
As stated in this paper, the experience of users and investigation of used units justify that there is no doubt about the insulation principle in the question.
The comparative examination of the material properties prove that after 25 years of service there are no signs of ageing of the material itself. Even under bad conditions, e.g. in poorly designed substations, hardly any failures have been reported purely due to the choice of epoxy resin as insulation material.
One may wonder whether this will hold for compact switchgear having for instance air as insulation.
In general, bad test results and failures in practice with both compact and semi-compact types

are not primarily caused by the choice of the insulation material, but by poor design.

Provided a proper design is made, which entirely meets the relevant requirements, for instance those of IEC-publication 466, cast resin is an excellent insulation material, which can lead to safe and reliable switchgear with a very interesting price-performance ratio.

REFERENCES

1. W.M.M. Menheere, B. Noordhuis, H.F. Reith, J.J.H. ten Zende, 1987, "Study of Magnefix under service conditions"
   HOLEC SYSTEMS AND COMPONENTS
   P.O. Box 23
   7550 AA Hengelo
   Holland (dept. Marketing MV)

2. B. Noordhuis, W.M.M. Menheere, J.Sikkenga, E.M. de Meulemeester, 1989, "Service experience with epoxy resin for both insulation and construction material and its application in a future design of insulation-enclosed switchgear"
   CIRED 1989, paper 1.09

3. W.M.M. Menheere, B. Noordhuis, 1989,
   "Safety and reliability of medium-voltage switchgear with solid insulation of present day and future design",
   IEE 1990