POWER SYSTEMS ENGINEERING DATA

SQUARE D COMPANY
Wherever Electricity is Distributed and Controlled

Volume 3 Number 12

PUBLISHED BY MIDDLETOWN HEADQUARTERS OF SQUARE D COMPANY, MIDDLETOWN, OHIO

September, 1983

Subject:

A Comparison of Vacuum and SF6 Technologies At 5kV Through 38kV

A Paper Presented at IEEE Petroleum and Chemical Conference, Denver, Colorado, September 14, 1983

By D. L. Swindler
Chief Engineer
Square D Company, Middletown, O.

ABSTRACT:
This paper discusses comparisons between characteristics of vacuum and SF6 (sulfur hexafloride) interrupters as a result of comparative tests and the review of papers relating to the subject. It deals with subjects not currently defined by existing industry standards, which are nevertheless, important to the user. At this point in time, vacuum tends to favor short range economics and yields longer life for highly repetitive operations at load break current levels. SF6 technology tends to increase system reliability due to a number of inherent characteristics.

Classes 6060/6065

INTRODUCTION

Vacuum and SF6 technologies as applied to high voltage circuit breakers and motor control have been used extensively for over 20 years in various forms. Particularly considering circuit breakers, these technologies are rapidly replacing older technologies such as oil, magnetic air and air blast breakers. Each technology has found specialties with certain technologies dominating specific applications. In recent years, vacuum interrupters have found more use below 38kV, and SF6, while more frequently used above 69kV, is now being used at all voltages down to 2.3kV. Within the range of 2.3kV through 38kV, there is an array of products. Among these applications are high voltage motor controllers, high voltage load break switchgear, station circuit breakers, metal-clad switchgear, and many others which now use either vacuum or SF6 technologies.

VACUUM TECHNOLOGY

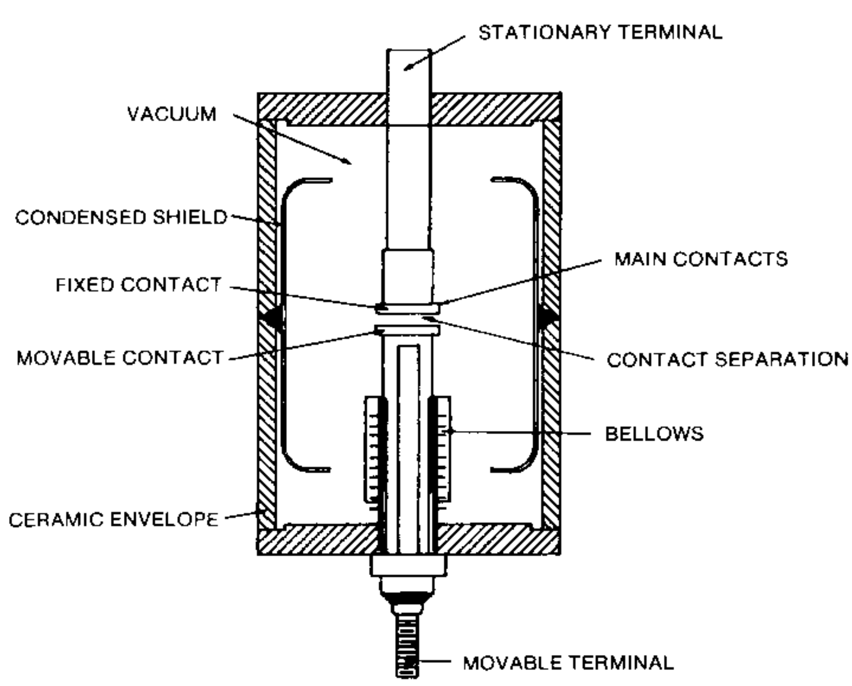

FIG. 1 – Vacuum Interrupter

A vacuum interrupter usually consists of two butt contacts arranged in a vacuum chamber having a pressure in the range of 10 -8 to 10 -6 torr. As the contacts separate an arcing plasma consisting of metallic ions develops, providing a media for the transfer of electron current until the arrival in time of the first current zero. The vacuum interrupter has the outstanding characteristic of fast dielectric recovery rate because of the rapid condensation of the metallic vapors. There has been a considerable amount of technological development in various systems within the vacuum interrupter to increase its interrupting ability, stabilize the arc plasma, and lower transient overvoltage levels. These goals have been achieved through magnetic field control, contact materials selection, and condensing shield arrangements. Many technical papers concerning these subjects have been written and presented. The result is that vacuum interrupters have gained a great deal of respectability when properly applied.

SF6 TECHNOLOGY

SF6 technology has been well respected for several years in systems rated above 69kV. Because of the unique properties of SF6 gas (1) this media of interruption is finding useful and economical applications at nearly all voltage levels. At present, the two predominant SF6 techniques are the puffer type interrupter and the magnetic type interrupter.

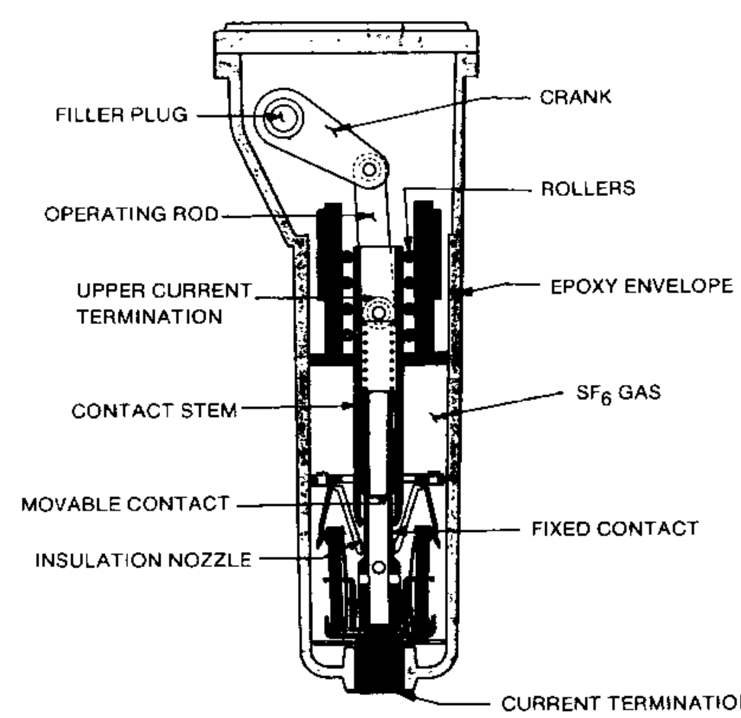

FIG. 2 – SF6 Puffer Type Breaker

PUFFER SF6 INTERRUPTER

The puffer type interrupter uses a piston to compress the SF6 gas in one portion of the interrupter and then forces the gas through a nozzle arranged in such a manner to exchange at a high rate the dielectric media in the region of the arc. Since the ionized gas has the ability to capture free electrons, has high thermal conductivity and has high insulating qualities, the ionized gas quickly regains its insulating qualities near current zero thus completing the current interrupting process.

---

(1) David L. Swindler, SF6 Puffer Type Circuit Breakers for Applications of 15kV through 38kV, Square D Company, Middletown, Ohio.

MAGNETIC SF6 INTERRUPTER

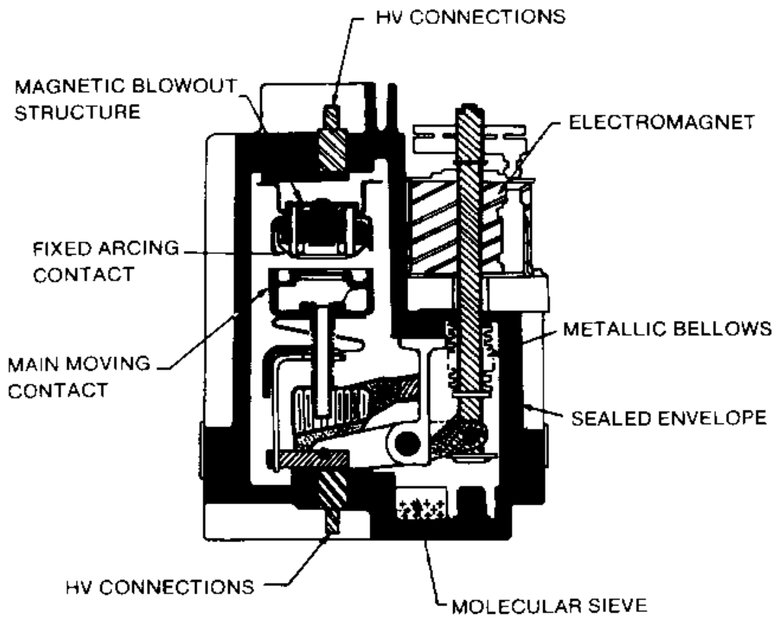

FIG. 3 — SF6 Magnetic Type Contactor

The magnetic SF6 Interrupter differs from the puffer type in the method of introducing fresh SF6 gas in the region of the arcing medium. Instead of moving the fresh supply of SF6 gas into the region of the fixed arc plasma, the arc plasma is moved by magnetic forces into a new region of fresh SF6 gas. The force due to the magnetic field has an intensity which relates as a function of the current. The interrupting characteristic is a function of the rate at which the arc plasma encounters fresh SF6 gas. Thus the interrupting characteristics of the interrupter is controlled, within limits, by the level of current being interrupted.

The puffer technique is used, typically, in circuit breaker products because of its interrupting capability at high current levels. Magnetic technology is typically used in motor control and small breaker applications where high interrupting capacities are not required. Magnetic technology is of particular importance at lower voltages (2.3 through 15kV) and at current levels such as would be applied in motor control. The performance is a function of the current assuring nearly perfect interruptions within motor controller capabilities.

Ratings

There are no limitations within either vacuum or SF6 technologies which would inhibit the design, manufacture and application of devices in accordance with applicable ANSI, NEMA, and IEC standards of performance. Areas of concern typically specified by standards are:

Continuous current capability
Fault closing performance (close and latch)
Momentary or short time withstand performance
Short circuit interruption performance
Transient recovery voltage performance
Life-load endurance
Mechanical endurance
Short circuit endurance (number of full fault interruptions)
Dielectric, one minute power frequency performance
Dielectric, basic impulse level performance

Size

One of the outstanding characteristics of vacuum technology is its small size and weight as compared to the traditional air magnetic or oil devices. Considering only the interrupting device, vacuum tends to remain the leader in smallness of size and weight. Although SF6 devices are also significantly smaller than traditional devices, SF6 interrupters tend to be physically larger in size as compared to vacuum. This is due to the SF6 open gap being larger than vacuum in order to support the BIL rating. Also, space is required for the puffer cylinder. This size disadvantage is usually compensated by the fact that the containment of SF6 gas is much easier to achieve than that of a vacuum. In SF6, there is a wide choice of materials that can be used. Epoxies and other polymers are typically used. This tends to provide a freedom of design in which several functions are combined into a single unit. As example, vacuum interrupters must be mounted on one or more insulators which are usually attached by means of additional parts. In the SF6 technology, the gas containment chamber is part of the overall insulation system which can be mounted directly to grounded metal. Often, all three poles are placed in a single insulating unit having a common gas chamber. The overall size of a SF6 finished product tends to be of comparable size to the equivalent vacuum device size. As example, the trend in 15kV metal clad switchgear is toward a two high, 36 inch wide, 90 inch high enclosure. There are both vacuum and SF6 metal-clad breakers which will meet this trend.

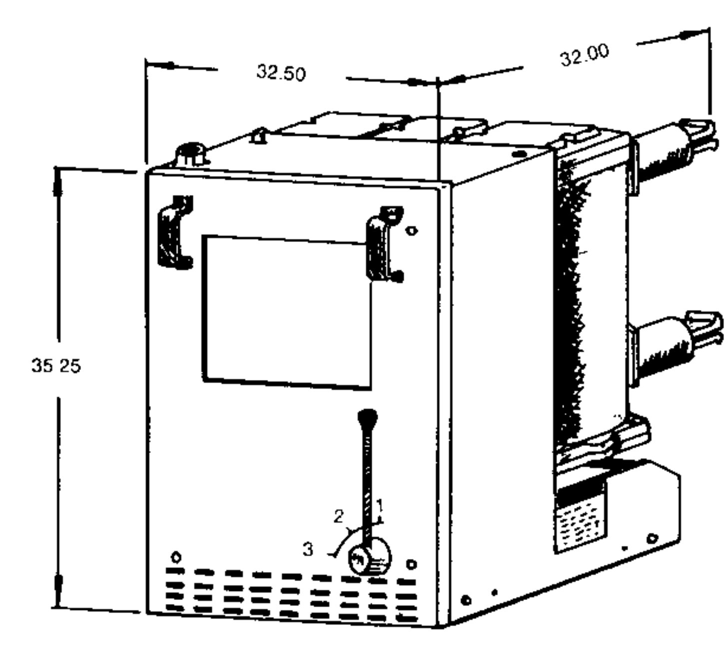

FIG. 4 — SF6 Metal-Clad Circuit Breaker (Weight 440 lbs.)

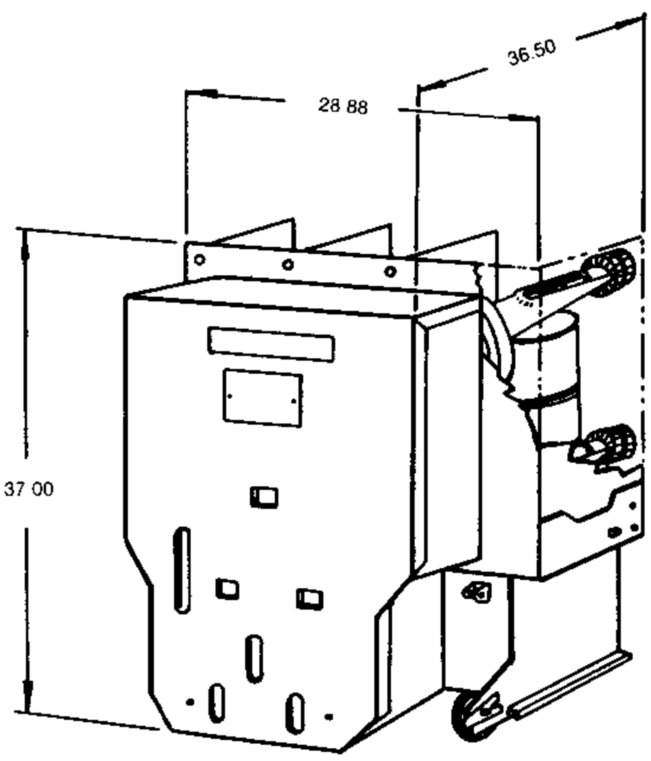

FIG. 5 – Vacuum Metal-Clad Circuit Breaker (Weight 550 lbs.)

Economics

Up to this point in time there has been no significant reason to favor one or the other technology, therefore, they have remained competitive in the marketplace. Considering a 25 KA, 15kV, 1200A SF6 single pole interrupter, the material cost is about $235. The material for a comparable rated vacuum device would cost about $160. It is well known that there are high technological and overhead costs associated with vacuum interrupters. Materials need to be chemically clean and each device must be aged and retested to insure published usable life. Also, considering additional insulating mounting features for the vacuum interrupter, the completed cost of a vacuum pole assembly would approach the cost of a SF6 device.

There is a tendency for the operating mechanisms for vacuum devices to require less energy. However, differences are rather small considering there is really not much work required in achieving additional open gap for SF6 devices since the structure is under very little load.

Performance and Applications

Present day standards, including ANSI, NEMA, and IEC, have made a significant effort in establishing criteria and procedures to define and qualify devices for specific use. Exact compliance with existing standards does not always assure equal performance from various technologies. In many instances, vacuum and/or SF6 devices exceed standard performances.

In other areas, such as the effects on a system as a result of overvoltage generation, standards have not offered a great deal of guidance.

Effect on Insulation Systems

Transient overvoltage conditions result from the presence of distributed inductance in a system and a high rate of change in current.

$$E = -L\, di/dt$$

Therefore, voltages will appear wherever inductance is found if there is a rate of change in current. There is a certain amount of inductance in the cables or transmission lines and, of course, there is a great deal of inductance associated with transformers and machinery. If we permit a very high rate of change in current, by virtue of a characteristic of the breaker, then a high voltage will appear in proportion to the amount of inductance present anywhere in the circuit. It is interesting to note that although the breaker or contactor has little inductance, the highest voltage will appear at the breaker or contactor contacts as a result of the summation of all the voltages in the system. Unless the breaker is applied to a long transmission system, we do not usually expect traveling waves. In most instances the level of di/dt permitted by the interrupter will permit the device in the system to stress itself with its own self-inductance. Therefore, our concern is to evaluate conditions which allow high rates of change in current (di/dt).

Insulation failures tend to result from the magnitude of the electric field intensity, presence of metal as a source of free electrons and time (2). It has been shown that complete failures can occur in less than 10 microseconds. Evidence of progressive failure was noted at less than 3 microseconds. It would not be surprising to discover that once a critical field intensity is reached, sufficient to accelerate electrons from metallic surfaces, that microscopic and progressive insulation deterioration begins and progresses in distance and time as successive dielectric stresses reach some critical field intensity.

It is desirable to reduce the magnitude and frequency of transient overvoltage conditions in order to extend the serviceable life of associated electrical equipment.

SOURCES OF HIGH di/dt AND OVERVOLTAGES

1. Current Chopping

   Current chopping is the sudden reduction of current to zero prior to a natural current zero. It is associated with arc plasma instability, high frequency current oscillations, and the interrupter's ability to re-establish dielectric strength. All interrupters display this characteristic in various degrees. During the interrupting process, the arc plasma can become unstable causing current oscillation with a frequency in the order of 100 KHz. During the periods of arc instability and high frequency current oscillation, the current with a high frequency component may reach zero. If the interrupter achieves dielectric recovery then the current remains at zero. This tends to trap stored energy within the system which then results in system

(2) E. O. Foster, Electrical Breakdown in Solid and Liquid Insulating Materials, Exxon Research and Engineering Company.

transient overvoltage. Figure 6 illustrates the occurrence of arc instability and then, as a result of current oscillations, current chop.

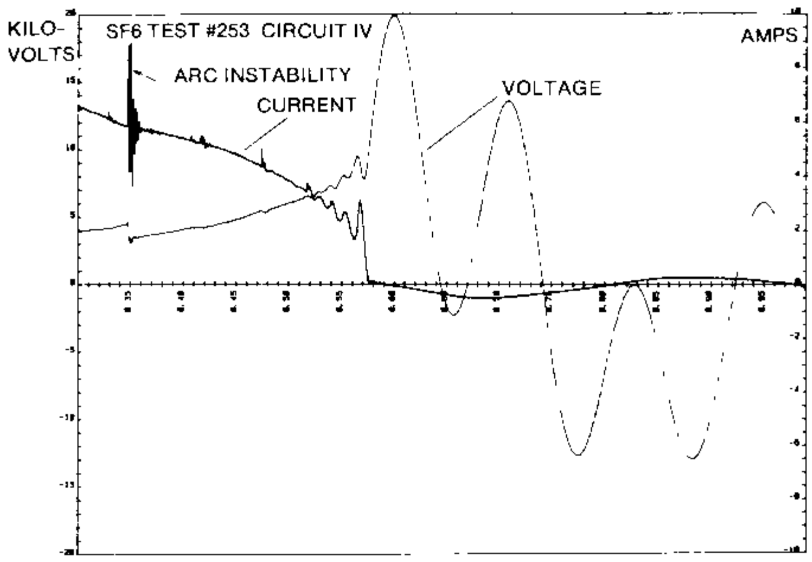

FIG. 6 – SF6 Circuit Breaker Rated 38kV, 16 KA Tested at 2.3kV, 19.1A, 7% PF

(Showing Arc Instability and Typical Current Chopping at 2 Amperes)

Current chopping depends on many factors including the characteristics of the circuit current levels, contact separation timing and interrupter design (M. Murano) (4) (A. T. Roguski) (5). Although SF6 displays a high magnitude of arc instability, the recovery rate is lower than vacuum. The result is that arc instability does not necessarily lead to normal chopping as is illustrated in Figure 7.

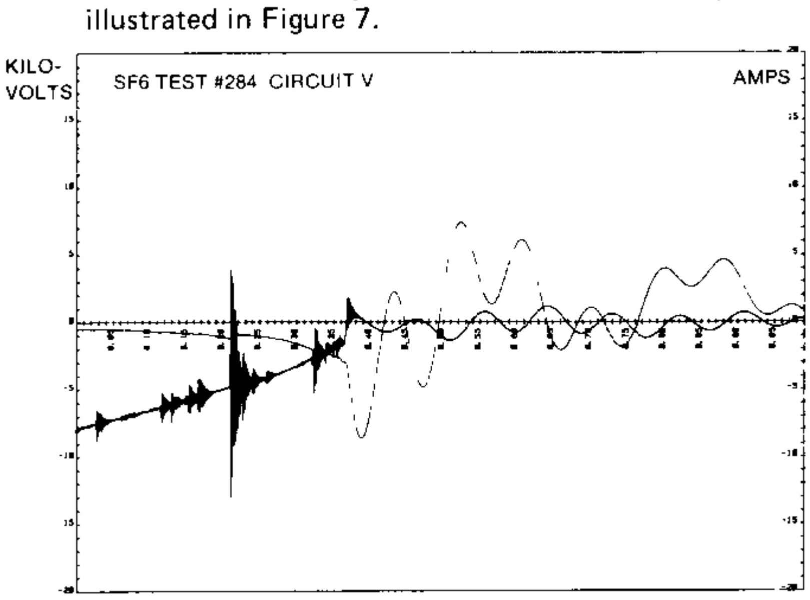

FIG. 7 – SF6 Circuit Breaker Rated 38kV, 16 KA Tested at 2.3kV, 20 A, 80% PF

(Showing the Absence of Virtual Chopping at High Frequency Zero Current Crossing)

This is because the dielectric recovery rate of SF6 is lower than that of vacuum interrupters enabling SF6 interrupters to remain ignited through high frequency current zeros. A great deal of effort has been expended over the years to moderate the arc instability in vacuum interrupters. Several techniques have been developed. Contact tip materials have been developed including low work function materials such as copper bismuth and copper chromium. The interelectrode capacitance has been increased to limit the effects of high frequency oscillations. The results of these efforts have brought the chop levels down to less than one ampere for vacuum interrupters intended for motor control service. For circuit breaker application requiring high interrupting capacities, chop levels are in the range of 3 to 8 amperes. Due to the natural characteristics of SF6, virtually no effort has been made to reduce the levels of current chop. There are virtually no chop levels associated with magnetic type SF6 interrupters. For the puffer type, chop levels range from .2 to 5 amps (5). Although puffer type SF6 devices display a significant amount of arc instability which results in high di/dt, arc instability quickly vanishes at currents above 50 amperes, as is illustrated in Figure 8.

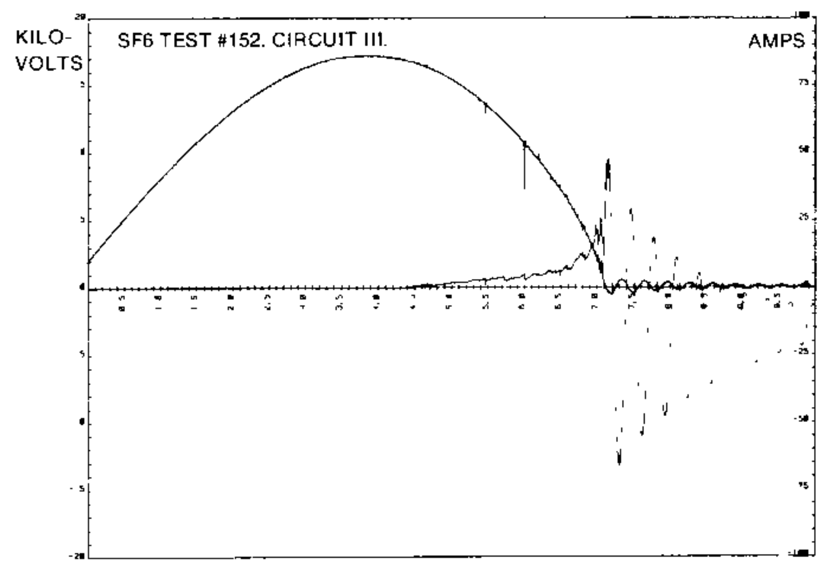

FIG. 8 – SF6 Circuit Breaker Rated 38kV, 16 KA Tested at 2.3kV, 59 A, 11% PF

(Showing Normal Transient Recovery Voltage at 59 Amperes)

The arc instability phenomenon does exist in systems having both vacuum and SF6 devices and further studies on its total effect on the system would be in order. It is envisioned that further developments in SF6 are possible, resulting in higher degrees of arc stabilization and lower di/dt's. Tests to date seem to support the fact that SF6 has a slight edge in the area of lower chop levels.

2. Virtual Chopping

There is also a rare phenomenon known as virtual chopping or simultaneous interruption (3). This occurs in 3 phase systems and is the result of the reignition of one of the poles which had previously interrupted.

The reignition in the one pole causes a sudden reduction in current for the other two as a result of system

---

(3) E. Slamecka, Interruption of Small Inductive Currents, Electra.

(4) M. Murano, S. Yanabu, H. Ohaski, H. Ishiyuka, and T. Ikazaki, Current Chopping Phenomena of Medium Voltage Circuit Breakers, IEEE PAS-96.

(5) A. T. Roguski, Laboratory Test Circuits for Predicting Overvoltages When Interrupting Small Inductive Currents with an SF6 Circuit Breaker, IEEE PAS.

capacitance and inductance. The reduction in current can be greater under these conditions than is experienced due to arc instability. Thus, chop levels due to virtual chopping can be higher than those published.

Reignitions are predominant with vacuum interrupters at low level inductive currents. Reignitions in SF6 interrupters are nearly non-existent. Although virtual chopping is a rare phenomenon, it is even less likely to occur with SF6 interrupters.

3. Restrike

   At low levels of inductive current an interrupter can develop a system instability in which transient overvoltages are generated of sufficient magnitude to cause rapid multiple reignitions as the interrupter contacts separate. This subjects the system to a series of five to 20 high di/dt experiences which result in associated high transient overvoltages. Such a phenomenon is illustrated for a vacuum circuit breaker in Figure 9.

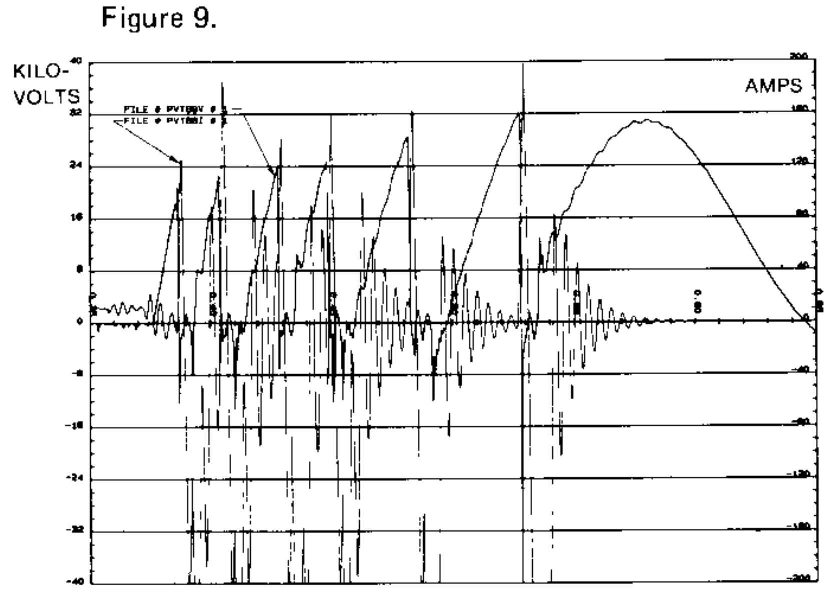

FIG. 9 — Vacuum Circuit Breaker

According to K. Yokokura (6), tests run on a small 66 KW motor and a vacuum contactor produced restrikes at a frequency of 250 KHz for approximately 0.45 milliseconds. The purpose of this work was to illustrate that transient overvoltages as a result of the restrikes did not exceed the BIL ratings of the motor insulation. Comparative tests run by Square D on both SF6 and vacuum circuit breakers indicate that restrike does not exist with SF6 breakers whereas it was experienced with vacuum breakers at 20 amperes.

4. Prestrike Interruptions

   Prestrike interruptions are very similar in nature to restrike only in this case—they occur during contact closing. As the moving contact comes in close proximity to the fixed contact the dielectric gradient between the closing contact can be sufficiently high to ionize the media and/or strip electons from metallic surfaces creating a momentary current flow. Due to the parameters of the system the rate of rise of the current can be very high resulting in oscillatory currents in the 100 KHz to 1 MHz range. As the oscillating current returns to zero it may be chopped, giving rise to transient overvoltages which cause another current oscillation while the contacts approach even closer. Such an occurrence requires the interrupter to have a very high recovery rate. Considering such a phenomenon, it is necessary that vacuum contactors have very little or no contact bounce in order to reduce such a phenomenon to a minimum.

   The comparative SF6 device displayed a significant contact closing bounce creating system overvoltages similar in nature to prestrike interruptions characteristic of vacuum. The magnitude of system overvoltages were lower for SF6 having contact bounce than those created as a result of vacuum prestrike interruptions. This would indicate that there is promise for improvements for SF6 in this area of closing transient phenomena.

TRANSIENT VOLTAGES

We have discussed four basic phenomena which result in subjecting the system to high di/dt's. Each of these has been associated with characteristics of the interrupter. The resulting transient overvoltage on the system is a function of the di/dt and the inductance of the system.

$E = -L \, di/dt$

If we assume that the di/dt throughout the system is relatively uniform then the transient overvoltage is generated wherever inductance is located in the system. If the inductance is higher in one portion of the circuit than another then a higher voltage is generated at that point. Each small -L di/dt within the system can be added together and the total system transient overvoltage appears across the opening contacts of the interrupter.

Since the total voltage appears at the interrupter it does not necessarily follow that the voltage is generated by the interrupter and propagates from that source to devices within the system to inflict possible damage. The problem is better understood by the existence of high di/dt at the portion of the system in question. The self-inductance of that portion of the system is generating its own voltage which in turn stresses its own insulation. With these concepts in mind, there are five basic philosophies applied in the control of transient overvoltage in an effort to protect system insulation.

1. System Engineering

   Given a type of interrupter (vacuum or SF6) and the system, an evaluation is made and perhaps no extra precautions are taken to protect the insulation. This is usually successful where lengths of cable having relatively high interelectrode capacitance are involved and the entire system has the same BIL rating as the interrupter and the system source.

(6) K. Yokokura, S. Masuda, H. Nishikawa, M. Okawa, and Ohas Ohashi, Multiple Restriking Voltage Effect in Vacuum Circuit Breakers on Motor Installation, IEEE 80MS697-3.

A paper presented by Buss, Dugan & Lyons (7) illustrated that in a mining installation involving 60 feet of cable, no protective measures were required to limit the transient overvoltage to approximately two times the normal line voltage. It is not unusual to see technical papers written, indicating that transient overvoltage exists well into the BIL rating of equipment which is usually at six times the normal line voltage level.

2. Metal Oxide Surge Arresters

   Metal oxide surge arresters are very often used with vacuum interrupters as a safety measure to assure the user that on a statistical basis, the equipment will be assured of protection. Metal oxide arresters are used to limit the voltage to within the BIL rating of the equipment but cannot modify the rate of rise of current (di/dt). Also, they are always connected line to ground, thus not really connected to the source of overvoltage which, in the case of switching transient, are more related to line to line phenomena. For these reasons metal oxide surge protection is not considered to be adequate for all applications. They have proven to be adequate in some cases as demonstrated by tests conducted on unloaded oil filled transformers connected to a cable system and vacuum breakers operating with restrike characteristics (8).

3. Surge Capacitors

   Surge capacitors are usually recommended for vacuum interrupters when using lower BIL rated equipment such as some dry transformers and rotating machinery. This technique lowers the rate of rise (di/dt) and is claimed to be of particular importance for rotating machinery. There is a concern that under transient voltage conditions that the first coil in a machine will share a disproportionate magnitude of voltage when the transient voltage has a high rate of rise. The added capacity lowers the rate of rise and the total voltage is not only lower but it is also more equally distributed throughout all the windings. Yokokura (6) demonstrates that there is sufficient capacity in a cable 50 meters in length to reduce the disproportionate transient of voltage to a level below levels recommended by machinery manufacturers. For lengths less than 50 meters capacitors must be added.

   Unless long lines and reflected waves are involved it would seem that overvoltage due to switching transients would have more uniformly distributed transient voltages. This would be due to the hypothesis that voltage is generated in the windings by virtue of the di/dt. If this is the case then transient voltages due to switching would be more uniformly distributed throughout the machine winding than is usually reported. Transient voltage ratings are established by the application of a voltage to the machine terminals. The test voltage wave front has a high rate of rise and is attentuated by the characteristics of the coils. Under these conditions a disproportionate voltage would appear in the first coils as has been reported. On the other hand, if the voltage is generated within the windings due to high switching di/dt, then it would be expected that the generated voltage would be evenly distributed. Thus it would be expected that the generated voltage would be evenly distributed. Thus it would be expected that machines would have a good history of performance under the influence of switching transients as would be caused by interrupters with severe characteristics.

4. Capacitor Resistor Network

   By adding a capacitor resistor network to the system, according to Murano (4) and Roguski (5), the interrupter plasma is stabilized and lowers the probability of pre-zero arc interruption and thus lowers the system transient overvoltage.

5. Interrupter Technology

   As stated, a great deal of effort and development have been made in improving the current chopping levels of vacuum interrupters. This has greatly reduced the probability of high magnitude transient overvoltage conditions. On the other hand, the recovery rate of vacuum interrupters remains high permitting phenomena such as restrike and prestrike interruptions. This permits a multitude of relatively high di/dt's to exist on the system which periodically stresses the insulation well into the BIL rating. SF6 interrupters have a combination of low chop levels plus a lower recovery rate. This permits the interrupter to rise through high frequency current zeros. This characteristic inhibits low current restrike and prestrike reducing the number of times the insulation system is stressed with transient overvoltages.

   When applying magnetic SF6 for use as motor control no suppression or other application precautions are required. The same is true for applying puffer type SF6 interrupters for general duty application and for motors down to 300 KW (400 hp). Below 300 KW (400 hp) surge suppression is suggested.

TRANSIENT RECOVERY RATE

As mentioned, vacuum has an extremely high rate of dielectric recovery after current interruption. It is this characteristic which gives rise to the concern of transient overvoltages. SF6 devices have a slower recovery rate, however, they meet the specifications as defined by ANSI C37.06 and ANSI C37.09. Recovery rate requirements in ANSI are higher than those specified by IEC. When considering the application of SF6 devices to duties such as air core reactor switching, consideration to the system TRV capability must be given. Should the rate of rise be greater than specified for general purpose breakers, lump capacity or cable can be added to bring the system rate of rise (9) to within standard limits. This is of particular importance at high levels of current.

---

(7) E. W. Buss, R. C. Dugan, P. C. Lyons, Vacuum Circuit Breakers and Dry Type Transformers Special Considerations for Mining Operations, IAS77 Annual.

(8) L. G. Ananian, K. W. Miller, C. H. Titus, and G. W. Walsh, Field Testing of Voltage Transient Associated with Vacuum Breaker No-Load Switching of a Power Transformer in an Industrial Plant, IEEE 1980.

(9) ANSI C37.09.

BREAKER SPEED

Some vacuum breakers are capable of 3 cycle ratings, both in speed of operation and interrupting capability. Some SF6 puffer breakers are limited to a 5 cycle rating due to speed of operation. This is primarily due to the time required to compress and move the gas. Interrupting capabilities are adequate. Development work in this area continues.

ELECTRICAL AND MECHANICAL LIFE

Both SF6 and vacuum have a sealed interrupter, maintenance free until end of life. Both are provided with a mechanical means of measuring contact tip wear. Considering circuit breaker duty, both promise 10,000 operations at load break current levels and 20 full fault or 2000% of a summation of fault level currents. This represents a significant improvement over earlier technologies. Considering motor control contactors, vacuum devices claim from 50,000 to 2 million operations. SF6 devices claim 300,000 operations. Both vacuum and SF6 devices in this class of equipment assume a no maintenance policy and at the end of life, the bottle is simply replaced and the old one discarded. In many cases the life of the interrupter exceeds the usefulness of the equipment.

CONTAINMENT

Both vacuum and SF6 require a gas tight enclosure or bottle. Vacuum interrupters must maintain a pressure in the range of 10 -8 to 10 -6 torr. As the pressure increases beyond 10 -4 torr, the performance falls off rapidly. As an example, the intrusion or development of a volume of 0.3 cubic inch of gas at atmospheric pressure would render a vacuum interrupter useless. Pressure changes at these levels are very difficult to detect. In service, monitoring equipment to continuously monitor vacuum pressure is available, however, costs prohibit frequent application. A great deal of technology has been developed in the production of gas free materials, manufacturing cleanliness, and assembly techniques. Quality assurance programs have produced a highly reliable device. Failure rates due to leakages amount to less than .01% and manufacturers promise life beyond 20 years.

Considering SF6, there have been several concepts employed in the containment of the gas and relative pressures employed. SF6 devices typically used for motor control and circuit breakers in the 15 to 38kV range tend to use relatively low pressure vessels designed to be sealed for the useful life of the equipment. SF6 gas has a rather large molecular structure and is easily contained by usual means. Interrupters of this class have diffusion rates in the order of 10 -6 cubic cm per second. Calculations would indicate that suitable pressures can be maintained for roughly 240 years. These interrupters are usually pressurized to about 45 PSIG but can operate to their full capability at less than half the normal as charged pressure.

Many SF6 interrupters will interrupt load break currents at 0 PSIG and some will perform at least one full fault interruption. Because of the interest in monitoring the performance of SF6 interrupters, pressure switches are being installed as standard equipment in many cases. Pressure switches are typically set to respond at one half the normal charge pressure to indicate the beginning of the degredation of the nameplate rating. Pressure readings may be taken on a periodic basis using a portable, detachable gas pressure gauge, however, this procedure is not recommended. Frequent pressure checks result in a loss of gas and eventually the interrupter would require reservicing. Field servicing can result in the dilution or contamination of the gas if adequate precautions are not taken. It is recommended that SF6 circuit breakers or contactors not be serviced unless an indication from a pressure sensor would indicate such service is required and recommended by the manufacturer.

Comparing the technologies, the SF6 technology provides an extra margin of performance, economical monitoring capability and serviceability when necessary.

MISCELLANEOUS FEATURES

Vacuum is capable of full fault interruption with the contacts fully open should an arc be established by a transient overvoltage condition which would flash the open contacts. This would not be so for puffer type SF6, but would be true for the magnetic type. Such a claim of performance is not very reassuring. Standards require the same BIL (Basic Impulse Level) for line to line, line to ground and across open contacts. For isolation devices, the BIL is 10% higher than the line to line, and line to ground values. A transient voltage which would reach the BIL level of open contacts would just as likely flash over line to line or line to ground. Because of the small contact gap associated with vacuum interrupters the question of contact flash is appropriate. Frohlich and Widl (10) determined that the dielectric strength of the open gap vacuum interrupters is lowered by certain operational conditions which cause irregular projections to be present on the surface of the contact. Projections caused by no-load openings of welded contacts produce the lowest dielectric strength.

SF6 interrupters do not have this problem, due to the design of the contact structures and the fact that the ratio of contact open gap to contact surface irregularities is much higher. BIL ratings in any condition are easily obtained.

Vacuum devices are sometimes provided with an X-ray radiation warning. At 50kV across open contacts, a vacuum interrupter will produce approximately 1 millirankin per hour of radiation. At 36kV (the test voltage for 15kV class equipment), radiation levels are equivalent to natural cosmic radiation. There are no precautions recommended at these levels.

SF6 gas in itself is not a toxic material and is used on occasion in surgical procedures. However, the arc inter-

(10) K. Frohlich and W. Widl, Breakdown and Field-Emission Behavior of Differently Pressurized Vacuum Interrupter Copper Contacts, IEEE Proc., Vol. 128, July 1981.

ruptions produce by-products which can be toxic to human life if ingested in sufficient quantities. There are minor precautions recommended when servicing open SF6 interrupters. In the class of equipment under discussion the interrupters are small and are sealed for life, requiring no internal maintenance. In case of an accident, ventilation and skin contact precautions are recommended. There are no regulations in regard to the handling of this material.

CONCLUSION

Vacuum and SF6 technologies are the useful technologies of the day and immediate future. SF6 equipment tends to be larger and more expensive in some instances. However, continuing development is making SF6 more competitive with vacuum.

Although vacuum has been successfully applied in many cases without precautionary measures, there is measurable evidence that SF6 has an advantage in the area of transient overvoltage control. Inherent transient overvoltage control has an effect on the overall economics of the systems.

REFERENCES

(1) David Lee Swindler, SF6 Puffer Type Circuit Breakers for Applications of 15kV Through 38kV, Square D Company, Middletown, Ohio.

(2) E. O. Foster, Electrical Breakdown in Solid and Liquid Insulating Materials, Exxon Research and Engineering Company.

(3) E. Slamecka, Interruption of Small Inductive Currents, Electra.

(4) M. Murano, S. Yanabu, H. Ohaski, H. Ishiyuka, and T. Ikazaki, Current Chopping Phenomena of Medium Voltage Circuit Breakers, IEEE PAS-96.

(5) A. T. Roguski, Laboratory Test Circuits for Predicting Overvoltages When Interrupting Small Inductive Currents with an SF6 Circuit Breaker, IEEE PAS.

(6) K. Yokokura, S. Masuda, H. Nishikawa, M. Okawa, and Ohashi, Multiple Restriking Voltage Effect in Vacuum Circuit Breakers on Motor Installation, IEEE 80MS697-3.

(7) E. W. Buss, R. C. Dugan, P. C. Lyons, Vacuum Circuit Breakers and Dry Type Transformers Special Considerations for Mining Operations, IAS77 Annual.

(8) L. G. Ananian, K. W. Miller, C. H. Titus, and G. W. Walsh, Field Testing of Voltage Transient Associated with Vacuum Breaker No-Load Switching of a Power Transformer in an Industrial Plant, IEEE 1980.

(9) ANSI C37.09.

(10) K. Frohlich and W. Widl, Breakdown and Field-Emission Behavior of Differently Pressurized Vacuum Interrupter Copper Contacts, IEEE Proc., Vol. 128, July 1981.

SQUARE D COMPANY

P. O. Box 558 · Middletown, Ohio 45042

RP 2M 6/86

Printed in U.S.A