TOC

The Design of a 245kV Vacuum Circuit Breaker

L. T. Falkingham[1*] K. W. Cheng[1], and W. J. Molan[1]
[1]Vacuum Interrupters Limited, Rugby, England

***Abstract-* This paper covers work carried out on the electrical design for a 245kV Vacuum Circuit Breaker, specifically the design of the Vacuum Interrupters. The design is based on a "T" style transmission breaker, with two Vacuum Interrupters in series. The VCB uses a single permanent magnetic actuator with a toggle mechanism to provide the opening and closing forces required and the synchronization of the two Vacuum Interrupters. Vacuum Interrupters are not presently used at these high voltages,**

but the continuing search for a replacement for the present SF6 based technology for environmental reasons leads us to consider the use of Vacuum Interrupters at ever increasing system voltages. At present single interrupter VCB are in service up to 145kV, and have been for many years. This logically leads to the simple concept of a two break VCB for 245kV. Multiple break circuit breakers using both SF_6 and Vacuum technology have been used for many years, and are well proven in service. Rather than taking existing 145kV Vacuum Interrupters and designing a VCB around them, we have taken the approach of designing special interrupters which are intended to work in pairs. Using Vacuum Interrupters in pairs gives significant advantages over single Vacuum Interrupters for these high voltages and this allows us to optimize the vacuum interrupter design for this application. The paper discusses the problems of achieving these high ratings and the methods of optimizing the performance, size, and cost to achieve these requirements. As part of the design process we have modelled the single Vacuum Interrupters and the pair of Vacuum Interrupters using 2D and 3D electrostatic finite element modelling to optimize the voltage design of the Vacuum Interrupters as well as modelling the arc control using 3D electromagnetic finite element modelling to give the required interruption performance. The electrostatic design of the Vacuum Interrupters is discussed in this paper, as well as the design of the VCB. The electromagnetic modelling will be discussed in a future paper.

I. INTRODUCTION

At present single break vacuum circuit breakers are commercially available up to 145kV rated voltage, and in fact have been available for a number of years [1]. Multi break VCB up to 126kV have been around for a very long time, in fact since the 1960's [2]. Historically SF_6 has been the dominant technology since it replaced Oil and Air in the 1970's for system voltages over 52kV.

Figure 1: 245kV Double Break VCB Concept

However, since the 1990's there has been increasing pressure to find a replacement for SF_6 due to its environmental problems. This has resulted in vacuum being used at ever increasing voltages, and today increasing numbers of vacuum circuit breakers at 72.5kV, 126kV and 145kV are in service [3].

There is significant interest in developing VCB to even higher transmission voltages, and this paper looks at the next step, specifically the design of a 245kV VCB.

A. *Existing Technology*

Figure 2: 72.5kV Single Break VCB (courtesy Siemens)

Figure 3: 145kV Single Break VCB (courtesy JAEPS)

Various companies have produced vacuum circuit breakers for voltages ranging from 72.5kV to 145kV with using both multiple and single break. In the world of SF_6 it is seen that single break is preferred giving a simpler, lower cost, more compact, design of circuit breaker. As SF_6 technology had developed over the years, the use of multiple break has moved up in voltage with lower voltages being covered by single break interrupter designs. However vacuum switching is quite different to gas breaking, and there are significant advantages in using two or more breaks for vacuum circuit breakers. One of the issues is the incidence of NSDD phenomena which is more prevalent in vacuum [4], particularly when switching capacitive circuits, and this issue can be effectively eliminated in correctly designed vacuum circuit breakers using multiple breaks.

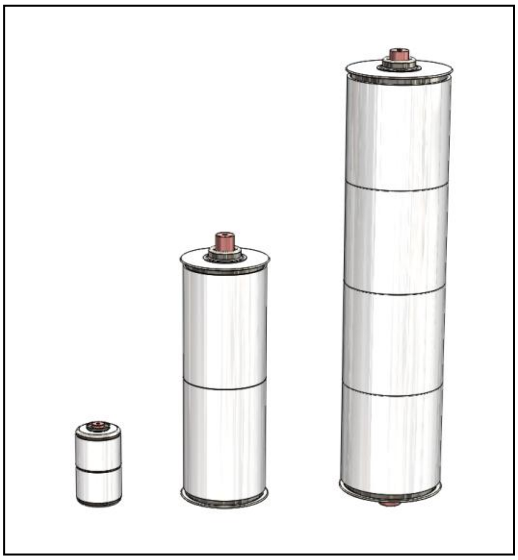

Figure 4: Size comparison of: 36kV, 72.5kV, and 145kV Vacuum Interrupters (all for GIS breakers)

Vacuum interrupters are an excellent solution for switching medium voltages up to 52kV, however as the voltages increase above this it rapidly becomes progressively harder to achieve both the switching and dielectric requirements [5]. In addition, as the VI become physically larger as shown in Figure 4, then the manufacturing techniques and equipment normally used in the manufacture of vacuum interrupters become impractical or extremely expensive. A single break vacuum interrupter design for 245kV would be almost 2m tall and weigh over 120kg! To manufacture this would require a specially designed factory and new processes, which would be prohibitively expensive.

Our conclusion from of all of this is that a solution using multiple interrupters for very high voltages is both more practical and lower cost than a single break solution, in addition to also giving superior performance.

As a result, we have only considered multiple break solutions for 245kV.

II. DISCUSSION

A. *The Concept*

We considered using two or four interrupter heads in series per phase. The four interrupter head solution is interesting, and allows the use of relative small vacuum interrupters with lower unit cost, however it has disadvantages in that it requires more complex drive linkages and a means to synchronise the interrupter heads when opening and closing. All of this adds to the cost and complexity and it was decided that at this stage a double break was a more practical solution as shown in Figure 5. This uses large vacuum interrupters which are probably at the limit of conventional manufacturing systems, but which can and are manufactured in existing factories. To give an indication of size, the circuit breaker is over 5m in height.

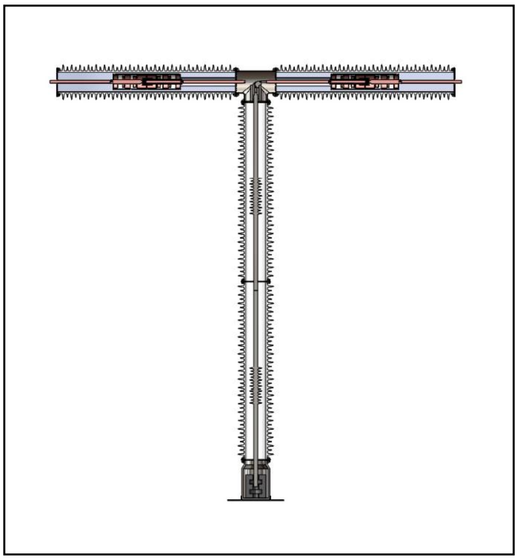

Figure 5: 245kV Double Break VCB

This approach also allows us to use a single mechanism to open both vacuum interrupters by means of a mechanical toggle linkage, giving simplicity and removing the need to take additional steps to provide synchronous opening and closing of the two vacuum interrupters.

B. *Electrostatic Modelling*

The circuit breakers and vacuum interrupters were electrostatically modelled in 3D using ElecNet software as shown in Figures 6 & 7. This is necessary, as the ground plane produces significant asymmetry in the fields around the breaker.

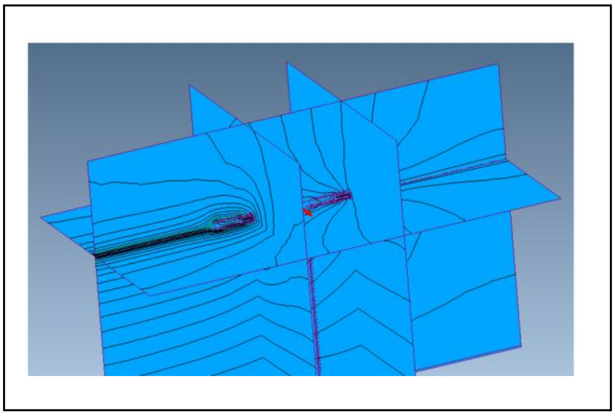

Figure 6: Two Break 245kV VCB 3D Field Plot

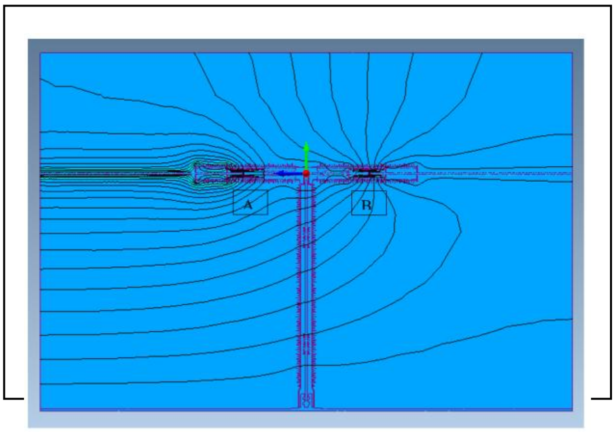

Figure 7: Two Break 245kV VCB Field Plot

We balanced the capacitance to give 50% of the applied stress at the centre point between the two interrupter heads, but even so, modelling the worst case condition, we can see in Figure 7 that the stress distribution on the two vacuum interrupters is not the same, with the interrupter head at the “live” side (marked A) being much more highly stressed than the other interrupter head (marked B).

Figure 8 shows the construction of the circuit breaker head containing one vacuum interrupter. It can be seen that even with large interrupters the interrupter itself is much shorter than the external insulation, due to the relatively poor dielectric strength of air compared to vacuum.

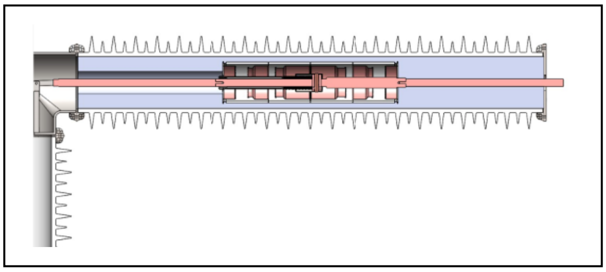

Figure 8: Interrupter Head B

Figure 9 shows the electrostatic field plot for interrupter head B, which shows relatively symmetric stresses across the interrupter head.

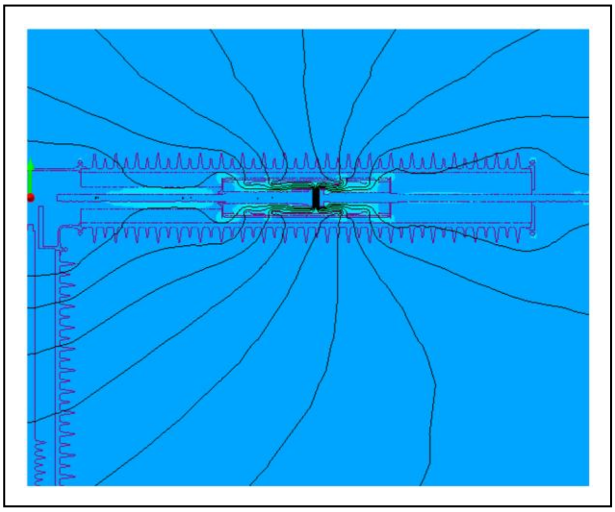

Figure 9: Interrupter Head B - Field Plot

Figure 10 however shows the equivalent stresses in interrupter head A are significantly asymmetric giving rise to increased stresses at one end of the unit.

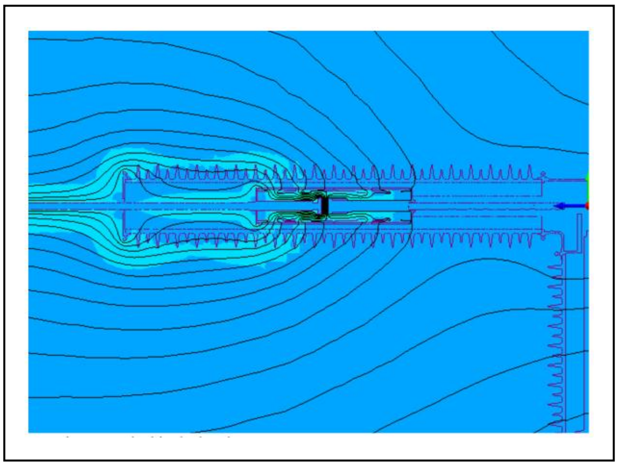

Figure10: Interrupter Head A - Field Plot

Looking more closely (Figure 11) we can also see that within the interrupter A, the electrostatic stresses are also highly asymmetric, with significantly higher stress across the shields and insulator at the fixed end. Interrupter B however is symmetrically stressed, and with lower levels of stress. This indicates that for a two break vacuum circuit breaker at these voltages it would be logical to design the vacuum interrupter with asymmetric shielding and stress control in order to give an optimized design

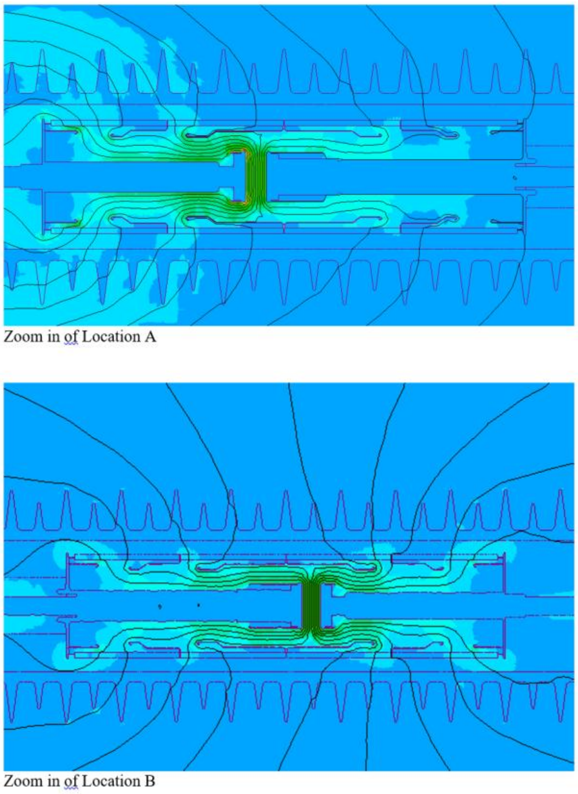

Figure 11: Field plots of the two vacuum interrupters

We are presently working on this asymmetric design which should significantly improve the performance of the pair of vacuum interrupters. It seems that rather than having two lower rated vacuum interrupters and using them in series, it is necessary to design them to work in pairs in order to obtain the optimized design performance.

III. CONCLUSIONS

The modelling shows that using a double break design, 245kV rating vacuum circuit breaker is certainly viable. It also indicates that the electrical stress on the vacuum interrupter can be significantly asymmetrical which means that, for example, using two 145kV rated vacuum interrupters in series does not result in the optimum solution. Instead it is necessary to design the vacuum interrupters and also the interrupter head to accept asymmetrical electrostatic stress in order to give the optimum technical solution. Figure 6: 245kV Double Break VCB Field Plot.

In designing the vacuum interrupters we determined that it is possible to meet the electrical requirements of a 245kV rated circuit breaker using essentially conventional vacuum interrupter design. As such this indicates that 245kV rating is certainly achievable using available technology.

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E-mail of the author(s): falkingham@vil.org.uk