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Outdoor Vacuum Switchgear – The State of the Art.

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***Abstract*-- This paper outlines the design of outdoor switchgear, concentrating on vacuum interruption technology. The paper reviews a brief evolution of vacuum switchgear from the 1970's to the present day, often in conjunction with SF_6 as insulation for outdoor use, including applications from 12kV up to 132kV. The historical review is important in order to understand the driving forces and evolution of this type of switchgear up to modern designs.**

The paper then goes on to look at the basic design aspects of outdoor vacuum switchgear, and in particular the needs and advantages of vacuum switching technology for this application. As with all technologies vacuum switchgear brings its own character to a design, and this must be taken into account by the switchgear designer.

Specifically switchgear designed for transmission and particularly the distribution of power is examined, as well as a key specialist application for railway use where vacuum switchgear has dominated the application for over twenty years due to its inherent capabilities.– both for traction and trackside use

***Index Terms*— Vacuum, circuit breaker, outdoor, magnetic actuator, design, evolution.**

I. INTRODUCTION

Vacuum circuit breakers for outdoor use have been in existence for over thirty years, and are well proven, however during this period the designs have evolved considerably. Figure 1 is of a modern 38kV dead tank design outdoor circuit breaker from 2001 with one interrupter per phase and all enclosed in a tank fabricated from stainless steel, containing SF_6 insulating gas.

In comparison, Figure 2 shows an early 132kV vacuum circuit breaker developed by AEI (AREVA) in the late 1960's.

This design used six vacuum interrupters in series per phase encased in a porcelain insulator with nitrogen gas insulation between the interrupters and the porcelain. The design was based on the then current technology and, although expensive

Figure 1 Modern stainless steel 38kV outdoor circuit breaker design in service in Mexico.

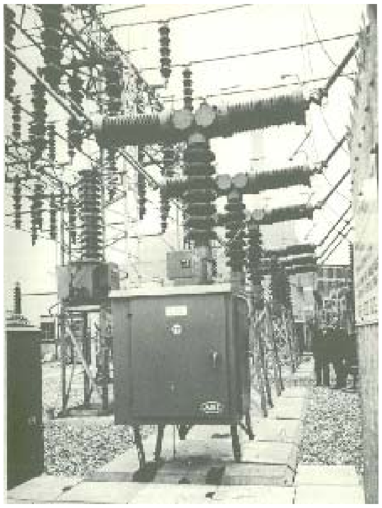

Figure 2. 132kV vacuum circuit breaker designed in the 1960's, in service in the UK.

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due to the number of interrupters required to meet the high voltage requirement, and the complex mechanism, performed well. In fact two units are still believed to be in service in the UK, some 35 years later.

Figure 3 shows our "OX" medium voltage design from the mid 1980's which followed the design concept of segregating both the interrupter tanks and the mechanism. The interrupters are held within Aluminium tanks containing SF_6 insulating gas. The gas is used to enable small interrupters to maintain the required insulation level (200kV bil) on the outside of the interrupter, and takes advantage of the fact that the vacuum insulation within a vacuum interrupter is significantly better than insulation in air. Inside each tank is one V8 type vacuum interrupter rated at 38kV; 25kA; 1250A. This is a dead tank design with the Aluminium tanks being earthed. The mechanism is not in SF_6 but is in the cabinet attached to the circuit breaker.

Figure 3. OX circuit breaker c.1982. The three tanks each containing a vacuum interrupter insulated in SF6 gas can clearly be seen. The windows in the tanks which acted as pressure relief in case of internal arc are at the bottom of each tank. The mechanism is housed inside the box underneath the circuit breaker. Inside each tank is one V8 type vacuum interrupter rated at 38kV; 25kA;1250A.

Although successful this design required each tank to be a separate sealed gas tight container, and as such required a seal for the mechanism drive into the tank to drive each vacuum interrupter. One reason for segregating the interrupters into different tanks was to facilitate changing of a phase if a vacuum interrupter should leak. We now know that this is not an issue, as the vacuum interrupters have proven to be incredibly reliable, so much so that we now have no problem in sealing them into a welded tank with no possibility of maintenance or replacement. The drive mechanism on the OX is a spring mechanism derived from the indoor circuit breaker designs, and is very reliable. The option of alternative drives was not technically feasible at the time of design. The bushings are Polyeurethane moulded over the copper conductors, and are sleeved in EPDM rubber sheds. CT's are fitted to the bushings outside the tanks allowing changes to be made to the CT's without entering the sealed gas tanks.

Also although the tanks are cast Aluminium, the rest of the circuit breaker is generally fabricated from mild steel, and is galvanised and painted for protection against the elements and external environment. As circuit breakers generally have a design life of forty years the protection against the external environment and particularly corrosion is very important. This design, although successful, was made over twenty five years ago, and technology for vacuum circuit breakers has progressed considerably since then. Modern outdoor circuit breakers have taken advantage of this progress, which is why they now look quite different.

Figure 4. VOX circuit breaker c.2001. All three interrupters (VG type rated at 38kV;25kA;1250A) are now housed inside a single stainless steel tank containing SF_6.

II. DISCUSSION

Overall Concept

The modern concept of outdoor circuit breakers is to align the inherent maintenance free qualities, extreme reliability, low operating energy requirements and small size of vacuum interrupters with a sealed operating environment, and corrosion resistant tank. In addition, once this has been achieved, to use the technical platform to develop a family of switchgear to meet diverse application needs but using the same solutions, and where possible the same components. The key aspects of outdoor switchgear breakdown into the following five components;

A. Vacuum Interrupters

The vacuum interrupters are the heart of vacuum switchgear and as such are perhaps the most vital component. The circuit breakers described use our own VG range of interrupters developed in house from our long experience of vacuum interrupter design extending over fifty years [1] [2]. Following the technical platform concept these interrupters have been designed as a family with the same overall length, connecting type, and contact stroke to allow for as much standardisation of the circuit breakers as possible.

Figure 5. VG range of vacuum interrupters covering all ratings between 12kV 20kA and 38kV 40kA.

B. Tank Design

We needed to provide a fully controlled internal environment for the circuit breaker in order to ensure complete insensitivity for the internal components to pollution, water and other problems associated with the external environment. This led inevitably to a gas filled tank design. However with any gas-filled tank the issue of leakage is always the primary concern, and the approach taken was that we needed to completely seal the tank for life. This in turn led to the requirement that the internal components within the gas tank must be made totally maintenance free. However once sealed it is necessary to make the design very robust to remove the threat of mechanical damage or corrosion attack causing a leak in service.

Fortunately with over 40 years experience in SF_6 technology we were able to put together a large amount of data, and when studied formally using an FMEA (Fault Mode and Effects Analysis) process it was revealed that gas leakage usually occurs at a joint or a gasket.

Of course by using the proven vacuum interrupter technology there is no need, or indeed possibility, of maintenance of the interrupting device. As all arcing is carried out within the sealed for life vacuum interrupters there is, of course, no degradation of the insulating gas within the tank.

Figure 6. V803 12kV:25kA:1250A vacuum interrupter designed in the late 1970’s showing welded construction of bellows and insulator flanges

As a result of this we made the decision to completely weld the tank, using no joints or gaskets. W also decided to totally fabricate the tank from stainless steel, as this clearly gave the best defence against corrosion and environmental attack. Although a quite radical approach this followed our extensive experience in designing vacuum interrupters which were fabricated and sealed by means of welding stainless steel components as shown in Figure 6. For vacuum interrupters the sealing must be absolute and our experience of over thirty years manufacture of hundreds of thousands of interrupters using this type of manufacture led us to believe that this is the optimum design solution. The design of the VOX has been detailed elsewhere [4,5], and in Figure 7 the single phase SDR circuit breaker is used to clearly illustrate this concept.

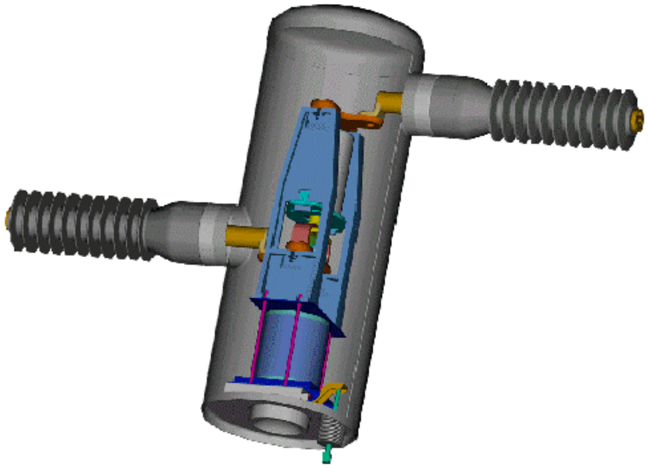


Figure 7. SDR single phase circuit breaker showing basic components and welded fabrication; Stainless steel tank , bushings, vacuum interrupter, and drive mechanism

C. Bushings

The bushings are designed with an electric conducting part made of copper insulated with an EPDM polymer.

EPDM bushings allow a good resistance against mechanical or electrical shock. Their high mechanical strength reduces the risk of damage during handling and installation or maintenance. The EPDM polymer also offers the advantage over porcelain that small projectiles and other minor shocks do not cause any chipping. This flexibility also gives them a high resistance to vandalism or accidental damage, and their generally inert properties makes them recommended for severe climatic and pollution conditions. In order to facilitate welding to the stainless steel tank, the bushings are fabricated with a stainless steel insert, which is directly welded to the tank (figure 8).

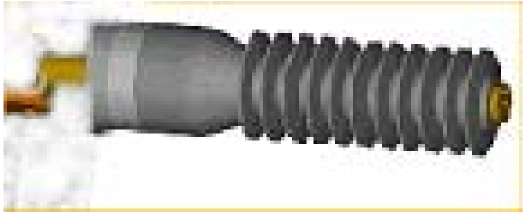


Figure 8. EPDM bushing with copper conductor and stainless steel insert to allow welding directly to the tank.

The bushings were also subjected to special tests including a test programme considered by some utilities to equate to up to 15 years service in real conditions. Further to this accelerated aging test, the bushings have successfully passed additional qualification tests (partial discharge, dielectric testing, tensile and traction strength).

D. Drive Mechanism

There are two main types of circuit breaker drives used for outdoor vacuum circuit breakers.

1) Spring Drive

The spring drive is the original type of mechanism used and is derived from the spring driven mechanisms used in indoor circuit breakers. Vacuum interrupters need quite low energies and short movements which means that the spring drives are low energy, which in turn makes them generally very reliable and durable.

2) Magnetic Actuator Drive

The magnetic actuator type of drive is a modern development linked directly to the low energy and short stroke requirement of vacuum interrupters coupled with the discovery and introduction of very high magnetic field permanent magnet materials. It is not possible within this short paper to discuss the principles of operation of a magnetic actuator, but this has been well covered elsewhere [3].

The main advantages of a Magnetic Actuator are the fact that they consume no energy when in the open or the closed position, and that as the magnetic actuator has only one moving part (like a vacuum interrupter), the design is mechanically quite simple. This allows for very many operations without any maintenance, which is ideal for recloser duties, or any application which needs a large number of operations.

Figure 9. Two SDR single phase circuit breakers for railway applications. This uses the basic design and many components of the VOX rearranged in a new stainless steel tank to give a compact, simple, single phase, catenary mounted, circuit breaker which can be mounted in several orientations depending on requirements.

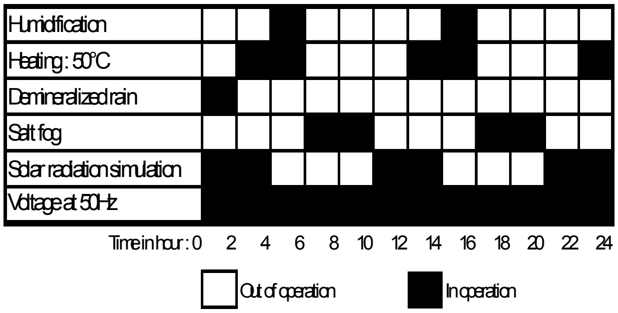
E. Testing

For any switchgear design testing for electrical performance to IEC 62271-100, ANSI C37, and other national standards such as GOST and GB is of course mandatory. However for outdoor circuit breakers a significant part of the testing and certification concerns the outdoor environment. This can range from a desert environment with extremely high temperatures due to direct solar radiation, through to arctic conditions with temperatures falling to –40’C or lower and the formation of ice and snow layers. The circuit breaker can be at high altitude, or perhaps by the sea and may be subject to wind, storm and salt spray. Mechanical issues are also significant such as ice or snow together with wind causing stresses on the bushings.

Figure 10. SDR mounted horizonatally in a climatic chamber at –40'C. For outdoor equipment environmental testing is absolutely essential to prove the design.

As a consequence of this, an important aspect of outdoor circuit breakers design is to be able to withstand extremes of temperature and weather. They must also be protected against other aspects of the external environment including salt corrosion, seismic movement, and mechanical impact. A full type testing programme has been carried out to validate this innovative concept according to all relevant standards.

The bushings are particularly important providing key insulation and mechanical properties and so were tested specifically for the most onerous conditions. The bushings have also been tested over 5000 hours, and subjected to 24 hour cycles according to Figure 11, which is considered to equate to over 15 years service in the field.



Humidification	□	□	■	□	□	□	□	■	□	□	□	□
Heating : 50°C	□	■	■	□	□	□	■	■	□	□	□	■
Demineralized rain	■	□	□	□	□	□	□	□	□	□	□	□
Salt fog	□	□	□	■	■	□	□	□	■	■	□	□
Solar radiation simulation	■	■	□	□	□	■	■	□	□	□	■	■
Voltage at 50Hz	■	■	■	■	■	■	■	■	■	■	■	■

Time in hour : 0 2 4 6 8 10 12 14 16 18 20 22 24

□ Out of operation ■ In operation

Figure 11. 24-hour test duty table for bushings.

One advantage of the platform approach to switchgear design is that the use of standardised key components and systems reduces the amount of testing required and the risk in developing new versions of the switchgear. Thus the family of outdoor switchgear is not only cost effective to develop but is also very well tested and proven.

Figure 12. VOX undergoing development testing

The family resemblance is quite clear in all of the members of this family, including the PMR pole mounted recloser shown in figure 13. This uses the main features of the VOX but in a smaller tank, and with a Magnetic Actuator as standard in view of the very large number of operations demanded in this type of application.

Figure 13. PMR three phase recloser unit. This pole mounted recloser is a member of the VOX family and uses the same technology for the tank and bushings as well as the same VG interrupter family. Due to the large number of mechanical and electrical operations required of a recloser, this unit includes the Magnetic Actuator drive as standard.

III. CONCLUSIONS

The paper has briefly shown the changes in outdoor vacuum circuit breaker design over the past twenty five years, and has described the latest outdoor vacuum circuit breaker designs. These designs have been incorporated in a coherent range of circuit breakers designed to meet the full range of applications from normal outdoor distribution requirements, pole mounted reclosers, through to single phase railway applications. In each case the same basic technology has been applied to meet the specific requirement. Outdoor switchgear can be more challenging in many ways than indoor switchgear. But with careful design and selection of materials, the authors believe that vacuum switchgear with it's inherent maintenance free and low energy requirement vacuum interrupters, together with the option of spring or Magnetic Actuator drives gives an optimum solution for all applications.

IV. ACKNOWLEDGMENT

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VI. BIOGRAPHIES

Leslie T Falkingham (M'1987, SM'2003) was born in Leeds, England, on May 13, 1955. He graduated from Lanchester Polytechnic, Coventry, England, in 1978 with BSc (Hons) in Combined Electrical and Mechanical Engineering, and has since studied part time at Cranfield University, receiving his PhD in Strategy & R&D Management in 2002.

Employment experience includes; Over ten years at VIL, London; two years with GEC South Africa where he designed and built a new factory to manufacture vacuum interrupters; ten years with GEC Alsthom Rugby, where he built up and then led the ALSTOM Centre of Excellence for Vacuum Switching Technology. He has spent most of his working life involved in the design, development, and manufacture of vacuum interrupters for medium voltage switchgear, and holds a number of patents in this field. Since 2001 he has been Technology Director for AREVA T&D Medium Voltage Business, based in the T&D head office, Paris, France.

He is a Fellow of the Institution of Electrical Engineers and a Fellow of the Institution of Mechanical Engineers in the UK. He received the Nelson Gold Medal from GEC 1n 1997 for "Outstanding Technical Innovation", and the J.J. Thomson Medal of the IEE in 2002 for his "Distinguished Contribution to Electronic Engineering".

Yuan Zhang (M'2002) was born in SuZhou China. She graduated from Institute of China East chemical Engineering in automatics, Shanghai (China) 1983. A masters degree in Automatics from the Institute National Polytechnic, Toulouse (France) 1985. A PhD in electro-technical Engineering from the Institut National Polytechnique in Toulouse, (France) (1988), and a master's degree in International Business Management from the Lyon II University (France) (1992).

She has worked as an R&D engineer in electrical transport systems, and also in the control industry before moving into the commercial role on joining ALSTOM T&D, in 1996, as Area Sales Manager for AMT in charge of Asia. In 2002 she was appointed Industrial Projects Manager for the Medium Voltage Business prior to returning to China where she is currently General Manager of the Medium-Voltage component activity in Beijing.

Xavier-Franck Braud was born in France, on November 8, 1966. Mechanical Engineer from the National Institute of Applied Sciences, Lyon, he also has a Master in Business Administration from the University of Lyon.

He has been working within the Transmission and Distribution division of ALSTOM since 1991, in the field of Medium Voltage.

Further to postings in Australia and United Kingdom with responsibilities over technology transfer and business development, Braud is currently Product Manager for the ALSTOM range of medium voltage switchgear for overhead distribution.