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"Vacuum for HV applications - Perhaps not so new? - Thirty Years Service Experience of 132kV Vacuum Circuit breaker"

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Abstract

In 1968 four 132kV, 3500MVA vacuum circuit breakers were manufactured by AEI in the UK and commissioned into service by the then Central Electricity Generating Board in the UK. This paper describes the design and history of these revolutionary circuit breakers which are believed to be the first application in the world of vacuum circuit breaker technology for circuit breakers at transmission voltages.

Although technically successful, in the 1960's these circuit breakers did not compare favourably against the SF_6 circuit breakers which had been developed some years previously and were being introduced to replace Oil and Air for Transmission voltages. As a result Vacuum did not go on to dominate the HV circuit breaker market, as it did for the MV market. This was mainly due to limitations of the vacuum technology at the time, as a consequence of which the AEI circuit breakers used eight interrupters in series per phase, fitted to a hydraulic mechanism. This resulted in a complex and expensive operating system, which was excessively costly in comparison with the SF_6 circuit breakers of the time.

However, vacuum interrupter technology has developed considerably over the past thirty five years, and today, due mainly to environmental considerations, vacuum is once again being considered as an alternative technology to SF_6 for Transmission voltages. The paper looks as the design and service history of these early vacuum circuit breakers and analyses the reasons for their lack of commercial success in the light of modern vacuum interrupter technology. It then goes on to consider the current possibilities of vacuum interrupter technology, compared to SF_6 for these HV applications.

Introduction

In 1968 the dominant switching technologies for Transmission applications (over 36kV) were Oil and Air Blast [Figure 1]. However the manufacturers of switchgear were actively seeking new technologies and investing heavily in Research and Development particularly into Vacuum interruption.

Figure 1: English Electric 400kV 35,000 MVA Air Blast Circuit Breakers

As a result of this Vacuum switchgear was being successfully introduced at distribution voltages where Oil switchgear had dominated, [Figure 2], as well as for Railway applications which previously used both Oil for trackside and Air for locomotive rooftop use.

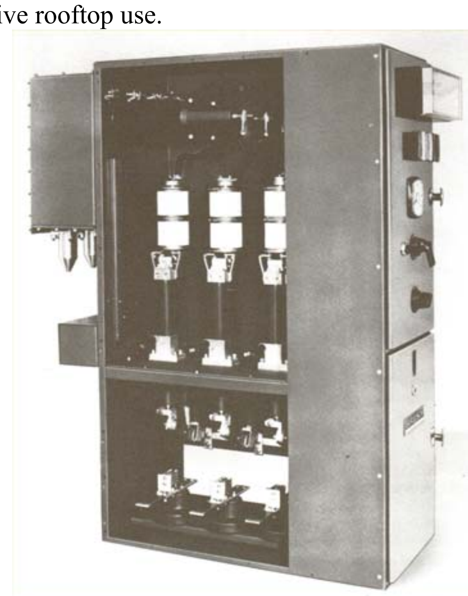

Figure 2: Early 12kV Vacuum Switchgear produced by Brush Switchgear Ltd.

The companies which were leading the development of Vacuum technology at this time – GE in the USA, and AEI/English Electric/ Reyrolle-Parsons in the UK (combining their technology into Vacuum Interrupters Limited – VIL in 1972) were active in all fields of switchgear and were interested in generally applying the new Vacuum technology as a replacement for the older Oil and Air technologies they were currently manufacturing and supplying for all applications and voltage levels. At the same time the same companies were also developing SF_6 technology in parallel, and a technical competition developed between the two technologies.

In the mid 1960's AEI in the UK decided to develop a new range of Transmission switchgear based on vacuum technology. In agreement with their customer – the Central Electricity Generating Board (CEGB), they decided to build a small number of HV Vacuum circuit breakers which would be rigorously tested and then evaluated in service on the UK grid over a number of years.

The VGL8 132kV Vacuum Circuit Breaker

The specification of the VGL8 was a modest 132kV 3500 MVA, 2000A. This was a real rating for the CEGB and meant that the circuit breaker could use the relatively low interruption capability vacuum interrupters in manufacture at the time. At the time the advantages of a sealed for life, zero maintenance on the interrupter, and compact size were all seen as giving significant benefits over the existing, mainly Oil based technology.

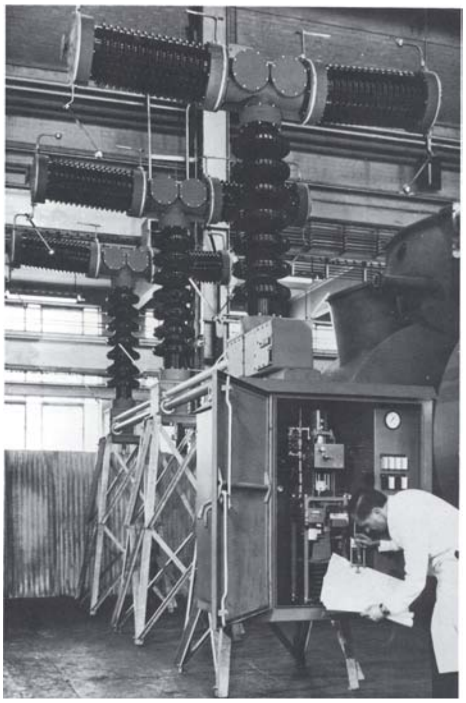

Figure 3: AEI VGL8 3500MVA Vacuum Circuit Breaker.

The concept was to use a number of MV (12kV) vacuum interrupters in series per phase in order to obtain the correct voltage capability, and to use an existing HV circuit breaker spring mechanism adapted for the short stroke of the Vacuum interrupters. This reduced development costs and time considerably and allowed the project to quickly produce the first prototype circuit breakers. However this approach did mean that the Vacuum interrupters were not optimised in any way for the high voltage application. The interrupters were to be mounted in two "arms" in a "T" layout with four interrupters in series per arm, giving eight interrupters in series per phase [Figure 4].

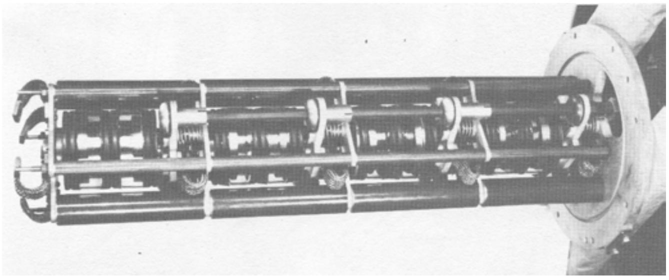

Figure 4: One "Arm" showing assembly of four interrupters with mechanisms and supports.

The interrupters were assembled into a structural subassembly which was then inserted into a porcelain insulator. This provided the outdoor protection and the sealed porcelain "Arm" itself was filled with pressurised SF_6 gas to provide internal insulation – an early form of vacuum Gas Insulated Switchgear (GIS).

As is common with "revolutionary" projects a number of concepts were introduced at the same time as the Vacuum technology, one of which was the concept of "rotating isolation". This is shown in Figures 5 & 6. This was a variant of the 132kV Vacuum circuit breaker with eight vacuum switches in series, and provided load switch isolation on the network. The whole circuit breaker design was capable of being rotated, providing a simple and effective isolation system for the unit while in service. These units were also put into service.

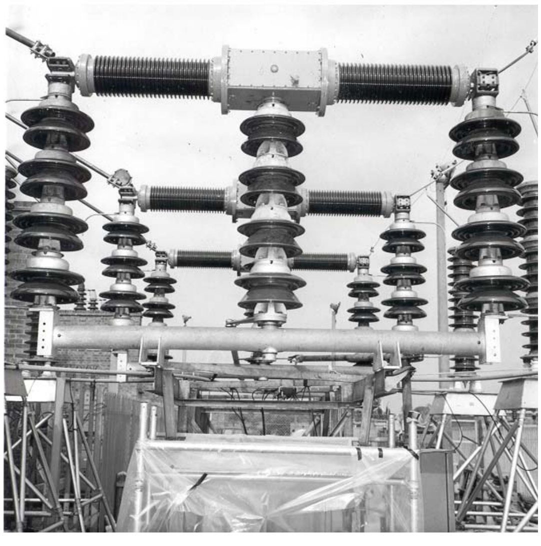

Figure 5: Vacuum switch isolator in service position.

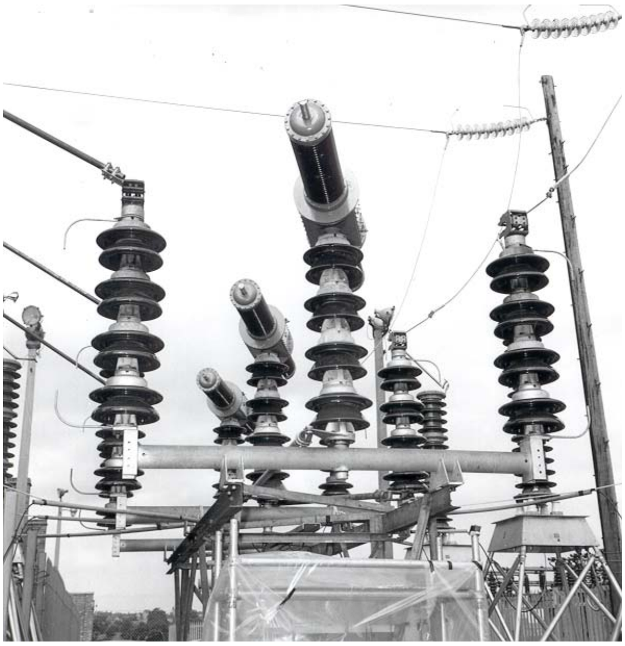

Figure 6: Vacuum Switch Isolator in isolated position.

The Multi-Break Concept

The idea of using a number of interrupter chambers in series was not new – this was common practise with Air and Oil equipment for higher voltages, but introduced a number of significant design complications.

The use of so many gaps in series necessitated the use of balancing capacitors to ensure an even distribution of voltage across each interrupter during operation. The calculation itself is quite complex, as shown in Figure 7. This is a later unit with only six interrupters in series.

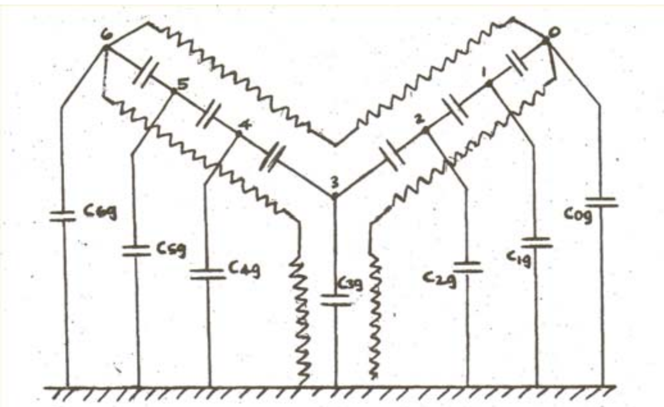

Figure 7: Basic capacitance distribution on each phase.

As a result of this it was thought necessary to mount voltage balancing units in parallel with each interrupter in order to control the capacitance and voltage distribution. This further complicated the construction and added significantly to the cost. These units were as shown in Figure 8 and each consisted of four capacitors and a resistor in series.

There were four of these units in parallel with each vacuum interrupter, giving 32 in total per phase. The 100Ohm resistor was there to damp out voltage oscillations if extremely high current chops occurred – a serious concern, as the excellent capability of vacuum to interrupt very high frequencies was already known. It was calculated that the effect of the resistor would be negligible at fault and normal power frequencies.

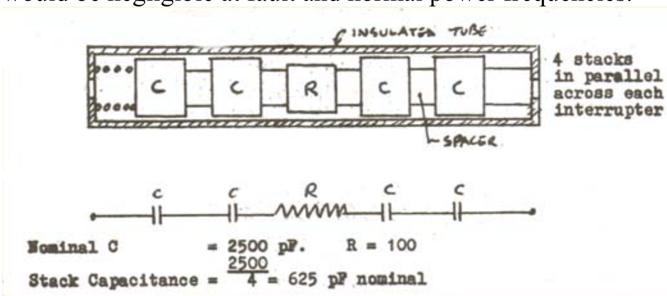

Figure 8: The voltage sharing Capacitor-Resistor units.

Another significant complication caused by the use of eight interrupters in series was that a highly complex mechanism was needed as in total 24 vacuum interrupters had to be opened simultaneously. This was further complicated by the decision to use an existing spring mechanism designed for an Oil circuit breaker. Vacuum interrupters have very short contact strokes compared to Oil and require much less energy to move them. As a result of this and the need to open 24 interrupters simultaneously it was necessary to significantly modify the mechanism. which resulted in a very complex, very expensive mechanism.

Mechanical Characteristics.

The stroke of the interrupters was set at 7/8” (22.2mm) plus an overtravel of 3/8” (9.5mm) for contact spring compression. The operating characteristics recommended by the newly formed VIL who supplied the vacuum interrupters were:

Average Closing Speed 2-3 ft/second (0.6 – 0.9ms^{-1})
Average Opening Speed 5-6ft/second (1.5 – 1.8ms^{-1})
Damping was to commence after ½” (12.5mm) contact movement to prevent bounce.

The designers calculated what the mechanism had a moving weight of over 500 lbs (227kg) and that the total energy requirements were 17600 lbs (78kN). Actually the combined moving mass of the contacts was less than 25lb (11.4kg), which is less than 5% of the total moving mass! The SF_6 pressure was set at 20psi. (136kPa) both to provide electrical insulation within the arms but also to perform damping on the operation of the mechanism via the vacuum interrupter bellows.

Vacuum Interrupter:

The vacuum interrupters used for these Circuit breakers were designated V3 with a later version being the V4 after the merger of the companies’ expertise into VIL.

The V3 interrupter was designed for 12kV applications, although they were used in pairs for Locomotive traction and Trackside applications at 25kV single phase. Their construction is shown in Figure 9.

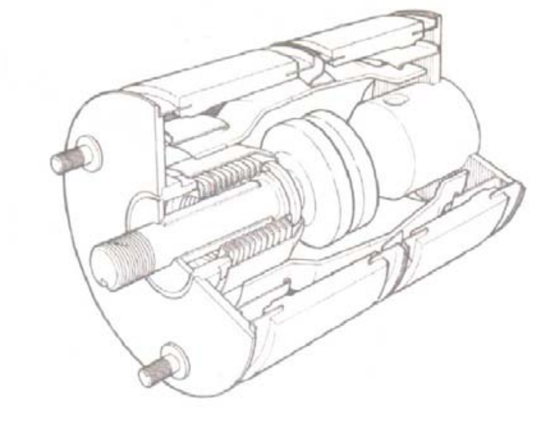

Figure 9: V3 Vacuum Interrupter manufactured by VIL.

The VGL6 Vacuum Circuit Breaker

In 1974 a project to develop a new six break 132kV 5000 MVA circuit breaker was initiated – the VGL6. This project made significant progress and incorporated many lessons learned from the VGL8 design, as well as reaping the benefits of only three interrupters per arm (six per phase). But the project ran into difficulties due to problems in transporting the new VIL V4 interrupters. These interrupters had no guide to prevent the moving contact from moving freely within the interrupter and transportation had resulted in severe damage to the sputter shield within the interrupters severely impairing their performance. A fact, which was only discovered during the testing of the circuit breaker. VIL were asked to provide an improved design, which they did – the V5 which proved an extremely successful design for MV applications up to 38kV, but this arrived too late for the project.

The project was dogged with problems, and eventually in August 1976 the project was ended without the prototypes being completed. This was due mainly to a comparative costing study made between the VGL8 and existing Bulk Oil and a new SF_6 puffer circuit breaker design. The study concluded that the vacuum breaker in production would cost almost twice as much as the other technologies. These high costs were mainly related to the complex spring mechanism and its high maintenance costs, as well as the complex assembly of the arms incorporating the capacitive voltage sharing units, and the high unit cost of the vacuum interrupters, which at that time were still being manufactured in small numbers. Essentially the costs were related to the number of breaks needed per phase to meet the voltage requirement for a 132kV circuit breaker. This was considered a fatal weakness, as eight or even six breaks per phase were clearly not economic. However it is interesting to note that at the same time the trackside railway Vacuum circuit breaker, mentioned earlier, with two breaks in series was dominating the railway market and almost completely replaced the older oil based circuit breakers due to its simple design and almost complete lack of maintenance needed [Figure 10].

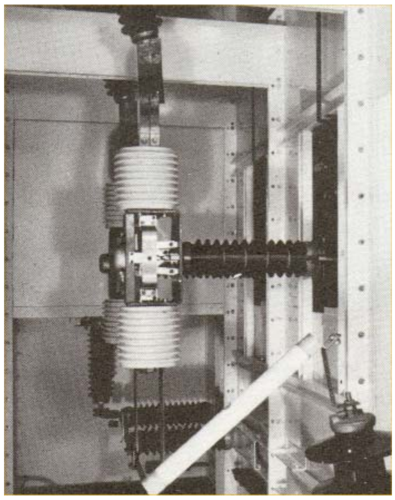

Figure 10; Early 12kV Vacuum Circuit breaker using two V3 interrupters mounted vertically in series, encapsulated in porcelain.

This is significant as the railway system is effectively one phase of a 44kV three-phase system. The same idea using two complete circuit breakers in series was also successfully applied to a 50kV single-phase railway system in South Africa. How is it that this system using effectively the same design of interrupters as the VXH6 circuit breaker was commercially successful? The reasons are believed to be

1. The simple spring toggle mechanism which opened two interrupters simultaneously
2. Air insulation meant that the mechanism did not need to overcome the significant pressure of SF_6 on the interrupter bellows
3. Low energy spring mechanism
4. The simple design allowed the inherent maintenance free nature of the vacuum interrupters to be fully exploited.

Service History

Four VGL8 132kV 3,500MVA circuit breakers were installed on the CEGB network in the UK in 1968, two at Tir John in North Wales, and two at West Ham (London). The circuit breakers performed successfully with the units at West Ham remaining in service until the late 1990's. The units at Tir John were removed in 1980 due to reconfiguration of the network and were reinstalled at East Yelland in Devon. Some time after the installation a problem was seen with overvoltages on the system, which it was thought may have been related to the vacuum circuit breakers. As a result a study was performed by the CEGB. This proved inconclusive as both computer studies and switching tests failed to reproduce the overvoltages, which were calculated to be of the order of 3.5 p.u. The circuit included large capacitor banks and a complex split busbar arrangement at the nearby power station. This study eventually concluded that specific configurations of the circuit including a number of large capacitor banks, coupled with the high frequency interruption capability of the Vacuum circuit breaker could be causing the overvoltages seen on the system. However the report also noted that during the study at least one overvoltage incident was caused by a Bulk Oil circuit breaker switching and on that occasion at least was unrelated to the Vacuum circuit breaker. In the end it was decided that as the system appeared to be vulnerable to overvoltages of whatever cause, surge suppression was fitted to the 132kV terminals of the transformers affected to prevent any further flashovers. This appears to have been successful and the system then continued without problem until the VGL8 circuit breakers were taken out of service in the late 1990's.

Overall the service experience of the four circuit breakers in three different parts of the transmission network was very good, and apart from the overvoltage incidents in East Yelland, the Vacuum circuit breakers behaved perfectly with no reported problems. If they had been economically viable as compared to Oil and SF_6 it appears that the CEGB would have been happy to have more Vacuum transmission circuit breakers in service. Indeed the VHX6 project intended to raise the fault interruption capability to 5,000 MVA and also to increase the rated voltage to 145kV was at the request of the CEGB. If the economics had been favourable then it is believed that today Vacuum switchgear would be a common technology at transmission voltages.

Conclusions

Since the 1960's Vacuum Switchgear has moved on to become the dominant technology for MV distribution systems worldwide (below 52kV) and has been for many years, with SF_6 becoming the dominant technology for transmission voltages.

However due to environmental concerns manufacturers and users are today looking for an environmentally friendly alternative to SF_6, and Vacuum is an obvious choice. A large number of companies including VIL have produced single Vacuum Interrupters for system voltages up to 38kV since the early 1980's, and more recently companies such as Toshiba have produced Vacuum circuit breakers with a single Vacuum Interrupter per phase for system voltages up to 84kV. More recently Japan AE Power Systems Corporation (JEAPS) (Figure 11) and a number of Chinese manufacturers have produced or are developing single Vacuum Interrupter circuit breakers for voltages up to 145kV. This approach immensely simplifies the construction of the circuit breakers and makes them much more economic.

However the development of vacuum interrupters for economic application at the higher transmission voltages requires a significant research and development effort in the field of HV Vacuum interrupters and further work is needed in this area. Another paper at this conference outlines the issues and challenges ahead.

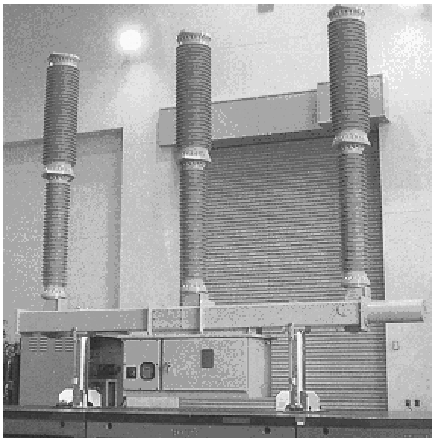

Figure 11; JAEPS Single Interrupter Vacuum Circuit Breaker rated for 145kV.

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