

Appendix A; Vacuum Interrupter Technology and its Historical Development

A.1 Introduction

In this chapter the evolution of the high technology product, which is the main output of the R&D section under study, is reviewed from its inception to its current position of dominance over competing technologies. Different versions of the same product are also developed by the unit's competitors in other companies. The R&D section under study is the sole unit performing R&D in this field in the Group and indeed in the UK. The history and technology described here form a background to the research related in this thesis.

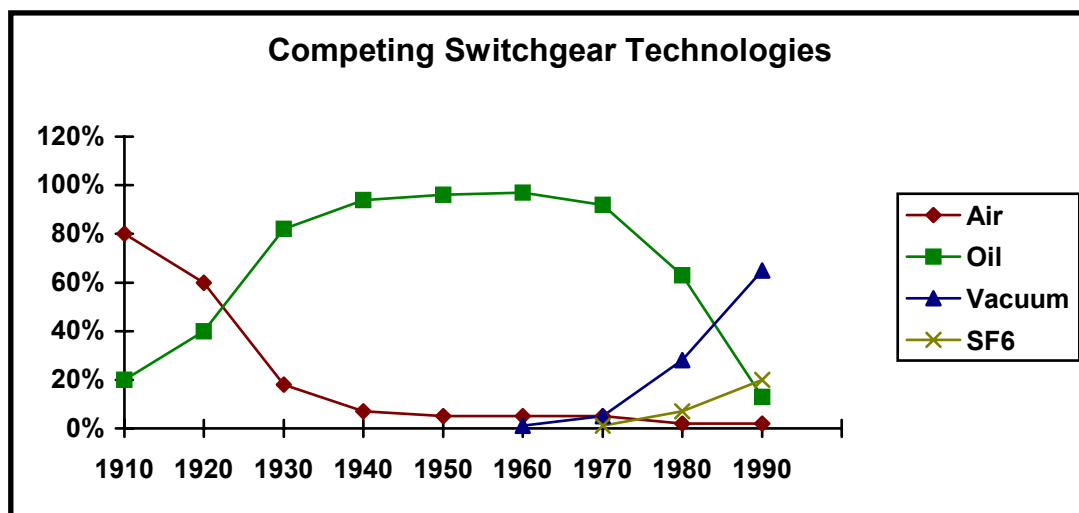
A.2 Three Successive Technologies

The technology in question is the use of Vacuum Interruption in medium voltage (MV) electrical switchgear used in the distribution of electricity. Switchgear performs two main functions within an electrical distribution system such as the ones run by regional electricity companies in the UK and overseas. Firstly it allows the service switching of normal load currents up to 3,150A at voltages up to 36kV. Secondly it acts as a protection system in emergencies to clear short circuit currents up to 40kA and more, within a few milliseconds.

MV electrical switchgear has a world-wide market of over £2 billion per annum¹, and is used in electrical power applications such as distribution by regional electricity companies, mining, oil platforms, ships, and railway traction. There is even a Vacuum Interrupter on the roof of each Eurostar train!

¹ Data sources are discussed in section A.2.1.1

At the start of the 20th century the dominant switching technology used Air as the interrupting medium. That is, switches simply consisted of copper contacts pulled apart in air. As the contacts separated an electric arc occurred between them, and the contact was not properly broken until the contacts were far enough apart that the arc collapsed. As the supply industry developed voltages and short circuit currents increased, and an alternative technology with improved performance was sought.



Graph A.1 The Competing MV Switchgear Technologies. This shows the substitution of Air by Oil and then Oil by Vacuum over an eighty year period. The graph shows the percentage of world output by technology manufactured in each year. As switchgear has a service life of over 40 years, even though the market has expanded steadily, today most switchgear in service is still Oil.

Oil Circuit Breakers (OCB) were developed in which the contacts were immersed in a special oil which quenched the arc. From about 1910 these rapidly became the dominant technology and remained so for the next fifty years.

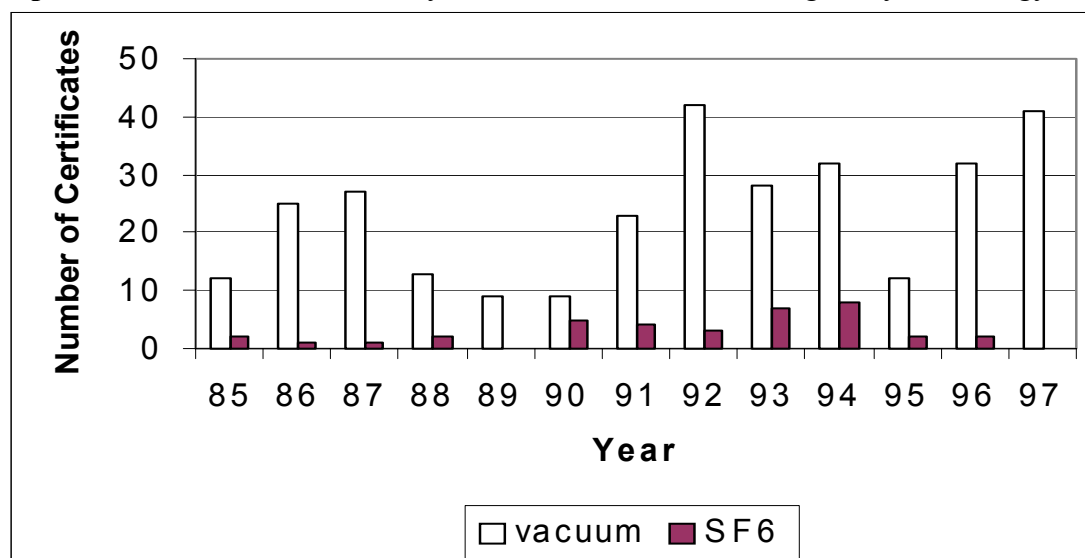
However from work carried out by Millikan in the 1920s and Sorenson & Mendenhall in the 1930's, it had been recognised that vacuum would be an ideal medium in which to switch electricity¹. However the technology needed to manufacture viable products was not yet available and in fact did not become available for some time.

Commercial products based on vacuum technology first appeared in the late 1960's and since then Vacuum Interruption has replaced Oil to become the dominant MV switching technology world wide [Graph A.1].

Vacuum switching technology has significant advantages over the old Oil technology including size, interruption capability, safety, lack of maintenance, and cost per performance. At the introduction of the technology a price premium had to be paid for moving to Vacuum, as is normal, so it was first used in applications such as railway traction and arc furnaces where its technical superiority was most critical.

In recent years the alternative technology based on the use of SF₆ (Sulphur Hexa Fluoride) has begun to break into the MV market. This technology has replaced Oil and Air for the HV (over 38kV) switchgear market over the past thirty years, and non-vacuum companies, mainly in France, have sought to introduce this technology into the MV market as an alternative to Vacuum. However due to environmental and safety issues this is not now seen as a successor to Vacuum and its rate of introduction has slowed down since 1994, with all but one previously SF₆ switchgear manufacturer now offering Vacuum as an alternative to their SF₆ products, [Graph A.2].

³ Photo Courtesy of GEC

Graph A.2 Certificates issued by KEMA for 12-38kV switchgear by technology,

1985-1997. This clearly shows the dominance of Vacuum technology.

A.2.1.1 Data Sources

The data used for Figure A.1, together with the graphs on company market share [A.2.3], were compiled from a number of sources. These were mainly information from internal GEC ALSTHOM marketing intelligence and published competitor information, together with discussions with competitors. For the early years production information was based on discussions with retired production and marketing personnel, as well as some company records. As such a large period is covered the information available is unfortunately incomplete, and the figures arrived at are sometimes the researcher's own interpretation of these diverse sources, based on a personal experience of many of the events for over ten years. The details vary considerably depending on source and so a mean view was taken, but in all but one cases the overall trends are quite clear. The exception is the level of SF₆ penetration of the market. The suppliers of SF₆ interrupters claim a much bigger share of the world market, a claim which is strongly disputed by the other manufacturers. The view shown is on the side of the vacuum view through examination of a neutral source. This was a list of certification of switchgear by year and technology from the international test

station KEMA in Arnhem, Holland which clearly supports the vacuum argument².

A.2.2 How a Vacuum Interrupter Works

Sorenson and Mendenhall(1926) discovered in 1923 that vacuum was an almost perfect medium for the interruption of currents at high voltages. In an AC circuit breaker the extinguishing medium normally absorbs the energy generated by the arc and cools it until such time as a current zero occurs. Then the arc extinguishes naturally and the interruption relies on the dielectric strength of the extinguishing medium recovering faster than the applied voltage can appear across the contacts. If this is so then the circuit breaker has successfully performed an interruption. If however the contacts or the dielectric overheats then reignition may occur. The problem lies in the energy generated during the arcing. This is basically Volts x Amps x time, with the voltage in question being the arc voltage, which is normally considerably less than the applied voltage.

The arc in vacuum appeared to be vastly superior to the conventional technologies mainly because vacuum had such an excellent dielectric strength (Latham (1981)). This allowed a very small contact gap to be used, giving rise to a much lower arc voltage which in turn generates less energy during arcing.

This is vital as the mode of failure of circuit breakers tends to be overheating of the contacts, and obviously the less energy dissipated during arcing, the easier it is for the interrupter to interrupt the current. Also, very importantly, a vacuum gap had a much faster rate of recovery of dielectric strength than conventional interrupting. In addition vacuum invariably interrupted at the first current zero, whereas oil and air tended to wait for later current zeroes, significantly increasing the energy to be absorbed.

Vacuum appeared to have all of the advantages. Due to the low arc voltage and

high rate of recovery interruption was greatly facilitated. The high dielectric strength gave rise to physically small interrupters, allowing the possibility of size reductions in switchgear. The small contact gap, and low energies required to open the contacts meant simpler lighter operating mechanisms. The sealed-for-life characteristic of the interrupter meant that it was truly maintenance free, and the hermetic sealing of the contacts meant that environmental conditions made no difference to the performance of the interrupter.

Although fundamentally sound, the vacuum interrupter concept took many years to bring to fruition. The reason for this was that although the concepts and design of interrupters are relatively simple, virtually every aspect of their design and manufacture required very careful development and testing, and the development of commercially viable products with a maintenance free life of over 20 years proved difficult. However since the 1960's these problems had been solved, and today vacuum interrupters are established as the main switching technology in medium voltage switchgear around the world.

Vacuum Interrupters are physically simple devices which consist of a vacuum tube of between 60mm and 200mm in diameter containing two electrical contacts. To cause interruption one contact is pulled apart from the other by a few millimetres. The vacuum casing incorporates a bellows to allow for this movement. A vapour shield is included to prevent metal vapour from the arc depositing on the inner surface of the insulator, thereby compromising its insulating properties. The basic construction of a vacuum switch or interrupter is shown below [Figure A.1]. The main difference between a vacuum switch and an interrupter is the inclusion of an arc control geometry to allow the interruption of higher currents.

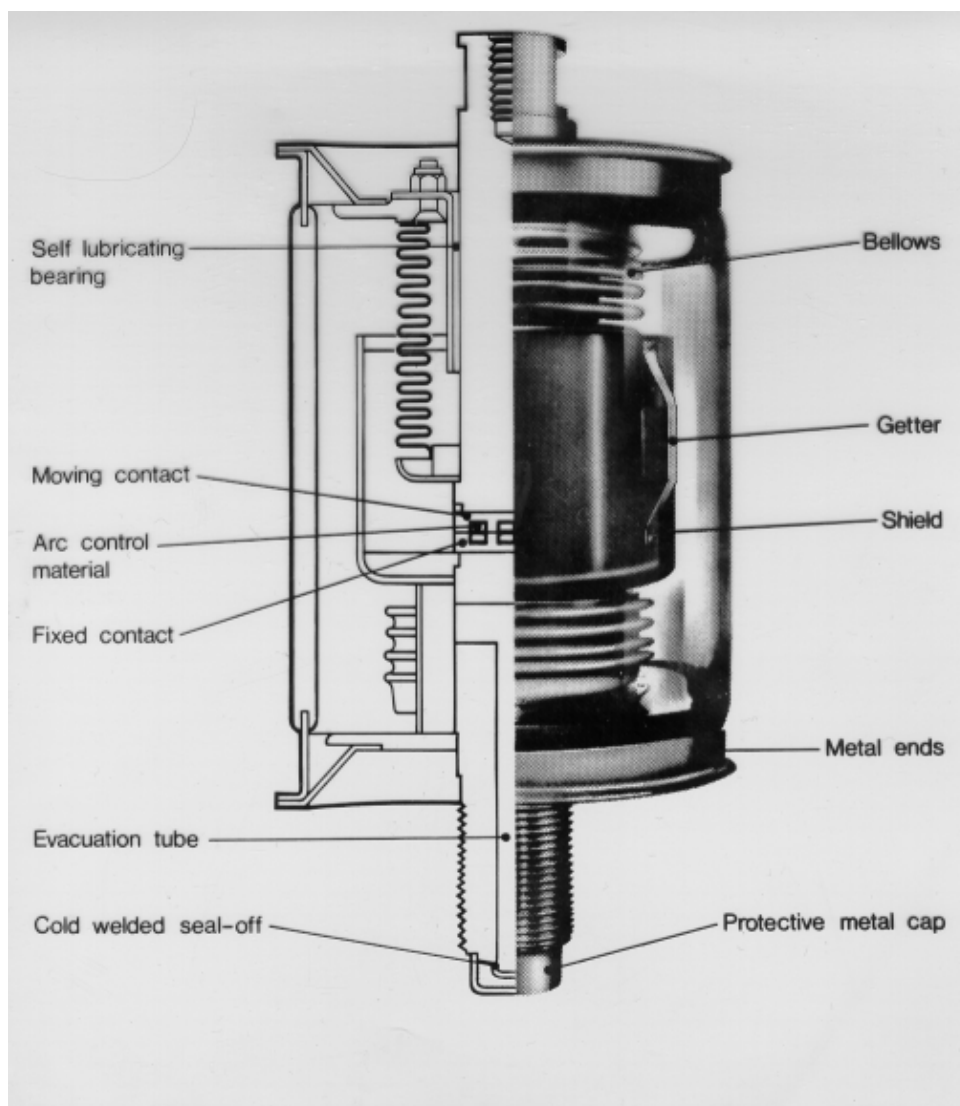


Figure A.1 Half Section of an early design of vacuum switch, manufactured by GEC 1968-1994³.

The mechanisms and controls to make the movement are part of the switchgear external to the interrupter itself, and do not concern us. The interrupters are sealed-for-life, with a design life of twenty years. Good descriptions of the technology, and how Vacuum Interrupters are developed, are given by Rushton & Turnbull (1984) and Falkingham (1986).

Figure A.2 shows the revolutionary “Shieldless” vacuum interrupter design developed by VIL in the 1980’s.

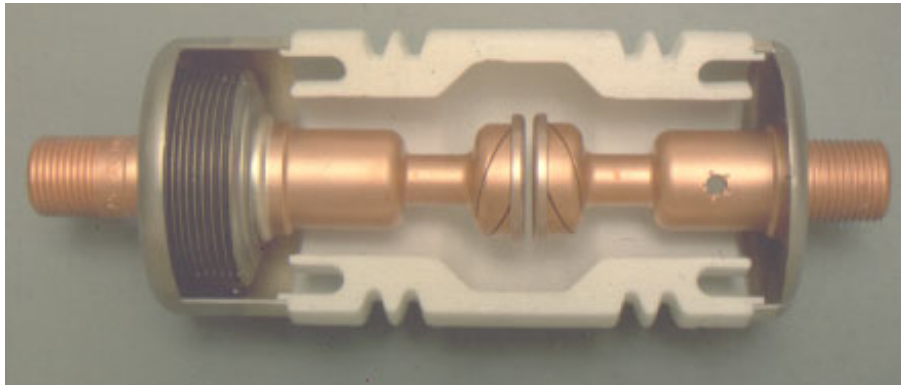


Figure A.2 The V204 Interrupter developed by VIL in the 1980's.

Once the basic performances had been achieved, the drive behind vacuum interrupter development over the past thirty years has been to reduce cost. This has resulted in a continuous uprating of existing interrupters to meet the higher ratings and the successive introduction of ever smaller interrupters for the lower ratings. As can be seen the progression over this period has been quite dramatic, and translates into an interesting situation [Figure A.3].

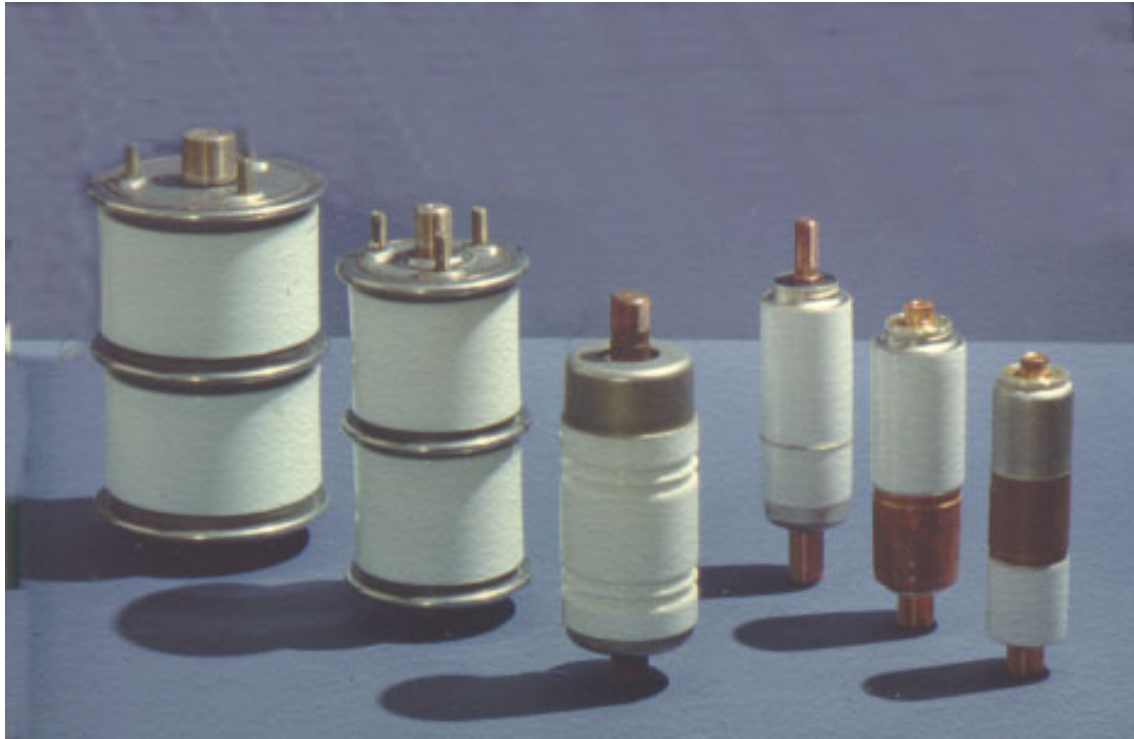


Figure A.3 Evolution Of Vacuum Interrupter Design For 12kV 20kA. The three devices on the left are production interrupters from 1970, (Called V5), 1978 (V8), and 1984 (V204). The three devices on the right are, from right to left, two of the TSR prototypes referred to in the Chronology and the VI 100 referred to in the case study. The reason for the long stems at each end of the VI 100 was to allow it to be a drop in replacement for a larger interrupter.

It is interesting that, as shown in Figure 2.20, the diameter of UK interrupters for a particular rating (12kV:20kA) has reduced almost linearly over a 30 year period. However although the contact diameter initially reduced in proportion and was the driving factor in size reduction, it has now effectively bottomed out in this case, and the continued reduction in body diameter was due to constructional changes in the interrupter design [Figure 2.19].

A.2.3 History of the Development of the Industry

This section describes the history of the development of the vacuum switchgear industry from its origins up to the present. The information for the early part of this section (up to 1978) was collected from discussions with participants and investigation of company records. Great help was given particularly by Professor Alan Greenwood and Dr Michael Reece who were both heavily involved in the development of the technology from the very early days. In 1978 the Participant-Researcher joined VIL and has since been personally involved in the history. As stated before, because of the large period covered the data presented is the participant-researcher's interpretation of diverse, incomplete and in some cases contradictory information gathered from a wide range of sources. It is believed, however, that the history described gives a true overview of the events and relative positions of the key players in the industry.

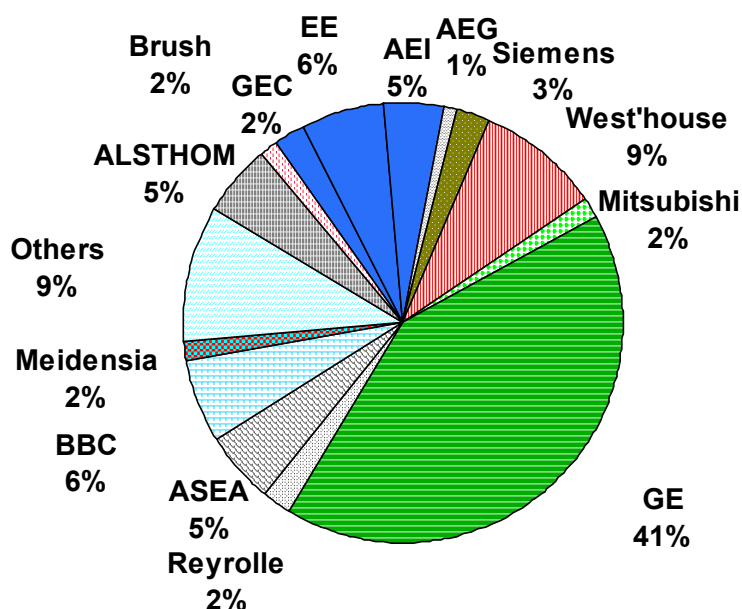
A.2.3.1 The Situation

In 1950 GEC was one of around twenty major companies world-wide manufacturing Medium Voltage Switchgear based on Oil switching technology (12kV –38kV constitutes MV Switchgear). This was a mature technology widely available with little chance for differentiation or opportunity for expanding market share. Due to the low technology content of the equipment there was only a low barrier to entry, and as a result new players were entering the market and diluting the market share of existing companies. In addition the ex-Axis country companies were rebuilding and had started to regain their traditional markets at the expense of companies in the old Allies countries.

A.2.3.2 GEC's Big Strategy

GEC looked to the introduction of a new advanced technology to significantly expand its market share. This is a classic strategy as described by Porter (1980) whereby new products or services are used to change the status quo to your advantage, and use high technology and specialised knowledge as a barrier to entry for the others. This was such a classic approach that GE in the USA also went for this strategy, partly driven by the knowledge that others, specifically in the UK, were heading this way. Also partly driven by the fact that as the largest player they had the most to lose from new entrants. Once this strategy was initiated there was in effect a small “arms race” in which the two players, once they had started, could not stop for fear of losing to the other. Von Braun (1997) argues that all of R&D is affected by this “arms race” philosophy and that a great deal of the current level of R&D is set by this inability to stop or slow down the effort. Interestingly he cites the 1960's as the start of this problem, which is ten years after this case.

A.2.3.3 1950's

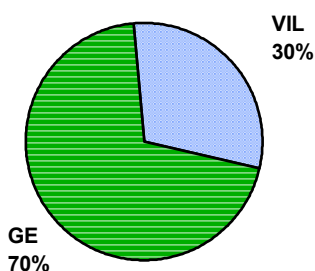


Graph A.3 Estimated World Market Share Of MV Switchgear (Oil) 1950. Companies which merged later are shown in the same shading. As can be clearly seen GE dominated this market, with the GEC/AEI/EE group second. However the Others section is large and rising due to the low barriers to entry.

The potential technical advantages of vacuum were widely recognised, and the first requirement, Vacuum Technology, was now available due to the wartime development and manufacture of large, reliable vacuum valves particularly for Radar. Vacuum technology was contemporaneously developed by branches of many of the switchgear companies, such as EE and GE and was therefore available to them in-house. Research now commenced in earnest to develop commercial vacuum interrupters by providing solutions to the other two requirements. The development of the Special Contact Materials was particularly difficult, as no single material had the required properties, and so combinations of materials had to be developed. The creation of an Arc Control Geometry also

proved extremely difficult, and despite intensive effort by many companies and research laboratories world-wide, over ten years work was needed to overcome these problems.

A.2.3.4 1960's



Graph A.4 Company Market Share (Vacuum) 1960. Vacuum's share of the MV switchgear market was very small, less than 5% at this time, (see Figure A.1), but split as shown between the two original players. GEC/EE/AEI are shown as VIL (Vacuum Interrupters Limited), whose figures show total sales to the GEC group plus others such as Reyrolle.

The race to manufacture the first commercial vacuum interrupters was eventually won by two companies. General Electric (GE) of the USA who released their first interrupters in 1962, closely followed by English Electric (EE). Which later merged with AEI/GEC and formed Vacuum Interrupters Limited (VIL) in 1968 to concentrate their activities in this field. For simplicity the GEC group activity is referred to in all charts as VIL.

GE developed their own Special Contact Material and also an Arc Control Geometry. In the UK, EE also developed a Special Contact Material, and AEI an Arc Control Geometry. These developments formed the basis of most of the world vacuum interrupter development from then on. Thus at the end of the 1960's in the world only two organisations had developed the new technology, and were theoretically in a very good position to exploit their advantages listed in

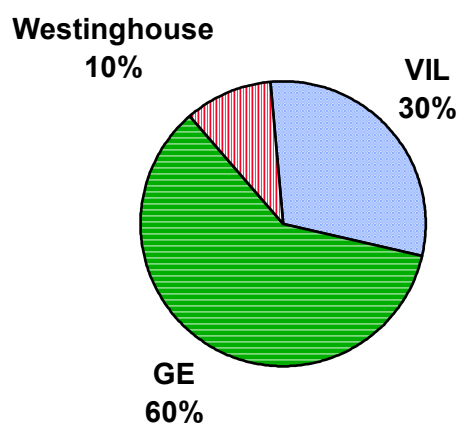
Table A.1;

- Both had major manufacturers of Oil switchgear in-house, and had a large existing market share.
- Both had good contacts with the market and had ascertained that the vacuum technology met a real market need.
- Due to patent restrictions and secret technology, other competitors would have a very large price to pay to develop the technology and expertise needed to enter the vacuum switchgear market.

Table A.1 Vacuum Switchgear - First To Market Advantages

These are classic strategic advantages which effectively gave the two companies a good head start over the competition in the exploitation of the new technology. However Westinghouse in the USA immediately obtained access to these technologies by means of pre-existing technology agreements with GE and English Electric, and the advantage was then shared between three companies.

A.2.3.5 1970's



Graph A.5 Company Market Share MV Switchgear (Vacuum) 1970. This shows the entry of the third company, Westinghouse, who mainly ate into GE's US based share of the market.

USA- GE

Unfortunately things then started to go wrong. From the very beginning the management of GE misunderstood the technology, and lost money heavily in an attempt to apply it inappropriately to High Voltage Switchgear applications (over 250kV). This soured the management's perception of the technology generally. There was also a series of technical problems, which although they were eventually solved, led to almost total disillusionment.

Although the Medium Voltage Switchgear applications now proceeded well, a GE corporate decision was made by GE to sell the technology to a competitor in order to recoup some of the development costs and the losses incurred in the abortive attempt at High Voltage Switchgear applications. Rights and complete technical knowledge were licensed to Mitsubishi.

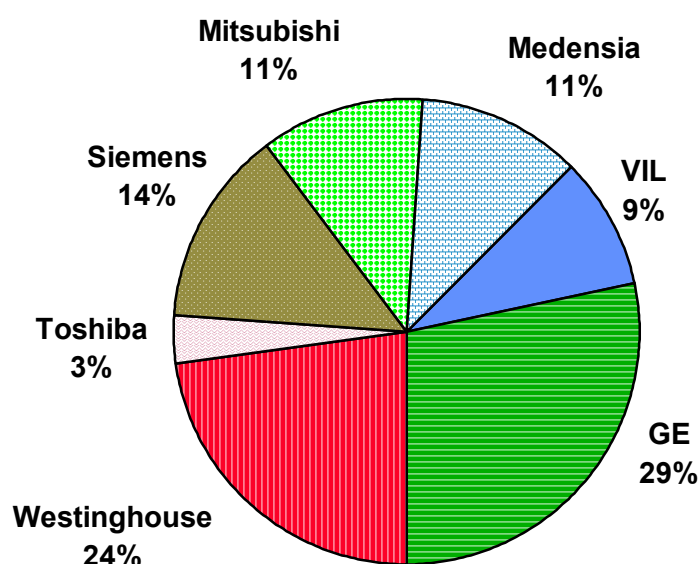
UK- VIL

Meanwhile in the UK, EE and AEI had been merged with GEC, and the new group also tried high voltage applications (132kV), but after some small successes this was quickly abandoned once the limitations of the technology were understood. As the UK approach was considerably more cautious than in the USA no real damage was done to the reputation of the technology and minimal financial loss occurred. The technology was then successfully applied into the medium voltage switchgear. However development costs of commercial products were high and in order to share these costs it was decided to create a new company as a joint venture with Reyrolle, another UK manufacturer of Switchgear. Thus Vacuum Interrupters Limited (VIL) was formed. This gave Reyrolle full access to the products, and some access to the technology. The third

large UK switchgear manufacturer, Brush Switchgear (later Hawker-Sidderly including South Wales Switchgear) also joined as a shareholder a few years later. Thus in order to share the costs and reduce the risks of the technology, GEC gave access to the technology to its main UK competitors, thereby abandoning its UK competitive advantage! This was serious as although a large proportion of the switchgear sales were for export, the UK companies all competed in the mainly ex-colonial markets.

Although there were technical difficulties in the UK these did not constitute a significant problem in the exploitation of the technology. The real problem was that commercialisation of the technology was slow, due mainly to a lack of investment by VIL's owners. In addition there were difficulties with the tripartite ownership of VIL. Eventually in an effort to recoup some of the development costs for short term benefit, the technology was licensed to an international competitor, Siemens of Germany, who went on to further license it to Fuji of Japan. The UK technology now became widespread with parallel development and sub licensing to other companies. Also in order to gain funding for the expansion of its manufacturing facilities VIL continued to sell its technology, although this time within the GEC Group, to units in Africa and India.

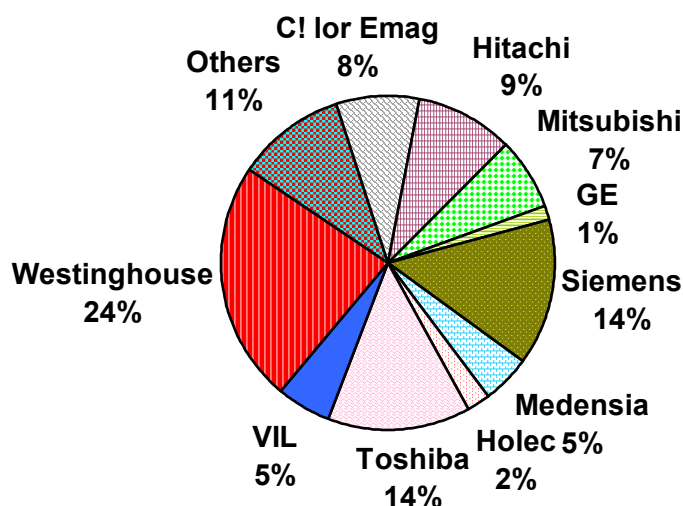
Thus amazingly, prior to exploitation both of the original companies, GE and GEC, had thrown away their advantage and had created a significant level of competition in the new technology.

A.2.3.6 1980's

Graph A.6 Company World Market Share (Vacuum) 1980. The licensing of competitors had by this time led to a spreading of the technology with most of the major switchgear companies acquiring in house capability. In addition Westinghouse and VIL grew their market share by selling loose interrupters to other switchgear manufacturers.

By now vacuum switching was in wide usage, and was beginning to dominate the switchgear market, however this domination was not by the originators of the technology, but by the second and third generation companies. In addition Sulphur-Hexa-Fluoride (SF₆) technology appeared to rival Vacuum Interruption for medium voltage switchgear.

A.2.3.7 1990



Graph A.7 Company World Market Share (Vacuum) 1990. This shows the state of the world market in 1990. It is interesting to compare this with the original chart showing Oil in 1950 [Graph A.3]. After forty years of development and competition the main outcome has been the loss by GE of its market share, despite being the instigator of the new technology strategy in order to prevent this.

By 1990 things had changed again. Firstly in the UK the other shareholders were bought out by GEC in 1988, and finally VIL became a wholly owned subsidiary of GEC. But then in 1990 in a surprise move GEC merged its power division with the power division of Alcatel (called Alsthom) of France. VIL was now part of a joint venture which was run separately from both GEC and Alcatel. Alsthom had no vacuum technology or experience, and instead manufactured SF₆ MV circuit breakers.

GE in the USA had by this time almost completely moved out of MV switchgear. GE's corporate strategy led it to move away from this part of the industry, due in part to the financial losses made and the steady loss of sales and market share.

Although a small unit still made Vacuum Interrupters and switchgear, GE had effectively lost nearly all of its market share to the other companies. From GE's point of view the new technology strategy had been a complete disaster.

A.2.3.8 Discussion of the Development of the Industry

The technology of vacuum interruption has been successfully developed over the past thirty years or so. However over this period the two companies which performed the original developments did not dominate the market despite considerable advantages. Mistakes were made in the exploitation of the technology, and unforeseen problems occurred. Competitors were allowed in by means of relatively low cost license agreements, and went on to take most of the market. Amazingly, the commercial situation after a development period of forty years was very similar to the original position, except that the key original player, GE, had lost its position and had faded to obscurity – contrast Graph A.3 and Graph A.7.

From GE's point of view, and to a lesser extent GEC's, the original strategy of introducing new technology to obtain market advantage had failed badly and in GE's case had effectively resulted in their demise. With hindsight the actions of GE and GEC in licensing their technology to the competition look bizarre, but it must be assumed that the decisions the managers made appeared logical to them at the time. Non structured interviews with people³ who were involved in the decisions at the time or just afterwards revealed that there was serious disagreement as to what to do at the time, and that the people involved in the development of the technology had difficulty in understanding the decisions made. To them the problems were technical, and they had confidence that they had been solved or would be solved soon. However they had serious difficulty in communicating this to the corporate management. This issue, of a situation which is quite clear to some players but other players differ in their assessment,

repeats itself throughout the history of this technology.

Significantly by 1990 the major competitors appeared to have widely differing views of the maturity of the technology and were pursuing different strategies to deal with the situation as they saw it. Since 1985, however all of the players seem to have frozen in their R&D level, with no player moving on to the next stage. In fact only one player has now changed its view, and that was against the logical trend. Westinghouse/Cutler-Hammer has invested heavily in R&D since 1992 and obviously has changed its view from a mature technology to one with a capability for significant development. Interestingly this change came about not by a strategy review by Westinghouse but as a result of a take-over by another company, Cutler-Hammer. This appears to be significant in that once again the corporation acted to frustrate, or in this case, change radically the strategy being pursued by the R&D unit.

<i>Company</i>	<i>View of Technology</i>	<i>Strategy</i>
• <i>VIL (Alstom)</i>	- <i>Technology not Mature</i>	<i>High R&D</i>
• <i>GE</i>	- <i>Technology Mature</i>	<i>Minimal R&D</i>
• <i>Westinghouse (Cutler- Hammer)</i>	- <i>Technology Mature</i>	<i>Minimal R&D</i>
• <i>Siemens</i>	- <i>Technology Fairly Mature</i>	<i>Some R&D</i>
• <i>Calor-Emag(ABB)</i>	- <i>Technology Fairly Mature</i>	<i>Some R&D</i>
• <i>Toshiba</i>	- <i>Technology Fairly Mature</i>	<i>Some R&D</i>
• <i>Hitachi</i>	- <i>Technology Fairly Mature</i>	<i>Some R&D</i>
• <i>Meidensha</i>	- <i>Technology Mature</i>	<i>Minimal R&D</i>
• <i>Holec</i>	- <i>Technology not Mature</i>	<i>High R&D</i>

Table A.3 The Competing Company Strategies 1990. This is the Researcher's categorisation based on his knowledge of the competitors and their products. Clearly there is no consensus on the state of development of the technology amongst competitors, who are concurrently pursuing widely differing strategies. More recently one player (Westinghouse/Cutler –Hammer) has changed strategy from Minimal R&D to High R&D as a result of a take-over, otherwise this diagram is still valid in 1999.

A.2.4 History of the Company Studied, up to the Commencement of the Case Study

The UK company studied was called Vacuum Interrupters Limited, (VIL) at the start of the study, and from its initial founding in 1968, VIL was a company intended to take the basic knowledge generated at the ERA, English Electric, and AEI, and to produce working Vacuum Interrupters suitable for industrial use. It was founded as a joint venture with Reyrolle, a large UK switchgear manufacturer, and competitor of GEC. Later on Brush Switchgear joined, giving joint ownership of VIL to the major players in the UK switchgear industry. The initial development went well, building upon the existing expertise and the original commercial products appeared around 1970. At this time VIL were very much pioneers in their field, and the view was taken that the company should initially concentrate on a limited range of product ratings, and that a deliberate

policy of over engineering would be applied in order to convince the extremely conservative Electricity Supply Industry (ESI) of the viability of the concept. The industry, which had long experience of relatively large tanks of oil using contact gaps of the order of several inches found it difficult to accept the reliability of a small vacuum interrupter using switching gaps of less than half an inch.

After the early development programme, production commenced on a limited basis, restricted both by a slow take up of the technology by the market⁴, and also by a lack of investment in production equipment, which severely restricted opportunities for growth. It soon became obvious that the commercial viability of the product rested on manufacturing relatively high volumes, the problem being the relatively high entry cost in terms of capital equipment. VIL needed to sell 10,000 devices a year to give a financial break-even. This continued as a chicken and egg problem throughout the 1970's, with the company locked into a position of no investment until sales increased, and the sales restricted due to the high prices generated by low production volumes.

VIL had during this period suffered not only from a lack of investment but also a lack of clear direction, both directly caused by its split ownership. As a result, although it had started with a ten year lead over its main rivals this had been severely eroded by 1980. High levels of competition had appeared with an effective glut of new lower-cost interrupters from Japan and the USA flooding the market. VIL's initial advantages were quickly eroded on the basis of cost, and the poor delivery record of VIL. The poor delivery record was created in the main by successive managements of the company attempting to break out of the situation by taking high levels of orders in order to justify investment in equipment, and show a short term "bottom line" profit. Unfortunately on each occasion the investment was not forthcoming and the company oscillated from 'Feast to Famine'. High levels of orders were accepted, the old equipment was run flat out, followed inevitably by breakdowns and quality problems.

This resulted in the company having major difficulties in coping with the production requirements. Deliveries were missed, resulting in orders being cancelled. Worse, having been let down by VIL, the major customers were forced to recertify their equipment with competitors' interrupters. Recertification is extremely costly, which was originally a major advantage to VIL in that once a customer had obtained certification of his switchgear using VIL products he would not look at a competitors' product, even a relatively large price advantage would not be enough to justify a change. This inherent barrier to competition was thrown away by VIL during this time. As a final problem, technical difficulties occurred in the early 1980's, which were mainly due to the problems of scaling up what was effectively laboratory manufacture into full-scale production, with minimal investment. At this time it was also discovered that the insulator flange material was prone to inter-granular corrosion. This coupled with another corrosion problem gave rise to severe doubts as to the viability of the 20 year interrupter life claim. This crisis of confidence was overcome by informing the customers and taking all appropriate corrective action both by changing the interrupter designs and by replacing suspect interrupters as necessary, but it resulted in a severe blow both to the company, and to the credibility of the technology. In 1983 the result of this was a huge operating loss by the company, and the effective loss of most of its business.

In fact, by the end of this period VIL had succeeded in provoking all of its' customers to at least dual source their interrupters, and as the alternative products were invariably newer and being manufactured in modern custom built facilities, they were usually of lower cost. This resulted in the competitors receiving the larger share of the demand. Eventually this extended even to VIL's major shareholder, GEC. At this point, with no sign of a change in VIL's status the future of the company was in doubt. Westinghouse, sensing an opportunity, built a vacuum interrupter manufacturing facility in Shannon, Ireland to take

advantage of VIL's expected demise !

VIL reacted by using its greatest strength, its technical expertise, to produce a new range of single high voltage interrupters for the low volume high price 36/38 kV end of the market where traditionally at least two lower voltage interrupters in series would have been used per phase. These new interrupters were based on VIL's traditional construction techniques and used as many existing components as possible. By following this approach the development required minimal investment in equipment and tooling, and the higher prices available for these products meant that the devices were commercially viable, and in fact were quite profitable. Also, although the world demand for this item was relatively low, it was still a significant demand for VIL, and had the advantage that the company would not be embarrassed by its inability to manufacture very large quantities without significant capital investment. Both Siemens and Westinghouse responded by trying to develop technically equivalent products to VIL's but failed.

VIL was still however too small to be completely viable and continued to rely on its diminishing sales of basic 12kV interrupters. It was obvious that if nothing were done the company would eventually lose this market, as no switchgear manufacturer would introduce new circuit breakers incorporating the old relatively expensive interrupter designs. Unfortunately there was still no sign of the company's joint ownership being changed, nor of any significant investment. In this situation it was recognised that not only was the introduction of a new range of cost effective products vital, but also that this would have to be coupled with a large increase in output. However due to the limitations imposed by the lack of investment no money would be available for the necessary new tooling and production equipment required. Even the cost incurred in performing the necessary development would be prohibitive.

This tricky situation was solved by VIL in a novel way. The first stage was to

investigate what could be done to cost reduce and uprate the existing basic designs. Existing interrupter designs were successfully uprated, but the potential for cost reduction was found to be limited, and the work carried out at this time actually resulted in the company moving away from the basic market. Whereas the bulk of the distribution switchgear market required 13.1 kA interruption only, the lowest cost interrupter VIL now offered was rated at 25 kA! The reason for the restriction in the ability to reduce cost lay in the basic construction of the interrupters, which had not significantly changed since the 1960's. This imposed a very large cost penalty both in cost of materials and the relatively complex and costly manufacturing processes required. In the course of this work it became obvious that normal incremental development would not produce the desired result, as even if a new range of cost reduced devices were to be produced then VIL would still not have the production capacity to meet expected demand unless substantial investment in capital equipment was forthcoming.

The cost of performing the new development was made possible by a UK Department of Industry grant of 30% of cost. This allowed VIL to use its expertise to the full, however there was still the basic problem of investment in production equipment to allow volume manufacture.

As the normal development approach did not offer a viable solution to the basic problem, a more radical course was pursued. Instead of only looking at the vacuum interrupter design, the entire concept of manufacturing a vacuum interrupter was examined, from performance requirements through the entire manufacturing system including manufacture, process and test. The target was to produce a radically new design which would not only meet the technical requirements of the bulk market, at a low cost, but could also be manufactured in very large quantities with existing equipment as far as possible and in any event without significant investment. The new design was intended to form the basis of a new family of interrupters which would eventually replace the old products.

After a crash programme, the new concept was achieved, and the first of the new generation devices, the V204, was successfully launched in 1986. This approach was so successful that Westinghouse closed their plant in Ireland. Two years later GEC bought out the other shareholders, and made VIL a wholly owned subsidiary. This was a significant R&D success and enabled VIL to do more than survive, indeed VIL had a perceived technical advantage over the opposition, which triggered the licensing of VIL technology within GEC world-wide.

This was the situation at the start of the case study.

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Appendix B; Vacuum Interrupter Technology and its Historical Development

This is a chronology of events thought significant which occurred prior to the start of the case study. This history is useful in providing background to the events in the case study.

1923

Sorensen & Mendenhall, (CALTECH) commence first research into Vacuum Interruption. Commercialisation not possible due to lack of supporting technologies.

1950-53

Electrical Research Association (ERA), (UK) commences research into Vacuum Interruption phenomena.

General Electric (USA) commences programme for Vacuum Interrupter development.

Spiral Petal arc control contact developed by General Electric (GE).

Copper-Bismuth Contact material developed by GE.

Development of Contrate arc control geometry by ERA/AEI.

1954

Westinghouse commences research into Vacuum Interruption.

1955

English Electric commences research into Vacuum Interruption.

1958

Development of Copper-Chromium contact material 'CLR' by English Electric. CLR made available to Westinghouse by Technical Collaboration Agreement.

1962

General Electric (GE) announces first development power interrupter rated at 15.5 kV; 12.5 kA; 650 A. CuBi material, Spiral Petal contacts.

1963

Westinghouse announce their first development of a power interrupter 15 kV; 12.5 kA; 650 A. CuCr Material, Modified Spiral Petal contacts.

1965

Announcement of the first commercially available Power Vacuum Interrupter by GE.

1966

Manufacture of first commercial UK Power Vacuum Interrupter by AEI. CuBi material, Contrate contact geometry.

1967

Westinghouse launch their first commercial interrupter rated at 15 kV; 12.5 kA; 800 A.

Manufacture of world's first 132 kV vacuum circuit breaker by AEI, with eight vacuum interrupters in series per phase.

Take-over of AEI by GEC.

GE decide to apply Vacuum Interrupter Technology to High Voltage applications, despite indications that the technology is not suitable.

1968

Joint development by English Electric and Reyrolle of Vacuum Interrupters. CuCr material, Spiral Petal contacts.

Merger of GEC-AEI with English Electric.

Founding of Vacuum Interrupters Limited (VIL) as a joint venture between GEC and Reyrolle-Parsons. VIL established

in Finchley (London). VIL Interrupters based on CuCr Material and Contrate contacts.

GE have major problems with application of vacuum technology to HV applications.

1969

Trial of English Electric 25 kV single phase breaker for British Rail.

Hawker-Sidderly (Brush) joins as a shareholder of VIL.

GE licenses Vacuum Interrupter technology to Meidensha, (Japan).

1973

VIL licences basic technology to Siemens, (Germany).

1984

VIL patents new "Folded Petal" arc control geometry.

1985

VIL Develops new "Shieldless" V200 interrupter incorporating Folded Petal contacts.

1986

GEC buys out other shareholders for control of VIL.

1988

VIL licenses GEC South Africa for Interrupter manufacture.

January 1989

VIL licenses GEC India for Interrupter manufacture.

March 1989

GEC Power Division merges with ALSTHOM of France as a Joint Venture. ALSTHOM had previous contact with Toshiba

(Japan) in connection with possibly obtaining Vacuum Interrupter technology.

April 1989

GEC ALSTHOM negotiates with Toshiba on a VIL based Joint Venture. Intended to supply the Group including Sprecher-Energie, a group company in Switzerland, who require 24 kV devices.

June 1989

GEC South Africa commence manufacture, Initially technical problems are experienced, finally found out to be due to faulty ceramics from supplier.

August 1989

Toshiba visit VIL and GEC ALSTHOM Vacuum Equipment Limited (VIL) as part of Joint Venture preparations.

November 1989

Representatives of VIL and VIL visit Toshiba in Japan in connection with the Joint Venture negotiations.

December 1989

M3 returns from Africa, Joins VIL on three month contract. Assists in Joint Venture Study.

Report compiled and issued on joint venture proposals by B. McKean at EPS(UK)Ltd, independent switchgear consultants.

January 1990

Managing Director of Electrical Distribution Group **resigns**.

February 1990

M3 joins VIL permanently as Technical Executive.

GEC ALSTHOM /Toshiba, VIL-based Joint Venture abandoned.

March 1990

M5 appointed as Managing Director of Electrical Distribution Group (Group)

New Joint Venture negotiated, called European Vacuum Interrupters (EVI). This is a manufacturing unit in France based exclusively on Toshiba technology, neglecting VIL.

April 1990

Deputy Divisional M.D. **resigns**. M1 takes over as sole Divisional MD.

May 1990

Chief Engineer Vacuum , VIL, has a heart attack, off sick for over three months.

June 1990

V404 Ring Main Switch, and all 24 kV developments by VIL suspended by Group. VIL is to be merged with VIL, in Rugby.

July 1990

Group states that; "All future developments at VIL are to be limited to 12 kV and below".

August 1990

Move of VIL to Rugby is announced. Run down of VIL commences.

September 1990

DVS240CA switch (24/27 kV) developed in Rugby is given limited release. Intended for Recloser and Ring Main Unit applications.

October 1990

Physical move of VIL to Rugby commences.

November 1990

New generation of integrated vacuum interrupters and switches, termed RVS1 Range is proposed.

January 1991

Engineering Director of GEC ALSTHOM Distribution Switchgear Limited (DSL) **resigns**.

February 1991

RVS1 proposal is not approved. Group states that VIL may not in the future sell interrupters and switches to competitor companies, a move which effectively restricts future sales to GEC ALSTHOM Group companies only, and reduces sales by one third.

March 1991

VIL move to Rugby completed. Majority of VIL specialists do not relocate. VIL Vacuum Engineering Department is 25% understaffed.

New Chief Engineer appointed at DSL.

April 1991

DSL is instructed to Redesign/Recertify equipment with EVI interrupters as a top priority. Costs to be met entirely by DSL.

May 1991

GEC ALSTHOM Traction Company expresses concern over rumours that VIL will not be able to continue to supply interrupters for railway traction applications. Rumours denied.

July 1991

M3 is instructed to transfer to DSL as Director of Research.

New manager appointed Engineering Director of DSL.

August 1991

Crash programme commenced to convert all of DSL products to EVI devices by March 1993. VIL use to be reduced to a

minimum, covering only those ratings not produced by EVI/Toshiba. VIL not officially informed of this programme.

September 1991

GEC India have quality problems with interrupter manufacture. M3 visits Calcutta to perform audit and to provide training.

DSL redesign their Recloser to take a Westinghouse interrupter instead of the DVS240CA switch, EVI/Toshiba do not have a suitable device. This action appears to contravene a GEC ALSTHOM Group directive to use Group companies as suppliers where ever possible.

November 1991

DSL "OX" circuit breaker certified with VIL V807 interrupter giving significant cost savings over old VIL V506 type.

Visit by VIL to Siemens Vacuum Interrupter Plant in Berlin. This is at the request of Siemens who wish to commence some technical and commercial co-operation! They express their high regard for VIL technology and their surprise at the establishment of EVI.

December 1991

Managing Director of DSL **resigns**.

M4 appointed M.D. of UK Distribution Group, and also M.D. of DSL.

GEC South Africa have problems with manufacture of interrupters. They suspect faulty ceramic manufacture. VIL provide limited technical support.

Appendix C - Literature References Listed by First Author

References are categorised by subject in this listing. Some books cover more than one major subject, if so they are listed more than once.

Papers referred to in the thesis are listed in section C.2, papers used in the **context analysis** are listed in the database, which forms Appendix H.

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Appendix D - The Questionnaire Sent to Authors

Title of Paper

Author(s);

Publication;

Respondent's Name;

Affiliation of Author;

1. Degree of relevance of this paper to R&D Management;

Please Tick one.

<i>Specific to R&D</i>	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>Not relevant to R&D</i>
	☐	☐	☐	☐	☐	

Comment;

2. The background of the Author(s)

	Main Contributor	Any second Contributor	Any third Contributor
<i>Academic</i>	☐	☐	☐
<i>Journalist</i>	☐	☐	☐
<i>Consultant</i>	☐	☐	☐
<i>R&D manager</i>	☐	☐	☐
<i>R&D practitioner</i>	☐	☐	☐

Comment;

3. The main subject area of the paper.*Tick one**Strategy**Tactics**Organisational structure or behaviour.*☐☐*General management..*☐☐*R&D management.*☐☐*Comment;***4. The methods used in the paper.***Primary**Secondary**Tertiary**Drawing from experience.*☐☐☐*Case Study.*☐☐☐*Interview.*☐☐☐*Theoretical discussion.*☐☐☐*Review of literature.*☐☐☐*Analysis of statistical or
database information.*☐☐☐*Comment;***5. Contribution of the paper to theory***yes**no**Does it describe a theory?*☐☐*Does it test a theory?*☐☐*Not relevant to theory*☐☐

Comment;

6. What does the paper give the reader?

Please Tick one.

A Measurement Technique.

☐

A Recipe or set of rules.

☐

Data or Information.

☐

A theory or model,

☐

Strategic concepts,

☐

Operational concepts,

☐

Comment;

7. Which of the following most closely describes the conceptual framework in which your paper is set?

please tick only one box.

Deterministic; R&D can be managed by logic and reason.

☐

Cookbook; Empirical rules can be found that apply most of the time.

☐

Biological; R&D management must adapt continuously to change

☐

Chaotic; R&D is complex and variable, and there are limits to manageability

☐

Comment;

8. Which papers of yours which are relevant to the management of R&D have I missed?;

1)

2)

Please append a list if necessary.

9. Which do you consider to be the three most significant papers relevant to the management of R&D by authors other than yourself?;

1)

2)

3)

Thank you for your assistance. Please return the questionnaire in the envelope provided.

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Appendix E - The Questionnaire Issued to Course Delegates

Strategy for R&D, 9-10 July 1996

Your experience of R&D publications

circle one

- 1) Have you read any books on R&D management? **yes / no**
- 2) Have you read any academic journal articles on R&D management? **yes / no**
- 3) Have you read about R&D management in the papers or technical press? **yes / no**
- 4) If you answered 'yes' to any of the above questions, please state how applicable what you read was to your work

very useful / useful / slightly useful / of no use

- 5) Have you ever published anything on R&D management in the press, journals or as books?

yes / no

- 6) The "Quantitative Methods" lecture just now had two parts. Please tick one box:

- product lifecycles ☐ this was the most useful part
- numerically based methods ☐ this was the most useful part
- or ☐ neither part was very useful

7) What is your background?

Academic

☒

Journalist

☐

Consultant

☐

R&D manager

☒

R&D practitioner

☒

Other manager

☒

Other practitioner

☒

Other:

8) Which of the following in your experience most closely describes the process of managing R&D?

Tick one box

Deterministic; *R&D can be managed by logic and reason*

☐

Cookbook; *Empirical rules can be found that apply most of the time*

☐

Biological; *R&D management must adapt continuously to change*

☐

Chaotic; *R&D is complex and variable, and there are limits to manageability*

☐

Comment?

9) If you have read books or journals, please state which you have consulted most:

☐ not applicable

-
-

Appendix F - The Questionnaire Sent to Practitioners

Alstom survey of R&D management experiences

An extensive survey of publications on R&D Management, together with an in-depth case study carried out within the Group has given rise to a number of potentially important hypotheses concerning the nature of the R&D process. This questionnaire has been designed to test one of these hypotheses using the experiences of the R&D professionals within the Group. The questionnaire is very simple and should take no more than eight minutes to complete.

You are asked for your personal details solely so that the researcher can if necessary seek clarification or amplification of replies.

Name of Unit;

Address;

Telephone;

Fax;

Respondent's Name;

Respondent's Position;

Respondent's Nationality;

SECTION 1. BACKGROUND

1.1 Your degree of involvement in R&D Management;

please tick one box.

<i>Role specific to R&D</i>	<i>1</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>5</i>	<i>Role peripheral to R&D</i>
	☐	☐	☐	☐	☐	

Comment;

1.2 Your amount of experience in R&D as a practitioner and/or manager

tick one box

<i>Less than one year</i>	☐
<i>One to three years</i>	☐
<i>Four to nine years</i>	☐
<i>Ten years or more</i>	☐

Comment;

1.3 Your educational background

<i>Engineering</i>	☐
<i>Science</i>	☐
<i>Management</i>	☐
<i>Financial</i>	☐
<i>Other</i>	☐

Comment;

1.4 Your professional background.

	<u>Current</u>	<u>Previous</u>	<u>Earliest</u>
<i>Academic</i>	☐	☐	☐
<i>Journalist</i>	☐	☐	☐
<i>Consultant</i>	☐	☐	☐
<i>R&D manager</i>	☐	☐	☐
<i>R&D practitioner</i>	☐	☐	☐
<i>Non-technical manager</i>	☐	☐	☐
<i>Comment;</i>			

1.5 Where does the R&D unit for which you are responsible fit into the company?

	<u>tick one box</u>
<i>Section within an R&D Department</i>	☐
<i>R&D Department within a Business Unit</i>	☐
<i>Group</i>	☐
<i>Division</i>	☐
<i>Corporate</i>	☐
<i>Comment;</i>	

SECTION 2 - YOUR EXPOSURE TO R&D THEORY

2.1 How much time have you spent during your career on formal R&D management training?

tick one box

- | | |
|--------------------------|--------------------------|
| <i>none</i> | ☐ |
| <i>5 days or less</i> | ☐ |
| <i>6 to 20 days</i> | ☐ |
| <i>more than 20 days</i> | ☐ |

Comment;

2.2 How many books or articles on R&D Management have you read?

in the last 12 months

previous to that

- | | <i>in the last 12 months</i> | <i>previous to that</i> |
|--------------------|------------------------------|--------------------------|
| <i>none</i> | ☐ | ☐ |
| <i>1</i> | ☐ | ☐ |
| <i>2 to 5</i> | ☐ | ☐ |
| <i>more than 5</i> | ☐ | ☐ |

Comment;

2.3 Have you published or presented papers which are relevant to the management of R&D?

Published

Presented

- | | | |
|------------|--------------------------|--------------------------|
| <i>yes</i> | ☐ | ☐ |
| <i>no</i> | ☐ | ☐ |

If "yes" please give references at the end of this questionnaire.

SECTION 3 - YOUR OPINION OF THE R&D ENVIRONMENT

3.0 Which of the following most closely describes the conceptual framework in which you work?

please tick one box.

Deterministic; R&D can be managed by logic and reason.

☐

Cookbook; Empirical rules can be found that apply most of the time.

☐

Biological; R&D management must adapt continuously to change

☐

Chaotic; R&D is complex and variable, and there are limits to manageability

☐

Comment;

General Comments;

Thank you for your assistance. Please return the questionnaire to:-

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Appendix G: χ^2 Test

G.1. Introduction

This appendix explains the χ^2 test used in this thesis to test the significance of the results of the surveys carried out. The χ^2 test is explained in many standard texts on statistical methods, and is often referred to as Pearson's χ^2 test. Howell (1997) is one of the most thorough sources. The χ^2 test is used to calculate whether the results of a statistical experiment based upon sampling are likely to be valid, by calculating the probability that they might have arisen by chance due to random sampling effects. The test is the standard measure of statistical significance and it applies to almost any type of statistical data.

The χ^2 test however has some limitations and it is necessary to consider these when applying the test (Howell (1997)). Firstly these concern the underlying assumptions of χ^2 .

- **Independence;** This is used in the sense that one choice does not affect another. As an example, this means that in Table G.1, a practitioner choosing, say, **Biological** will not affect the choice of any other respondent. As far as the data in the thesis is concerned there was no possibility of this as all data was collected independently, with no possibility of the respondents knowing the responses of others. This may be a problem for future researchers, however, as for example, if an academic knows of this research by reading this thesis or Falkingham & Reeves (1998), then it is possible that their choice may be swayed by this knowledge and then the results would not be independent. A variant of this, concerning the idea of a

possible “right answer”, is also discussed in Chapter 3, section 3.6, under the section entitled Non Threatening Questions.

- **Normality;** It is necessary to avoid small samples as, if the sample is too small it is no longer possible to relate it to the χ^2 distribution with any useful accuracy. The advice of Howell (1997) is to ensure that all expected frequencies is at least 5. The data in this thesis meets this requirement.

The test can be applied using a proprietary specialist software package such as SPSS 6.2, (Norusis (1994)), or by using Nomographs such as those published by Oppenheim (1992, Appendix II) or by using the CHISQUARE function of MS EXCEL 97.

As an example the significance of the data in table 9.1 from Chapter 9, relating **school of thought** to **researcher type** will be examined. The table is reproduced below.

School of Thought	Journalist	Academic	Consultant	Corporate	Practitioner	TOTALS
Deterministic	9	89	11	93	12	214
Empirical	30	189	55	46	11	331
Biological	5	10	3	7	21	46
Chaotic	7	26	8	2	13	56
None	1	6	0	1	0	8
TOTALS	52	320	77	149	57	655

Table 9.1 School of thought and researcher type.

Let us consider the Practitioner column, which appears to indicate that practitioners authors favour the **biological** school, against the trend of other authors. We ignore the None row, since this really means "don't know". The total number of papers then reduces to 647. Consider the Total column: this can be converted to percentages to tell us what proportion of papers would be expected to be in each of the four classes, and this can be used to calculate the Expectation values for the practitioners in each class, as in Table G.1. below.

School of Thought	Observed number of Practitioner publications O	Expectation values of practitioner publications E	Totals of all publications	Percentages of each school
Deterministic	12	19	214	33.1%
Empirical	11	29	331	51.2%
Biological	21	4	46	7.1%
Chaotic	13	5	56	7.72%
TOTALS	57	57	647	

Table G.1 Analysis of data from Table 9.1

It can be seen that 21 practitioner papers were observed to be biological, against 4 expected. Could this disparity have arisen by random chance? We calculate

$$\chi^2 = \sum \frac{(O - E)^2}{E} = 98.80$$

Where O is the observed number of papers in each cell, and E is the expected number on the basis of no correlation between School and Author Type. See, for example, Kennedy and Neville (1976, p182). The number of degrees of freedom in this problem is 3, since once three numbers have been chosen the fourth is determined by subtraction from the total. Consulting a χ^2 table, (Table A-7 of the same book), we find that for three degrees of freedom, the probability of a χ^2 value greater than 16.268 arising by chance is 0.001, i.e. 0.1%. The χ^2 value we have, 98.8, is off the scale of the table, because the table does not extend to results of extremely high significance.

The test is being used to examine the likelihood of the observed responses of the respondents not being simply due to random selection of data. The higher the χ^2 probability, the more confidence we have that the result is real. The choice of level needed to consider the result significant depends on the researcher, who places it in the context of the research. Typically in social science work 95% statistical confidence is considered acceptable because higher confidence levels usually require far too much data gathering to be feasible (e.g. Norusis (1994, p226-227)). The results presented in this thesis however were all shown by the test to be significant at much higher levels of significance, except where indicated. In fact to those familiar with the χ^2 test, these results are so significant that there is no real need to apply it. The extraordinarily high levels of significance displayed in table 9.2 for example is very strong evidence for the robustness of the **four schools** construct.

G.2. References:

Falkingham L. T. & Reeves R., (1998), Context Analysis, *Scientometrics*, 42, 21.

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Appendix H; Electronic Data Supplied with this Thesis

A.1. Introduction

The CD ROM enclosed with this thesis contains a full electronic copy of the thesis together with a copy of the literature database created during the research and used in connection with the **context analysis**.

Originally Microsoft Word 2.0c was used for the thesis and MS Access 1 for the database. At an early stage the database software was changed to MS Access 2, and later it was changed to MS Access 97. The Word files were upgraded to MS Word 97. MS Excel 97 was used for charts and some tabular calculations throughout. All files on the CD are thus in the format of the MS Office 97 Professional suite of programmes.

