# A History of Fifty Years of Vacuum Interrupter Development. (The English Connection)

L.T. Falkingham, *Senior Member, IEEE* and G.F. Montillet, *Senior Member, IEEE*

*Abstract*—**From the very beginning the UK has significantly contributed to the development of the vacuum interrupter.**

**During the early years of the technology, important techniques and materials were developed which today form the basis of much of modern design.**

**In order to develop viable vacuum interrupters four key technologies are needed. They are discussed in this paper as the “Contact Material”, the “Arc Control”, the “Interrupter Construction”, and the “Interrupter Manufacture”.**

**The description of the 50-year’s contribution of the UK to these four technologies opens the door for a future generation of designers of vacuum circuit breakers.**

*Index Terms*—**Switchgear, Circuit breaker, Vacuum technology, Development history.**

## I. Introduction

THIS document provides an illustration of the role played by Vacuum Interrupters Limited, its historic antecedents and its outgrow in England and its influence in the world in the development of this key technology. Here, we will cover only the last fifty years of innovation, and we will emphasize the key developments and the main ideas generated in the UK world during this period that had some effect on the US technology.

## II. A Very Brief History

Switchgear performs a vital role in the distribution of electrical power acting to control and protect the electrical distribution system. During the past century electrical switchgear has evolved from simple knife switches breaking the hundreds of Amps up to modern circuit breakers capable of interrupting tens of thousands of Amps. Medium voltage switchgear ranges from 1kV up to 38kV, and as the technology has evolved, so the preferred medium for arcing has changed.

Originally this was Air, but in the 1920’s Oil became dominant and remained so up until the 1970’s when Vacuum appeared. Since then Vacuum has become the technology of choice, with a challenge from another technology, $SF_6$ gas, in the 1980’s and 1990’s. Both technologies are currently available but vacuum remains dominant. (See Fig. 1)

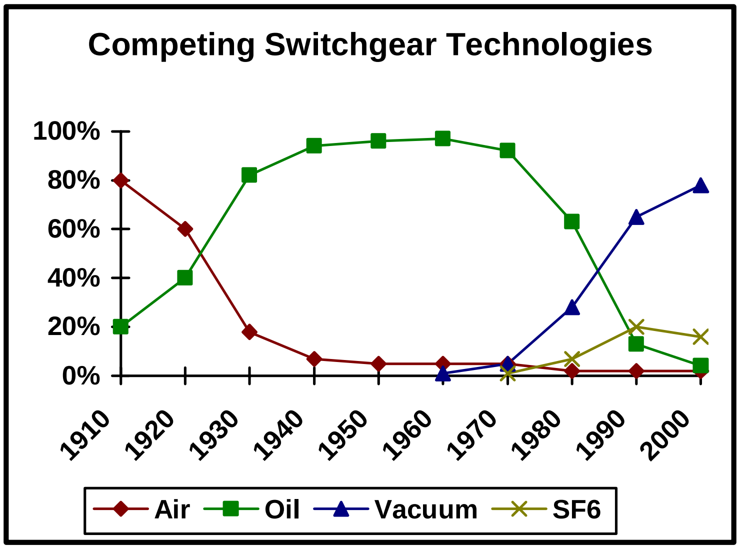

Fig. 1. The competing switchgear technologies in Medium Voltage Switchgear during the 20th Century.

Vacuum switching technology was developed originally in the USA in the 1920’s but remained non-viable until the late 1940’s and early 1950’s, when the support technologies and expertise in vacuum systems, materials technology and clean assembly had become mature and widely available. Serious development of Power Vacuum Interrupters started both in England and the USA in 1953.

English Electric and the member companies of what became the Associated Electrical Industries (AEI) were involved in the English effort together with the Electrical Research Association (ERA).

## III. Electrical Research Association (ERA)

The ERA was heavily involved in this development, led by Dr Michael Reece. Dr Reece had started work on this technology in early 1953, and went on to publish a number of internal reports within the ERA [1]. At the time this work was secret, and was only finally made public in the seminal article “*The Vacuum Switch and its Application to Power Switching*” [2] published in 1959, followed by “*The Vacuum Switch*” [3] in 1963.

ERA was primarily concerned with the interrupting process and the work was concentrated on developing arc control systems which would lift vacuum switching over its inherent 7kA interruption limit (As shown in Fig. 2). Good progress

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was made [4] and in 1968 the “Contrate“ arc control system was patented [5, 6].

Fig.2. The world’s first “contrate” contact vacuum interrupter prototype (right side) built by Dr. M. P. Reece in 1966. The interrupter cleared 16 kA at 12 kV. The interrupter is now in the Science Museum in London, U.K.

### *A. AEI ( part of British Thomson Houston) & English Electric*

In parallel with the work carried out by AEI, English Electric were working on contact materials and the first patent for vacuum switching by English Electric concerning vacuum interrupter contact material based on Silver was registered in 1960. This proved not to be really viable for power interrupters, but after considerable work, English Electric created an almost perfect material with the invention of CLR Chrome copper contact material, patented in 1970 [7].

English Electric had a technical co-operation agreement at that time with Westinghouse Corporation, and the material was then further developed by both organizations. Meanwhile AEI produced the world’s first 132kV vacuum circuit breaker in 1967, using eight vacuum interrupters per phase. However, after the wave of mergers carried out in the 1960’s, English Electric joined AEI in the new GEC (General Electric Company of UK, with no relationship with GE in the USA) organization.

At this time it was decided to bring together the whole UK technology under one organization, and Vacuum Interrupters Limited (VIL) was founded in 1968.

### *B. Vacuum Interrupters Limited (VIL)*

VIL was set up as a joint venture, originally between GEC and Reyrolle-Parsons, but later including Hawker-Sidderly (a division of Brush), at that time effectively covering most of the UK switchgear industry.

At its foundation, VIL had all of the key technical requirements for viable vacuum interrupter [8]. The “Contrate” Contact from ERA/AEI, the Chrome Copper contact material CLR from English Electric, plus vacuum knowledge and manufacturing capabilities from English Electric and AEI.

In fact the unit was located in Finchley, London, in the premises of the AEI Medical unit (Newton & Wright) which had formerly made X-ray tubes, so that high voltage vacuum capability was readily available. (See Fig. 3)

Fig.3. The Assembly Clean Room (Class 100) in Finchley, circa 1978. (Author L.T. Falkingham in center).

VIL not only went on to produce world-leading technology over the following 20 years. Between 1972 and 1992 over 150,000 devices were produced in London alone, and by 1992 VIL had three factories in total producing its designs.

These were located in England, South Africa, and India. The early technology was also licensed to Siemens in Germany.

### *C. The Four Key Technologies*

In order to develop viable vacuum interrupters four key technologies are needed. The description of the contribution of the UK to these four technologies is the main aspect of the paper.

#### *1) Contact Material*

The key contribution in this field was the development of binary Chromium based contact materials.

In a vacuum interrupter the contact material fundamentally determines the properties not only of the arc but also other important properties of the interrupter such as welding.

The first Chromium based material was “CLR”, patented by English Electric, which consisted of a matrix of Chromium infiltrated under vacuum with copper (See Fig. 4).

Later variants included powder metallurgy versions such as “LR” developed by Westinghouse Corp., and “ZLR” developed by VIL [8] (See Fig. 5).

Chrome copper materials have such advantages over other materials that they are now almost universally used for power vacuum interrupters worldwide.

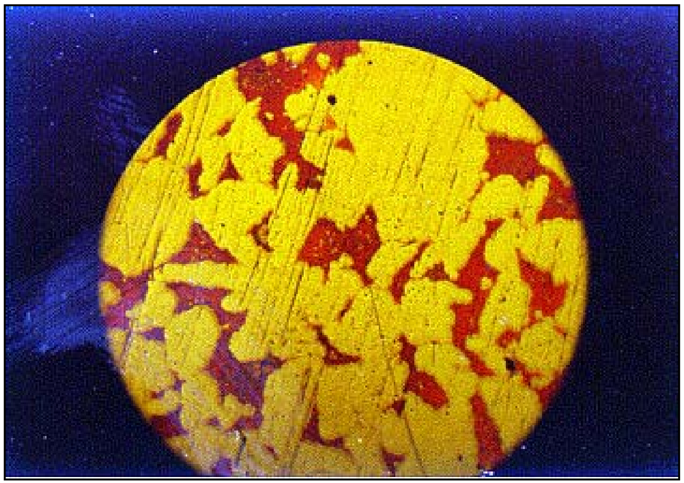

Fig.4. ”CLR” Chrome Copper infiltrated contact material 57% Cr 43%Cu. (VIL circa 1978)

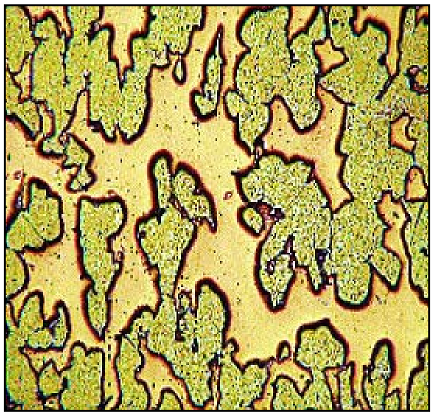

Fig.5 ”ZLR” Chrome Copper sintered material 40% Cr 60%Cu. (VIL 1982)

### 2) *Arc Control*

A fundamental aspect of vacuum interrupter design is the arc control geometry. The interrupter is operated by means of the operating mechanism of the switchgear, the mechanism opening the moving contact by a few millimeters.

After which the interrupter normally interrupts the current atthe first available current zero.

A contact gap of 12mm is sufficient to allow interruption of voltages of 38 kV rms, and currents up to 40 kA.

Fig.6. Still frame from High Speed Film at 10,000 fps showing constricted arc on plain contact geometry CLR carrying 5000 A. The liquid spilling over the edge of the contact is boiling chromium and copper. (VIL circa 1970)

However there is a problem with interrupting large currents. At low currents (less than 7 kA peak) the arc is naturally diffuse, spreading the current evenly over the contact surface, and the contacts interrupt the current naturally at the first available current zero. (See Fig. 6).

However at higher currents the arc constricts and the energy is then concentrated over a small area of the contact resulting in local overheating and a failure to interrupt.

This crucial problem was solved in a novel way. The large current to be interrupted was made to travel in such a way that the self induced magnetic field made by the arc between the contacts move in exactly as an electric motor turns as in Fig.7.

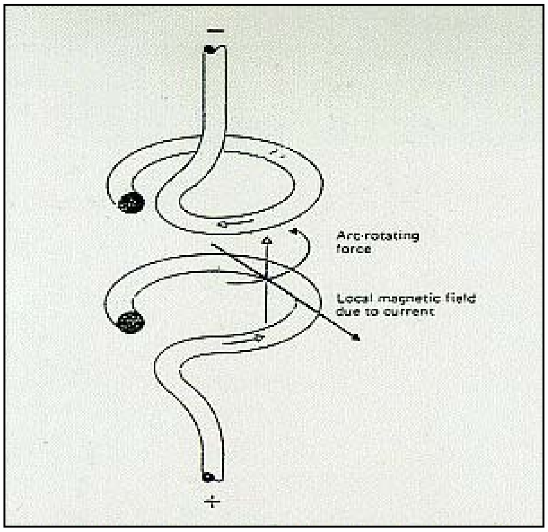

Fig.7. The principle of operation of a Radial Magnetic Field contact (RMF)

The slots in the sidewalls of the cup force the current to flow in such a way as to develop this field and the result is shown in Fig. 7 & Fig. 8. The arc is driven around the periphery of the contact just like an electric motor.

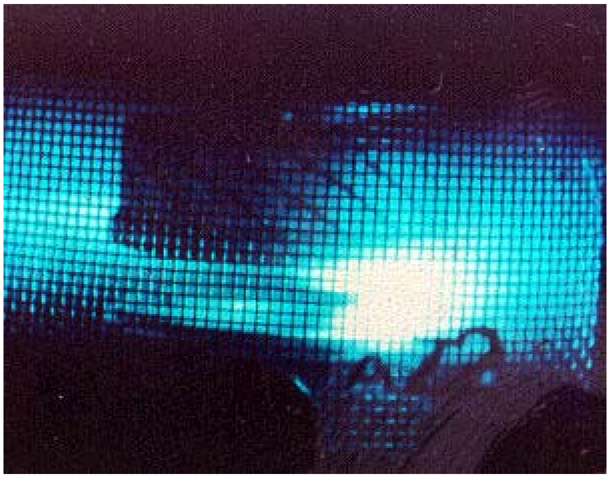

Fig.8. Still photo from a High Speed film at 5,000 fps showing a 55 mm diameter RMF contact interrupting 31.5kArms (VIL circa 1982)

At Vacuum Interrupters Limited (VIL) in 1983 a new form of RMF contact geometry was developed.

This is the “Folded Petal Contact“ [9], which significantly improved upon the power handling capability of the “Contrate“ and allowed the production of the world‘s smallest

20 kA vacuum contact at a voltage rating of 12 kV (32mm dia.).

In the 1990's this work continued with a new Axial Magnetic Field (AMF) contact geometry being developed by the ALSTOM team in Rugby.

Fig. 9 shows the change in size of Arc Control System as developed by VIL between 1968 and 1984.

Both contacts are rated at 20kA for a voltage of 12kV.

The contact on the left (Folded Petal) actually performs better, and is still the smallest contact in the world for its rating (32mm diameter).

Fig. 9. Comparison of size of contacts for 12 kV at 20 kA rating from 1968 to 1984.

The size of the contact fundamentally defines the size and cost of the interrupter, and Fig. 10 shows how work to continually reduce the size of the contacts at a given rating resulted in constant reductions in product size. This figure shows four interrupters ranging from a type V5 of 1975 to a type VI 100 of 1995. All of these are production devices and are rated at 20 kA at a voltage of 12 kV.

The smallest is only 60mm in body diameter, with a 32-mm diameter contact.

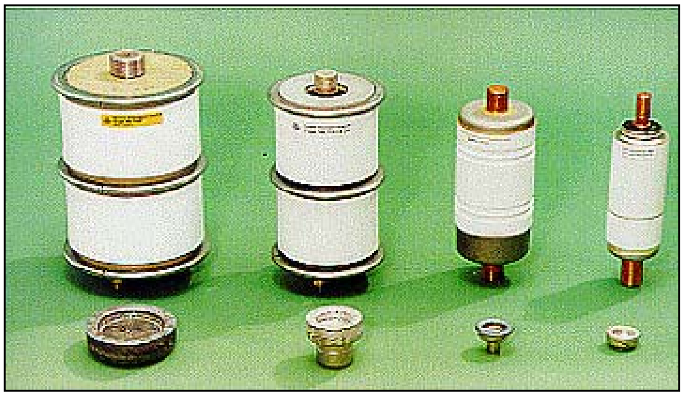

Fig. 10. Picture showing the reduction in size of interrupters from 1975 to 1995, for a constant performance of 12kV at 20kA.

### 3) *Interrupter Construction*

In order to use this reduction in the size of arc control contact, VIL also looked at radically changing the construction of the interrupters, together with their methods of manufacture.

Traditional interrupter construction as shown in Fig. 11 resulted in devices, which comprised about 35 components, plus braze.

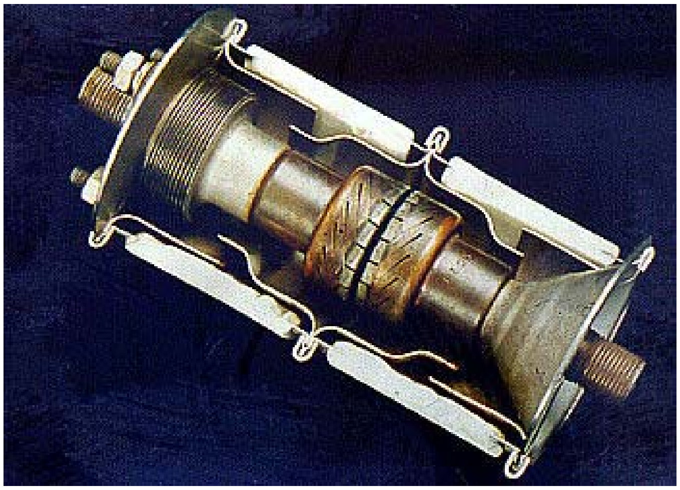

Fig. 11. Typical interrupter design from the 1970's.

The design was dominated by the fact that an anti-vapor shield was needed to prevent metal vapor produced by the arcing coating the insulating envelopes leading to electrical breakdown.

The basic design of VIL interrupters follows the style of Fig.11. This consists of cup shaped or "Contrate" arc control contacts, Glass-ceramic insulators, and metal anti-vapor shields to protect the insulators. The devices consisted of subassemblies, which were assembled, vacuum brazed, and then subsequently welded together, after which they were sealed off in a vacuum furnace. All of this was carried out under strictly controlled conditions in a Class 100 Laminar Flow clean room. For high voltages this shield had to be electrically floating which resulted in a need for two insulators with the vapor shields being mounted between them.

This added both complexity and cost. It also resulted in a large number of vacuum seals being required. VIL's approach was to produce a "Shieldless" interrupter with one ceramic, with no metallic vapor shield. Together with the new "Folded Petal" arc control system, this allowed the device to be built using only seven components plus the braze washers. The interrupter is shown in Fig. 12.

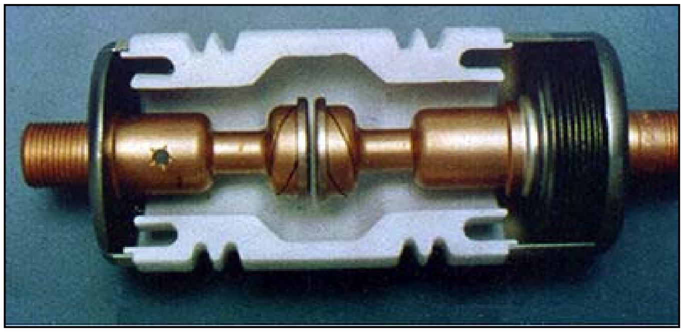

Fig. 12. The V204 interrupter which was the world's first "shieldless" vacuum interrupter. It is rated at 20 kA at a voltage of 12 kV.

The design worked by including internal fins at each end of the ceramic, which protected a small area of the surface of the ceramic. When metal vapor from the arcing arrived at the ceramic it coated the central section, but did not coat the ceramic protected by the fin. This small length of ceramic is more than sufficient to meet the dielectric requirements of the device (75kV or 95kV BIL). By this innovation the size and complexity of the devices was radically reduced [12].

### 4) *Interrupter Manufacture*

However a further significant innovation was also made. The simplicity of construction of the shieldless interrupter allowed the possibility of assembling the device in one operation, removing the need for subassemblies.

This concept was taken much further and the device was designed to be self-jigging and self-venting during brazing. This allowed the device to be completely assembled, loaded into a vacuum furnace, pumped down and heated to clean the components.

Finally the temperature was raised to melt the braze material sealing the device with vacuum as well as joining the components.

This is now called the "One Shot Seal off" system. Fig. 13 shows a facility where this type of assembly is done, and Fig. 14 outlines the specific process of melting the braze material and sealing the device with vacuum.

With a large furnace 100 or more interrupters can be sealed off in one go, and this innovation resulted in a very significant saving in time, effort and cost.

## IV. CONCLUSIONS

Overall, from the very beginning the UK has significantly contributed to the development of the vacuum interrupter.

During the early years of the technology important techniques and materials were developed which today form the basis of much of modern design.

The Copper Chromium material is now universally used. The approach of simultaneously designing both the product and the manufacturing process led to the "One Shot Seal Off" technique, which today is the manufacturing method of choice.

Fig. 13. This shows "One Shot Seal Off" of V204 vacuum interrupters in a clean room in South Africa. After assembly the interrupters are loaded into a vacuum furnace and brazed and sealed at the same time.

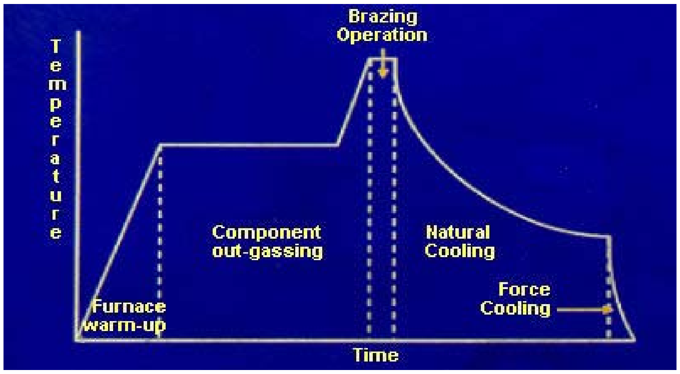

Fig. 14. The "One Shot Seal Off" Cycle

Innovations such as the "Shieldless" interrupters have shown a willingness to try what conventional wisdom said was not possible, together with the skills to make the solutions work. The UK success was recognized by the award of two Nelson Gold Medals (1983 & 1996) for workers in this field.

Over the past fifty years the world has moved away from national companies and technology towards a multinational view. With the transfer of English Electric facilities to the GEC ALSTOM company and then to the Alstom's facilities in France, Vacuum Interrupter design and manufacture has now physically ceased in the UK. However, the technology developed will continue in a European and world context with UK Engineers' continuing involvement, and future generations will be based on the solid foundations of fifty years of Vacuum Interrupter development in the UK.

## V. ACKNOWLEDGEMENT

The main ideas of the subject material were previously presented in a different form at the XXth International Symposium on Discharges and Electrical Insulation in Vacuum (ISDEIV) June 30 - July 5, 2002, in Tours, France.

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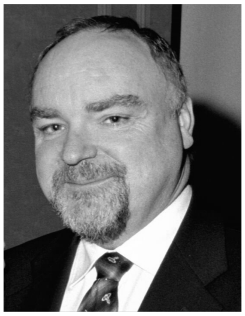

**Leslie T Falkingham** (M 1998, SM 2003) was born in Leeds, England, on May 13, 1955, is married and lives in Rugby, England.

He was made a Fellow of the Institution of Electrical Engineers (IEE) in 1988 and a Fellow of the Institution of Mechanical Engineers (IMechE) in 1987. He is a Chartered Engineer in the UK (C.Eng) and is also a European Engineer (Eur.Ing).

He graduated from Lanchester Polytechnic, Coventry, England, in 1978 with BSc (Hons) in Combined Electrical and Mechanical Engineering, and obtained his PhD by part time study from Cranfield University (UK) in 2002. His thesis was on the subject of optimization of industrial R&D and R&D Strategy. He is currently a Visiting Fellow of Cranfield University. He is a member of the Permanent International Scientific Committee of the International Symposium for Discharges and Electrical Insulation in Vacuum (ISDEIV) and is also a member of the Current Zero Club, which is an international group of world leading Scientists and Engineers with an interest in electrical switching phenomena.

His employment experience includes; Over ten years at Vacuum Interrupters Limited, London, England which he joined as a graduate apprentice and where he performed R&D, and designed and developed vacuum interrupters ending up as engineering manager. This was followed by two years with GEC South Africa where he designed and built a new factory near Johannesburg to manufacture the vacuum interrupters he had designed. After which he spent ten years with GEC Alsthom Rugby where he built up and then led the ALSTOM World Centre of Excellence for Vacuum Switching Technology and in addition was heavily involved with the ALSTOM vacuum interrupter plant in Calcutta, India. Since 2001 he has been Technology Director for ALSTOM T&D Medium Voltage Business, based in the T&D head office, Paris, France.

He has spent most of his working life involved in the research, design, development, and manufacture of vacuum interrupters and switches for medium voltage vacuum switchgear. He holds 26 patents, and is an acknowledged expert internationally in this field. During his career he has produced papers and presented lectures on the technology worldwide. His special fields of interest include all aspects of vacuum interrupter design & manufacture; R&D Management & Strategy and in particular the optimization of industrial R&D.

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 "distinguished contribution to electronic engineering".

**Georges Montillet** (M 1970, SM 2003) was born in Nice, France on December 8, 1944.

He graduated from the Polytechnic Institute of Grenoble (Ecole Nationale Superieure d 'Ingenieur) in 1968 in Power Electrical Engineering (MSc) and in 1974 obtained a MBA in Finance/Operational Research from NYU-Stern School of Business in New York (Beta-Kappa-Sigma). He joined Cogenel, now ALSTOM, New York, in 1971 after working on several projects in France, Algeria and New York.

He was Assistant to the President from 1976 to 1990, and he was Executive Vice President of GEC– ALSTHOM T&D from 1990 to 1997, Deputy General Manager of the ALSTOM US High Voltage Switchgear from 1997 to 2000, and is now Vice President Marketing and Communications for the High Voltage Switchgear. He is a member of IEEE since 1970, and a member of the High Voltage Switchgear Committee, and various Subcommittees, one of which is High Voltage Circuit Breakers. He is also a member of CIGRE and SEE.