GER-3186

Reprinted from June 1978
Industrial Power Systems
The Magazine of Modern Industrial and Commercial Electrical Practices

Vacuum Interrupter Reliability in Power Circuit Breakers

by Rod W. Houston and
Charles H. Titus

SWITCHGEAR BUSINESS DEPARTMENT
PHILADELPHIA, PA.

GENERAL ELECTRIC

Vacuum Interrupter Reliability in Power Circuit Breakers

by Rod W. Houston and Charles H. Titus

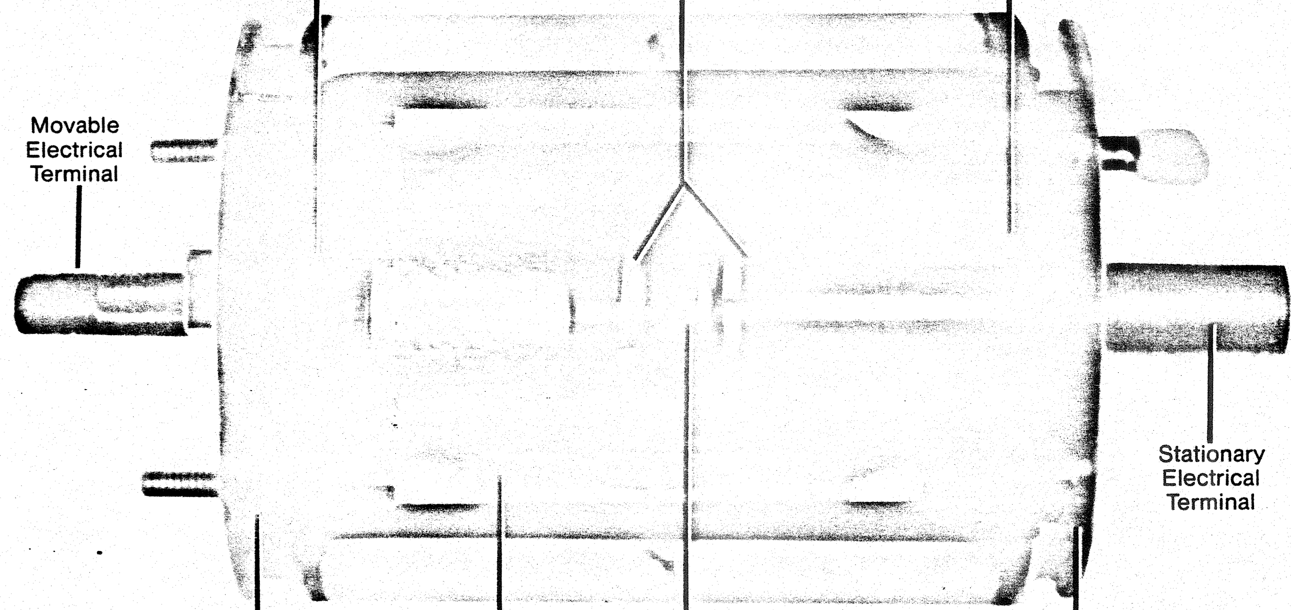

Fig. 1. The sealed vacuum interrupter is the heart of the vacuum circuit breaker.

Rod W. Houston
Manager—Industrial Sales
Switchgear Business Department
Philadelphia, PA

Charles H. Titus
Department Consultant
Switchgear Business Department
Philadelphia, PA

Vacuum interrupters, pioneered in the 1920's, have been accepted as a practical method for switching electric power circuits. The first power vacuum circuit breaker was introduced in 1962; (Reference 1) after an eight-year development period of extensive laboratory and field testing. Since 1962, General Electric has produced over 50,000 vacuum interrupters and has accumulated 200,000 interrupter-years of field service.

The heart of the vacuum circuit breaker is the sealed vacuum interrupter shown in Figure 1. The vacuum interrupter uses a special glass insulating enclosure. The end plates are metallic and are fused to the glass envelope. Inside the enclosure are metallic shields which grade the electric field and protect the casing from vaporized contact material present during arc interruption. The fixed and stationary contacts are centered in the bottle. The stationary contact is supported by a current-carrying member or rod which is attached to one of the end plates. The movable contact is supported by a current-carrying rod which is brazed to a metallic bellows. The stroke or contact sep-

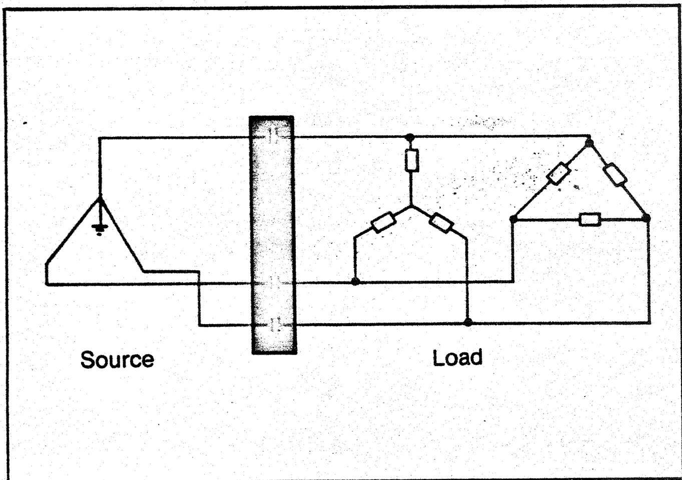

Fig. 2. When the neutral of a power source is grounded and the load is ungrounded, the interrupter still can function even though vacuum is lost.

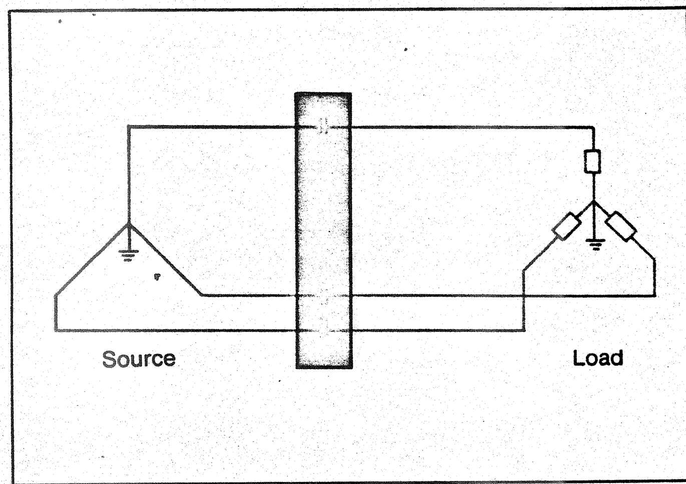

Fig. 3. When the source and load neutrals are both grounded and the interrupter loses vacuum, it will continue to arc until otherwise terminated.

aration is in the range of 3/8 to 3/4-inches as contrasted to several inches for oil or air magnetic breakers of comparable rating.

Reliable Vacuum Measurements

The dielectric and interruption integrity of a vacuum interrupter depends on maintaining a gas density less than a predetermined critical value. Because vacuum is in reality a low gas pressure, measurement of vacuum is a measurement of pressure. For vacuum interrupters, pressure may be 10^{-8} Torr or mm of mercury with a maximum permissible pressure in the order of 10^{-3} Torr.

Sophisticated measuring techniques (Reference 2) verify the low pressures reached during manufacture. These techniques are practical for use during the manufacture of vacuum interrupters but are not practical for measuring the pressure in an interrupter when mounted in a circuit breaker. The breaker service environment, and particularly the presence of power system voltages, support this conclusion.

There is no reliable vacuum gauge which will monitor the vacuum in the interrupter during power circuit breaker operation which does not degrade the integrity of the vacuum interrupter. Through proper design and production of the breaker the possibility that the interrupter will ever lose vacuum in service is extremely remote.

Vacuum Integrity

There are two reasons for vacuum interrupter pressure increases after evacuation and sealing: leakage of air into the interrupter and the release of gases from the metallic components inside the interrupter bottle.

Release of internal gas is rare since manufacturing techniques routinely clean and de-gas all interrupter materials and surfaces.

All joints in the interrupter are designed, manufactured, and tested to assure they are leak free. Processes have been developed for making glass-to-metal seals, brazed joints, and welded parts so that a reliable, leak-free interrupter is obtained. In addition, these interrupters are designed and tested to withstand conditions well beyond the mechanical, thermal and electrical stresses encountered in service.

Finally, after assembly and evacuation, a unique method is used to check the pressure and to detect possible leaks in each sealed interrupter. In this case the vacuum interrupter is used as its own pressure gauge, employing the magnetron principle (Reference 3). The magnetron method requires a strong axial magnetic field, high voltage dc, and an ion-current electrometer capable of reading fractions of a micro-ampere. This equipment is capable of measuring pressures from 10^{-3} to 10^{-8} Torr. The interrupter is given severe mechanical stress, then stored for futher comparison of pressure measurements. This procedure confirms the integrity to be sure that no potentially leaking vacuum interrupters are put into service.

Interrupter Field Experience

Overall field problems have been minimal from the first vacuum breaker shipment to the present. Additionally, the first breaker shipped in 1962 is still in service and operating well. Over 50,000 General Electric vacuum interrupters have been placed in service since 1962, and field experience has been excellent, with vacuum failures being very infrequent and non-violent. It is estimated that field failures involving the vacuum interrupter for all reasons are less than 0.1 percent and for vacuum breakers less than 0.3 percent. This compares with industry statistics of 0.36 percent for medium voltage, non-vacuum metalclad drawout breakers in industrial plants (which are predominantly air magnetic).

Vacuum users are sometimes concerned about vacuum loss and what might happen when vacuum is lost while the breaker is closed and carrying current.

In this unlikely event, the breaker continues to carry current since neither the current-carrying ability of the interrupter nor its dielectric strength to ground is impaired by the loss of vacuum.

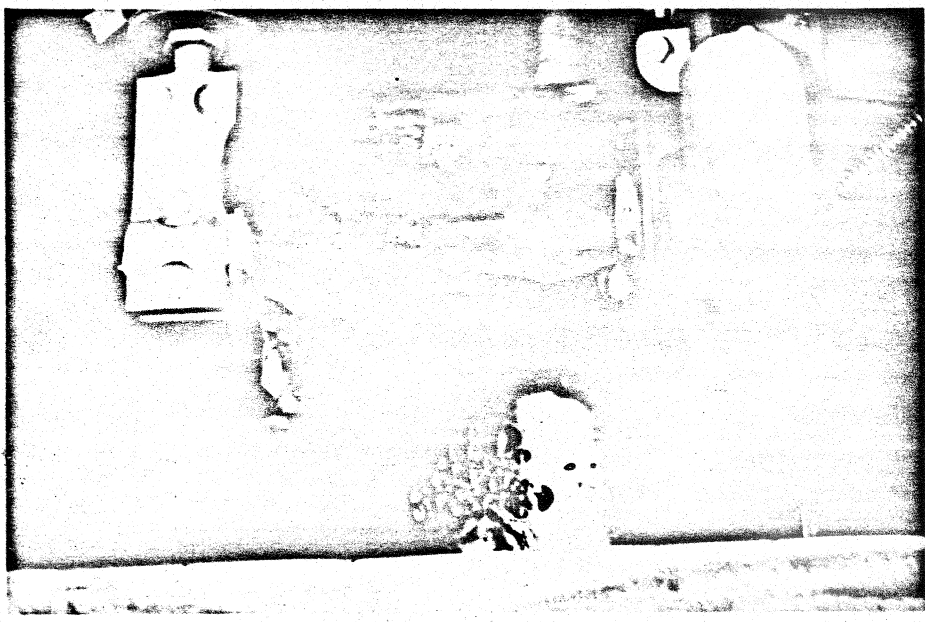

Fig. 4. Vacuum interrupter after a planned test demonstrates the non-violent effect of a failure. The interrupter was opened to atmosphere and 600 A was carried at 15 kV across open contacts for 90 seconds.

If one interrupter has lost vacuum and the breaker is opened while carrying load current, nothing will happen since the current will be interrupted in the normal manner if the neutral of the power source is grounded and the load is ungrounded as shown in Figure 2. Reference tests of this type are available showing currents up to 2000 A at 15 kV successfully interrupted with one of the three interrupters opened to air (Reference 6).

Fig. 5. General Electric's first outdoor model of the vacuum distribution breaker rated 15 kV, 12000 A interrupting current.

As indicated above, the breaker may be closed safely and reopened when the sole system ground exists at the neutral of the power source.

A breaker whose interrupter has lost vacuum while connected in a system with a grounded neutral source and an ungrounded load (Figure 2) may be moved to a test or disconnect position. The interrupters on the other two phases will interrupt the load current and the interrupter which has lost vacuum will continue to interrupt normal system charging current.

A breaker that loses vacuum in one interrupter may be opened while carrying load current, and while the neutrals of the power source and the load are grounded as shown in Figure 3. The arc will then persist in one interrupter.

Arcing current whose magnitude does not exceed the continuous current rating of the breaker may be contained inside the interrupter for many seconds before the glass envelope melts and an arc to ground is formed. There is, however, no explosion or violent bursting of the vacuum interrupter envelope, but the arc-to-ground fault must be interrupted by a back-up breaker.

If a fault-to-ground occurs in either circuit (Figures 2 and 3) and an interrupter loses vacuum during fault clearing, the interrupter will continue to arc until the breaker is reclosed or until a back-up breaker is opened.

The amount of time that an arcing fault may be contained inside the interrupter before the glass envelope melts is a function of the magnitude of the arc current. For example, a 40,000-A arc may be contained for 15 cycles while a 2000-A arc may be contained for several hundred cycles. In both cases, the vacuum interrupter will melt and crack rather than shatter from an internal explosion.

A 600-A single phase opening test was made on a vacuum interrupter which was opened to air and then resealed. The arc current was left on for approximately 90 seconds. The condition of the interrupter following this experiment is shown in Figure 6. Although the interrupter melted and the envelope cracked, there was no explosion.

Since most fault detection schemes will detect the magnitude of fault or ground fault current in less time than it takes for the arc to escape from the bottle, the probable result of a loss of vacuum in a properly coordinated system is that the backup breaker will operate and no significant damage will occur to the switchgear equipment.

Detecting Vacuum Loss

The simplest way to prove the existence of vacuum is to check high potential withstand capability. This is achieved by applying a high potential across each interrupter with the breaker open. This procedure is recommended during routine maintenance.

For the POWER/VAC® Metalclad Circuit Breaker, Figure 6, a light weight, portable 50-kV dc high potential test set is available to conduct this type of test. This set operates from a conventional 5-A single-phase, 120-volt, 60-Hz power supply. The short circuit output current of this equipment is limited to 5mA. OSHA and Underwriters Laboratories recognize that a dc current of 5 mA is not harmful regardless of the available open circuit voltage. A self-contained instrument is used to show that both the high potential set and the vacuum interrupter are operating correctly.

A sensitive breaker failure relay has also been developed for those who wish to monitor in-service performance of the POWER/VAC Metal-clad Vacuum Circuit Breaker.

Loss of vacuum may be detected in the following manner. Figure 7 shows the addition of a normally open "a" auxiliary breaker contact which is connected across the coil of the residually connected breaker failure relay. This permits the relay to operate if the breaker is open and the current is flowing through one of the vacuum interrupters for more than three cycles after its contacts part. Under normal interrupting conditions, the duration of current through the residual current circuit is approximately one cycle after the contacts part.

If the current continues for more than three cycles, the relay contacts will trip the back-up breaker, thereby confining the arcing within the interrupter, and only the failed interrupter need be replaced.

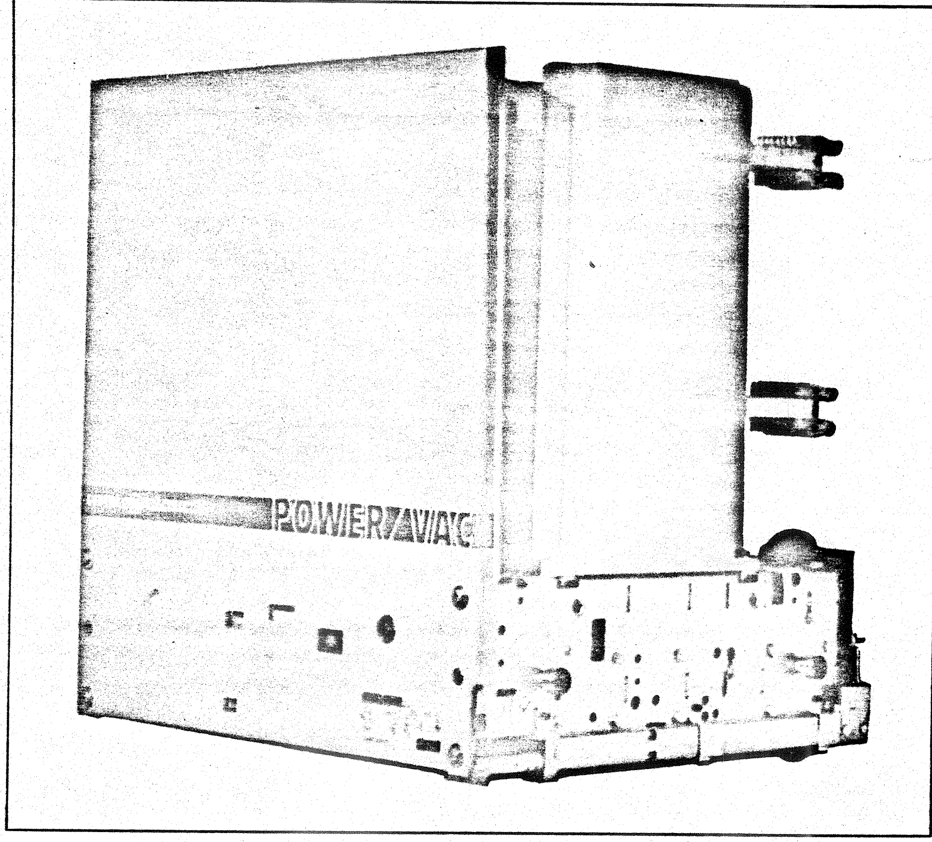

Fig. 6. The newest member of the switchgear family is the POWER/VAC breaker for metalclad switchgear. It includes ratings 5 to 15 kV, 250 to 1000 MVA, 1200 A to 3000 A continous current.

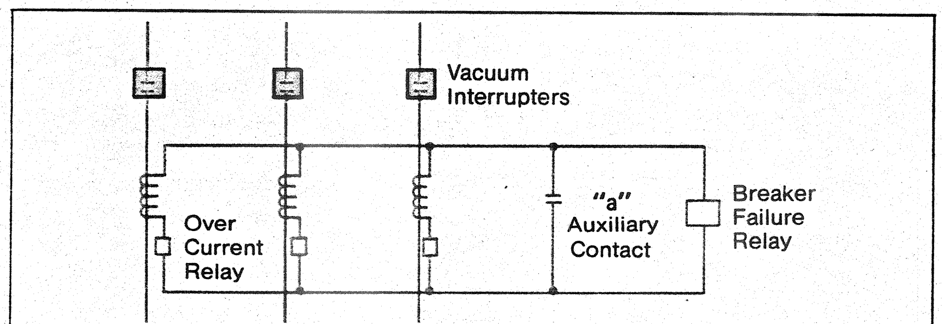

Fig. 7. This schematic illustrates the loss of vacuum detection circuit, an option for use with vacuum breaker.

Maintenance Requirements

While questions about loss of vacuum are sometimes raised, operating experience over the past 15 years has shown that maintenance and reliability of vacuum circuit breakers have been even better than those of comparably rated breakers employing oil and air as the interrupting media.

The maintenance procedures are simple:

- ☐ Check that the mechanism is clean, lubricated, and operating properly.
- ☐ Make a visual inspection that corrosion of contact material has not exceeded the recommended amount. This is done easily as the gauge is integral with each interrupter assembly.
- ☐ Use a high-potential set to check that vacuum integrity still exists.
- ☐ If above conditions are met, the breaker may be placed in service.

Conclusion

The acceptance of medium voltage vacuum metalclad equipment is accelerating rapidly for its advantages are recognized and the reliability of the vacuum interrupters has been excellent with 200,000 interrupter-years of trouble-free service since 1962. ☐

References

1. *A. L. Streater, R. H. Miller, J. C. Sofianek, "Heavy Duty Vacuum Recloser," IEEE Trans. PAS Vol. 81, pp. 356-362, 1962.*
2. *S. Dushman, and J. M. Lafferty, "Scientific Foundation of Vacuum Techniques," 2nd edition, John Wiley and Sons.*
3. *J. R. Lucek, and W. J. Pearce, U. S. Patent 3, 263, 162, "Apparatus and Method for Measuring Pressure Inside a Vacuum Circuit Interrupter," July 1966.*
4. *J. Cogle, "Are Vacuum Breakers Justified?" — Electrical Review, Vol. 196, pp. 424-425. April 11, 1975.*
5. *W. L. Passant and A. J. Ruddock, "The Future of Vacuum Circuit Breakers in the Electricity Supply Industry" presented at the Conference on Metalclad Switchgear, London, England, by the Power Division of the British Institution of Electrical Engineers, Mar. 28-30, 1972.*
6. *G. Auten, "Electrical Endurance Tests Favor Vacuum," Electrical Review, Vol. 199, No. 19, Nov. 12, 1976.*